

**INTERIM FINAL**  
**RCRA FACILITY INVESTIGATION (RFI) GUIDANCE**

**VOLUME I OF IV**

**DEVELOPMENT OF AN RFI WORK PLAN  
AND GENERAL  
CONSIDERATIONS FOR RCRA FACILITY  
INVESTIGATIONS**

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**WASTE MANAGEMENT DIVISION  
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U.S. ENVIRONMENTAL PROTECTION AGENCY**

## ABSTRACT

On November 8, 1984, Congress enacted the Hazardous and Solid Waste Amendments (HSWA) to RCRA. Among the most significant provisions of HSWA are §3004(u), which requires corrective action for releases of hazardous waste or constituents from solid waste management units at hazardous waste treatment, storage and disposal facilities seeking final RCRA permits; and §3004(v), which compels corrective action for releases that have migrated beyond the facility property boundary. EPA will be promulgating rules to implement the corrective action provisions of HSWA, including requirements for release investigations and corrective measures.

This document, which is presented in four volumes, provides guidance to regulatory agency personnel on overseeing owners or operators of hazardous waste management facilities in the conduct of the second phase of the RCRA Corrective Action Program, the RCRA Facility Investigation (RFI). Guidance is provided for the development and performance of an investigation by the facility owner or operator based on determinations made by the regulatory agency as expressed in the schedule of a permit or in an enforcement order issued under §3008(h), §7003, and/or §3013. The purpose of the RFI is to obtain information to fully characterize the nature, extent and rate of migration of releases of hazardous waste or constituents and to interpret this information to determine whether interim corrective measures and/or a Corrective Measures Study may be necessary.

## **DISCLAIMER**

This document is intended to assist Regional and State personnel in exercising the discretion conferred by regulation in developing requirements for the conduct of RCRA Facility Investigations (RFIs) pursuant to 40 CFR 264. Conformance with this guidance is expected to result in the development of RFIs that meet the regulatory standard of adequately detecting and characterizing the nature and extent of releases. However, EPA will not necessarily limit acceptable RFIs to those that comport with the guidance set forth herein. This document is not a regulation (i.e., it does not establish a standard of conduct which has the force of law) and should not be used as such. Regional and State personnel must exercise their discretion in using this guidance document as well as other relevant information in determining whether an RFI meets the regulatory standard.

Mention of company or product names in this document should not be considered as an endorsement by the U.S. Environmental Protection Agency.

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# **RCRA FACILITY INVESTIGATION (RFI) GUIDANCE**

## **VOLUME I**

### **DEVELOPMENT OF AN RFI WORK PLAN AND GENERAL CONSIDERATIONS FOR RCRA FACILITY INVESTIGATIONS**

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## LIST OF ACRONYMS

AA	-	Atomic Absorption
AI	-	Soil Adsorption Isotherm Test
ASCS	-	Agricultural Stabilization and Conservation Service
ASTM	-	American Society for Testing and Materials
BCF	-	Bioconcentration Factor
BOD	-	Biological Oxygen Demand
CAG	-	EPA Carcinogen Assessment Group
CPF	-	Carcinogen Potency Factor
CBI	-	Confidential Business Information
CEC	-	Cation Exchange Capacity
CERCLA	-	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	-	Code of Federal Regulations
CIR	-	Color Infrared
CM	-	Corrective Measures
CMI	-	Corrective Measures Implementation
CMS	-	Corrective Measures Study
COD	-	Chemical Oxygen Demand
COLIWASA	-	Composite Liquid Waste Sampler
DNPH	-	Dinitrophenyl Hydrazine
DO	-	Dissolved Oxygen
DOT	-	Department of Transportation
ECD	-	Electron Capture Detector
EM	-	Electromagnetic
EP	-	Extraction Procedure
EPA	-	Environmental Protection Agency
FEMA	-	Federal Emergency Management Agency
FID	-	Flame Ionization Detector
Foc	-	Fraction organic carbon in soil
FWS	-	U.S. Fish and Wildlife Service
GC	-	Gas Chromatography
GC/MS	-	Gas Chromatography/Mass Spectroscopy
GPR	-	Ground Penetrating Radar
HEA	-	Health and Environmental Assessment
HEEP	-	Health and Environmental Effects Profile
HPLC	-	High Pressure Liquid Chromatography
HSWA	-	Hazardous and Solid Waste Amendments (to RCRA)
HWM	-	Hazardous Waste Management
ICP	-	Inductively Coupled (Argon) Plasma
ID	-	Infrared Detector
K <sub>d</sub>	-	Soil/Water Partition Coefficient
K <sub>oc</sub>	-	Organic Carbon Adsorption Coefficient
K <sub>ow</sub>	-	Octanol/Water Partition Coefficient
LEL	-	Lower Explosive Limit
MCL	-	Maximum Contaminant Level
MM5	-	Modified Method 5
MS/MS	-	Mass Spectroscopy/Mass Spectroscopy
NFIP	-	National Flood Insurance Program

## LIST OF ACRONYMS (Continued)

NIOSH	-	National Institute for Occupational Safety and Health
NPDES	-	National Pollutant Discharge Elimination System
OSHA	-	Occupational Safety and Health Administration
OVA	-	Organic Vapor Analyzer
PID	-	Photo Ionization Detector
pKa	-	Acid Dissociation Constant
ppb	-	parts per billion
ppm	-	parts per million
PUF	-	Polyurethane Foam
PVC	-	Polyvinyl Chloride
QA/QC	-	Quality Assurance/Quality Control
RCRA	-	Resource Conservation and Recovery Act
RFA	-	RCRA Facility Assessment
RfD	-	Reference Dose
RFI	-	RCRA Facility Investigation
RMCL	-	Recommended Maximum Contaminant Level
RSD	-	Risk Specific Dose
SASS	-	Source Assessment Sampling System
SCBA	-	Self Contained Breathing Apparatus
SCS	-	Soil Conservation Service
SOP	-	Standard Operating Procedure
SWMU	-	Solid Waste Management Unit
TCLP	-	Toxicity Characteristic Leaching Procedure
TEGD	-	Technical Enforcement Guidance Document (EPA, 1986)
TOC	-	Total Organic Carbon
TOT	-	Time of travel
TOX	-	Total Organic Halogen
USGS	-	United States Geologic Survey
USLE	-	Universal Soil Loss Equation
UV	-	Ultraviolet
VOST	-	Volatile Organic Sampling Train
VSP	-	Verticle Seismic Profiling
WQC	-	Water Quality Criteria

## SUMMARY

The Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act (RCRA) were enacted into law on November 8, 1984. One of the major provisions (Section 3004(u)) of these amendments requires corrective action for releases of hazardous waste or constituents from solid waste management units (SWMUs) at hazardous waste treatment, storage, or disposal facilities. Under this provision, any facility applying for a RCRA hazardous waste management facility permit will be subject to a RCRA Facility Assessment (RFA). The RFA is conducted by the regulatory agency and is designed to identify SWMUs which are, or are suspected to be, the source of a release to the environment. If any such units are identified, the owner or operator of the facility will be directed to perform a RCRA Facility Investigation (RFI) to obtain information on the nature and extent of the release so that the need for interim corrective measures or a Corrective Measures Study can be determined. Information collected during the RFI can also be used by the owner or operator to aid in formulating and implementing appropriate corrective measures. Such corrective measures may range from stopping the release through the application of a source control technique to a full-scale cleanup of the affected area. In cases where releases are sufficiently characterized, the regulatory agency may require the owner or operator to collect specific information needed to implement corrective measures during the RFI.

This document provides the owner or operator with guidance on conducting a RCRA Facility Investigation. Based on release determinations made by the regulatory agency (generally resulting from the RFA), the owner or operator of a facility will be notified, through an enforcement order or permit conditions, of those unit(s) and releases (known or suspected) which must be further investigated.

This guidance is divided into fifteen sections presented in four volumes. Volume I presents recommended procedures to follow in developing a work plan for conducting the investigation. It also describes the criteria that the Agency will use to interpret the data collected during the RFI. This interpretation is an integral part of the RFI and is discussed in Section 8, which describes the Health and Environmental Assessment (HEA) that is conducted by the Agency. The primary element of the HEA is a set of criteria (chemical concentrations), against which concentrations of hazardous constituents identified during the release



characterization are compared. The health and environmental assessment is used in determining the need for a Corrective Measures Study (CMS) or Interim Corrective Measures (ICM), and is based primarily on EPA-established chronic-exposure limits.

Volumes II and III describe specific methods for characterizing the nature, extent, and rate of contaminant release to soil, ground water, subsurface gas, air, and surface water. Each medium-specific section contains an example strategy for characterizing releases, which includes characterizing the source and environmental setting of the release, and conducting a monitoring program that will characterize the release. Also, each section provides a checklist of information that may be needed for release characterization, formats for data presentation, and field methods that may be used in the investigation. Highlights of the medium-specific sections are provided below.

#### Section 9 (SOIL)

- Gives specific emphasis to the potential for inter-media transfer of releases from the soil medium to other media;
- Explains the significance of surficial soil and deep soil contamination; and
- Highlights the role of leaching tests.

#### Section 10 (GROUND WATER)

- References the RCRA Ground Water Monitoring Technical Enforcement Guidance Document (TEGD) to characterize site hydrology;
- Encourages the use of flow nets for interactive/verifiable site characterization; and
- Focuses on basement seepage as an important pathway for contaminant migration and exposure.

### Section 11 (SUBSURFACE GAS)

- Focuses on methane gas from refuse landfills because of its explosive properties, as well as volatiles from underground tanks;
- Emphasizes the importance of subsurface gas as a pathway for inter-media transport (e.g., transfer of contamination from subsurface gas to soil and air); and
- Presents a subsurface gas migration model, detailed in in Appendix D.

### Section 12 (AIR)

- Addresses monitoring and modeling of unit emissions and dispersion modeling for off-site receptors at or beyond the facility property boundary; and
- Provides an air release screening assessment methodology that may be used as a transition between the general quality determinations made in the RCRA Facility Assessment (RFA), regarding air emissions that warrant the actual performance of an RFI.

### Section 13 (SURFACE WATER)

- Emphasizes the importance of understanding the form and frequency of releases to surface water and the role of biomonitoring; and
- Explains when sampling bottom sediments is important.

Volume IV presents a number of case studies selected to illustrate various concepts and procedures presented in Volume I, II and III. Most of the case studies are based on actual sites. In some cases, existing data have been supplemented with hypothetical data to illustrate a particular point.

Prior to conducting the investigation, the owner or operator will in most cases be directed, through a permit or enforcement order, to submit a written plan (the RFI Work Plan) that should propose, in detail, the manner in which the investigation will be conducted. Specific components of this plan are defined in Volume I of this guidance.

In planning the investigation, the owner or operator should consider a logical progression of tasks that will be followed in investigating the release. Generally, these tasks will consist of:

- Gathering information on the source of the release to the environment (e.g., gathering information on the unit and the waste in the unit);
- Gathering physical information on the environment surrounding the unit that will affect the migration and fate of the release (e.g., ground-water flow direction, average windspeeds, soil types); and
- Using the above information along with any existing monitoring or modeling information, to develop a conceptual model of the release, which will be used to plan and conduct a monitoring program to define the nature, rate and extent of the release.

The owner or operator should use existing sources of information when these sources can supply data of the quality and type needed. Information on waste constituents, for instance, may be available from operational records kept at the facility. In other instances, the owner or operator may propose a waste sampling and analysis effort to characterize the waste in the unit of concern, thereby producing new data on the waste. In either case, the owner or operator should ensure that the data is of the quality necessary to adequately define the release because such data will be used in determining the need for corrective measures.

Characterizing the release source and the environmental setting of the release will allow the owner or operator to design a monitoring program which will lead to adequate characterization of the release. This effort may be conducted in phases, if necessary, with each monitoring phase building on the findings and conclusions of the previous phase. For example, in those cases where the regulatory agency has

identified a suspected release, the first phase of the monitoring program may be directed toward release verification. The level of effort required in an initial monitoring phase will thus be dictated by the level of knowledge on the release. The hypothetical examples of this approach given below illustrate that RFIs can vary widely in complexity and, thus, will not always involve elaborate studies.

- A facility contains both active and inactive landfills. All active landfills at the facility are regulated for ground-water releases under 40 CFR Part 264, Subpart F; however, an inactive unit was identified by the regulatory agency as being the source of a release to ground water. The waste in the unit was identified by the owner or operator as being supplied solely by a single, well-characterized process.

Hydrogeologic information, such as identification of the uppermost aquifer and ground-water flow direction and rate, were defined in the RCRA Part B permit application for the active units required for compliance with Subpart B of 40 CFR Part 270. Environmental characterization data relevant to the inactive landfill, such as flow direction and hydraulic gradient, was readily derived from monitoring wells already installed to comply with the monitoring requirements of 40 CFR Part 264, Subpart F.

In this case, the owner or operator was able to use existing information to characterize both the environmental setting and the source of the release and conduct a limited sampling program, starting with wells near the inactive unit, to define the release. After installation and sampling of these initial wells, the owner or operator determined the need for further well installation and sampling. In this case, the level of effort required to characterize the release, especially in characterizing the contaminant source and environmental setting, was minimal due to the detailed information already available.

- In another case, the owner or operator of a commercial facility with an inactive surface impoundment that had received waste from several generators was directed to conduct an investigation of a suspected release to a nearby stream. The suspicion of a release was based on

several fishkills noted in the stream during periods of heavy rains and reported observations of impoundment overflow during these periods. The owner or operator's knowledge of the impoundment's contents was limited due to the varying wastes managed, and a survey of drainage patterns around the impoundment had not been performed. Also, monitoring of the receiving stream itself had not been conducted at the time of the notification.

In this case, a rather extensive level of effort was required to characterize the release. Because the waste could not be readily characterized by direct sampling due to its varying nature over time, the owner or operator proposed to forego a direct waste characterization effort and conduct monitoring of the receiving stream for the constituents of concern. The owner or operator conducted a survey of drainage patterns around the site, developed a conceptual model of the release, and established a network of monitoring stations. Initial sampling was conducted in drains and swales around the unit, with subsequent monitoring taking place in drainage ditches and eventually the stream itself, with the design of each sampling effort based on knowledge gained from the previous effort. In addition, because contamination of the surface water column coincided with periods of heavy rains, sampling of the water column was conducted during such periods. The owner or operator also determined, through analysis of samples collected in the initial phases, that the waste constituents being released were highly water soluble and not likely to adhere to bottom sediments. In addition, the owner or operator determined that these constituents had a low potential to bioaccumulate. Stream sampling, therefore, was limited to water column samples; bottom sediment and biota sampling were not performed.

- During a visual site inspection conducted by the regulatory agency as part of the RCRA Facility Assessment, evidence was found that ten drums, placed in an unrestricted storage area, were releasing their contents to soils surrounding the area. Evidence observed by the investigative team included discolored soils and stressed vegetation. The regulatory agency issued a compliance order requiring the owner or operator to

immediately remove the drums (as an interim corrective measure) and to conduct an investigation of the nature and extent of the contamination. The owner or operator complied with the order for removal and conducted sampling to characterize the waste in the drums. After identifying the constituents of the waste, the owner or operator proposed a work plan to characterize the release, starting with a screening survey of the area using an organic vapor analyzer (OVA), followed by the collection of samples in the immediate vicinity of the drum storage area, then additional sampling at progressively further distances from the area, if necessary. After collection of three rounds of sampling, sufficient data had been gathered to adequately define the extent of the release.

The above three examples illustrate general concepts that may vary on a site-specific basis.

The owner or operator should understand that the regulatory agency has a significant oversight responsibility to ensure the protection of human health and the environment. Accordingly, the regulatory agency may often choose to be present to observe RFI-related operations, especially field and sampling operations. Regulatory agency oversight of RFI field work is very important for ensuring a quality study. In planning and conducting the RFI, therefore, the owner or operator is encouraged to interact closely with the regulatory agency to assure that the data supplied during the investigation and, thus, the interpretation of the data, will be acceptable. The compliance order or permit conditions requiring the investigation will specify a schedule for conducting the investigation, including the reporting of data. The owner or operator should keep the regulatory agency advised of the progress of the investigation, including any delays, and changes to, or deletions of specific investigation activities.

This document presents guidance specific to the RFI and the RFI process. General subject areas which are common to many types of hazardous waste management activities (e.g., quality assurance and control, sampling, analytical methods, health and safety procedures), which are also important to the RFI, are addressed in a summary fashion. More detailed references on these subject areas are provided.

This RFI Guidance is tailored to the structure and goals of the RCRA Corrective Action Program. The RFI process described in this document parallels the technical components of the Remedial Investigation (RI) and removal guidance issued under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The RFI Guidance has been developed to address releases from operating as well as inactive and closing units. When such releases have been adequately characterized, the next step in the RCRA corrective action process can be initiated (i.e., determination of the need for corrective measures).

In order to assess the effectiveness of this Guidance Document an "RFI Feedback Questionnaire," is provided at the end of Volume I. This feedback will also help EPA determine the need for additional guidance.

## **SECTION 1**

### **OVERVIEW OF THE RCRA CORRECTIVE ACTION PROGRAM**

#### **1.1 Introduction**

The primary objective of the RCRA corrective action program is to clean up releases of hazardous waste or hazardous constituents at treatment, storage, or disposal facilities subject to Subtitle C of RCRA. "Release" means any spilling, leaking, pouring, emitting, emptying, discharging, injecting, pumping, escaping, leaching, dumping, or disposing of hazardous wastes (including hazardous constituents) into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles containing hazardous wastes or hazardous constituents).

The 1984 Hazardous and Solid Waste Amendments (HSWA) provided EPA with broad and expanded authorities for ensuring corrective action at facilities subject to RCRA. Authorities that may be used by EPA to ensure corrective action include:

- **Section 3004(u) - Corrective Action for Continuing Releases**

Section 3004(u) of HSWA requires that permits issued after the date of enactment of HSWA (November 8, 1984) require corrective action for releases of hazardous waste or constituents from any solid waste management unit (SWMU) at any hazardous waste treatment, storage, or disposal facility seeking a permit, regardless of the time at which waste was placed in the unit.

- **Section 3008(h) - Interim Status Corrective Action Orders**

Section 3008(h) of HSWA authorizes EPA to issue orders requiring corrective action or to take other appropriate response measures to protect human health and the environment based on any information



that there is or has been a release of hazardous waste into the environment from a facility authorized to operate under Section 3005(e).

- **Section 3004(v) - Corrective Action Beyond the Facility Boundary**

Section 3004(v) authorizes EPA to require that corrective action be taken by the facility owner or operator beyond the facility property boundary where necessary to protect human health and the environment, unless the owner or operator demonstrates that he was unable to obtain permission to undertake such action.

Section 3005(c)(3) of HSWA (commonly known as the "Omnibus" provision) gives EPA authority to add to RCRA permits any conditions deemed necessary to protect human health and the environment.

In addition, Section 3004(n) of HSWA directs EPA to set standards for the control and monitoring of air emissions at hazardous waste treatment, storage, and disposal facilities as necessary to protect human health and the environment. These standards are presently being developed and will form the overall basis for regulating air emissions at these facilities. These standards may be used by EPA in evaluating corrective measures associated with air releases at solid waste management units. However, until these standards are sufficiently developed, EPA will use this RFI Guidance to address air releases that may require corrective measures.

EPA may also apply RCRA authorities existing prior to the passage of HSWA to implement the corrective action program. These authorities include RCRA Sections 3013 and 7003. Section 3013 may be used to order an owner or operator to conduct monitoring, testing, analysis, and reporting at a facility which is or may be releasing hazardous waste that may present a substantial hazard to human health or the environment. Section 7003 can be applied where hazardous waste management activities may present an imminent and substantial endangerment to health or the environment. Under this provision, the EPA Administrator may bring suit against an owner or operator to cease activities causing such endangerment or to take other appropriate action as may be necessary.

Section 3004(u) has been codified as 40 CFR §264.101. A companion to EPA's July 15, 1985 (see 50 FR 28702), codification rule specifies additional information and data requirements for owners or operators of solid waste management units to support the conduct of RCRA Facility Assessments by the regulatory agency (see 52 FR 45788 - December 1, 1987). These authorities broaden the scope of the RCRA corrective action program from detecting and correcting releases to the uppermost aquifer from regulated units, to cleaning up continuing releases to any media resulting from other waste management units and practices at RCRA facilities. Prior to passage of HSWA, EPA exercised its authority under Section 3004 to require corrective action for releases of hazardous constituents to ground water from only certain land-based waste management units; 40 CFR Part 264, Subpart F contains requirements for corrective action at these "regulated units." Regulated units include surface impoundments, landfills, waste piles, and land treatment units that received hazardous waste on or after July 26, 1982. Also, EPA applied Sections 3013 and 7003, as appropriate, toward meeting corrective action program objectives. HSWA expanded RCRA authority to correct releases of hazardous waste or hazardous constituents to all media at RCRA facilities, and encourages the use of other authorities, as needed or appropriate, to help achieve corrective action objectives at these facilities.

Section 3004(u) of the HSWA corrective action provisions focuses on investigating releases from solid waste management units (SWMUs). A SWMU is any discernible unit at which solid or hazardous wastes have been placed at any time, irrespective of whether the unit was intended for the management of solid or hazardous wastes. Such units include any area at a facility at which hazardous wastes or hazardous constituents have been routinely and systematically released. A SWMU does not include an accidental spill from production areas and units in which wastes have not been managed (e.g., product storage areas).

This RFI Guidance addresses investigations of all releases from SWMUs (hereafter also referred to as units) to all media, including soil, ground water, subsurface gas, air, and surface water. Ground-water releases from regulated units will continue to be regulated under 40 CFR Part 264, Subpart F.

## 1.2 Overall RCRA Corrective Action Process

The RCRA Corrective Action Process consists primarily of the following four steps: the RCRA Facility Assessment (RFA), the RCRA Facility Investigation (RFI), the Corrective Measures Study (CMS), and Corrective Measures Implementation (CMI). A summary of the overall Corrective Action Process for identifying, characterizing, and correcting releases is presented in Figure 1-1. This process is discussed below.

### RCRA Facility Assessment (RFA)

Release determinations for all environmental media (i.e., soil, ground water, subsurface gas, air, or surface water) will be made by the regulatory agency primarily through the RFA process. The regulatory agency will perform the RFA for each facility seeking a RCRA permit to determine if there are releases of concern. The major objectives of the RFA are to:

- Identify SWMUs and collect existing information on contaminant releases; and
- Identify releases or suspected releases needing further investigation.

The RFA begins with a preliminary but fairly comprehensive review of pertinent existing information on the facility. If necessary, the review is followed by a visual site inspection to verify information obtained in the preliminary review and to gather information needed to develop a sampling plan. A sampling visit is performed subsequently, if necessary, to obtain appropriate samples for making release determinations.

The findings of the RFA will result in one or more of the following actions:

- No further action under the RCRA corrective action program is required at that time, because no evidence of release(s) or of suspected release(s) was identified;

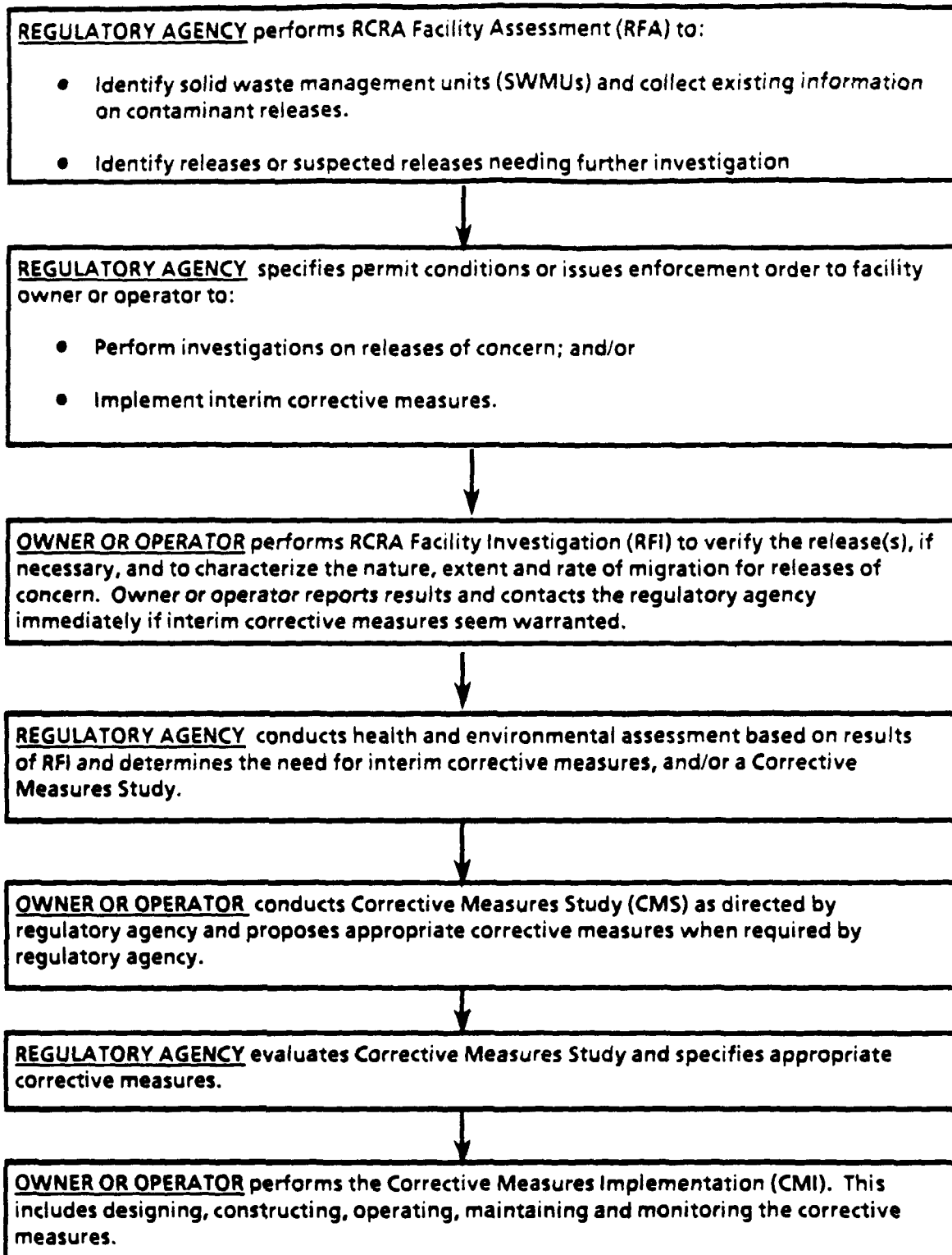


Figure 1-1: RCRA Corrective Action Process. Note that although certain aspects of the Corrective Action Process are the responsibility of either the regulatory agency or the owner or operator, close coordination between the regulatory agency and the owner or operator is essential throughout the process.

- An RFI by the facility owner or operator is required where the information collected indicates a release(s) or suspected release(s) that warrant(s) further investigation;
- Interim corrective measures by the owner or operator are required where the regulatory agency believes that expedited action should be taken to protect human health or the environment; and
- In cases where problems associated with permitted releases are found, the regulatory agency will refer such releases to the appropriate permitting authorities.

Guidance for conducting the RFA is presented in the following reference:

- U.S. EPA. October, 1986. RCRA Facility Assessment Guidance. NTIS PB 87-107769. Office of Solid Waste. Washington, D.C. 20460.

#### RCRA Facility Investigation (RFI)

If the regulatory agency determines that an RFI is necessary, this investigation will be required of the owner or operator either under a permit schedule of compliance or under an enforcement order. The regulatory agency will apply the appropriate regulatory authority and develop specific conditions in permits or enforcement orders. These conditions will generally be based on results of the RFA and will identify specific units or releases needing further investigation. The RFI can range widely from a small specific activity to a complex multi-media study. In any case, through these conditions, the regulatory agency will direct the owner or operator to investigate releases of concern. The investigation may initially involve verification of suspected releases. If confirmed, further characterization of such releases will be necessary. This characterization includes identification of the type and concentration of hazardous waste or hazardous constituents released, the rate and direction at which the releases are migrating, and the distance over which releases have migrated. Inter-media transfer of releases (e.g., volatilization of hazardous constituents from contaminated soils to the air medium) should also be addressed during the RFI, as appropriate.

The RFI also includes interpretation by the regulatory agency of release characterization data to established health and environmental criteria to determine whether a CMS is necessary. This evaluation is crucial to the RCRA Corrective Action Process. The regulatory agency will ensure that data and information collected during the RFI adequately describe the release and can be used with a high degree of confidence to make decisions regarding the need for a CMS.

Identifying and implementing interim corrective measures may also be conducted during the RFI. If, in the process of conducting the investigation, a condition is identified that indicates that adverse exposure to hazardous constituents is presently occurring or is imminent, interim corrective measures may be needed. Both the owner or operator and the regulatory agency have a continuing responsibility to identify and respond to emergency situations and to define priority situations that warrant interim corrective measures. The need for consideration of interim corrective measures, if identified by the owner or operator, should be communicated to the regulatory agency at the earliest possible time. As indicated earlier, the need for interacting closely with the regulatory agency is very important, not only for situations discussed above, but also to ensure the adequacy of the data collected during the RFI and the appropriate interpretation of those data.

#### Corrective Measures Study (CMS)

If the potential need for corrective measures is identified during the RFI process, the owner or operator is then responsible for performing a CMS. During this step of the Corrective Action Process, the owner or operator will identify, and recommend as appropriate, specific measures to correct the release.

Information generated during the RFI will be used not only to determine the potential need for corrective measures, but also to aid in the selection and implementation of these measures. For releases that have been adequately characterized, the owner or operator may be required to collect such information (e.g., engineering data such as soil compaction properties or aquifer pumping tests) during the RFI. Selection and implementation of corrective measures will be

addressed in future regulations and in separate guidance to be developed by EPA. In the interim, guidance for corrective measures selection and implementation is provided in several references, including the following:

U.S. EPA. September, 1986. Data Requirements for Remedial Action Technology Selection. Final Report. NTIS PB87-110813. Office of Emergency and Remedial Response and Office of Research and Development. Washington, D.C. 20460.

U.S. EPA. October, 1985. Handbook of Remedial Action at Waste Disposal Sites. EPA/625-6-85-006. Office of Emergency and Remedial Response. Washington, D.C. 20460.

U.S. EPA. June, 1985. Guidance on Feasibility Studies Under CERCLA. NTIS PB85-238590. Office of Emergency and Remedial Response. Washington, D.C. 20460.

U.S. EPA. June, 1987. RCRA Corrective Action Interim Measures. Interim Final. OSWER Directive No. 9902.4. Office of Waste Programs Enforcement. Washington, D.C. 20460.

U.S. EPA. May, 1985. Guidance Document for Cleanup of Surface Tanks and Drum Sites. OSWER Directive 9380.0-03. Office of Emergency and Remedial Response. Washington, D.C. 20460.

U.S. EPA. June, 1986. Guidance Document for Cleanup of Surface Impoundment Sites. OSWER Directive No. 9380-0.06. Office of Emergency and Remedial Response. Washington, D.C. 20460.

U.S. EPA. November, 1986. EPA/540/2-85/004. OSWER Directive No. 9380.0-05.

U.S. EPA. December, 1988. Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites. OSWER Directive No. 9283.1-2. Office of Emergency and Remedial Response. Washington, D.C. 20460.

EPA has developed a draft of a guide for assessing and remediating contaminated sites that directs users toward technical support, potential data requirements and technologies that are applicable to several EPA programs such as RCRA and CERCLA. The reference for this guide and a general discussion of its content are provided below.

U.S. EPA. 1989. Draft Practical Guide for Assessing and Remediating Contaminated Sites. Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

This document is intended as a practical guide and reference source for EPA, state and industry personnel that are involved with assessing and remediating contaminated sites. Special emphasis is placed on technical support, potential data requirements and technologies related to assessing and remediating point-source contamination (e.g., problems associated with landfills, surface impoundments, and underground storage tanks). The guide is designed to address, in a general manner, releases to ground water, soil, surface water and air.

The principal objective of the guide is to facilitate technology transfer regarding the assessment and remediation of contaminated sites. It is anticipated that the guide will be available in two forms: (1) as a hard copy, i.e., in three-ring binder form and (2) stored on computer files within the OSWER Electronic Bulletin Board System (BBS). (Note: The OSWER Technology Transfer Bulletin Board Users Guide is available from OSWER headquarters.) This dual format will provide maximum flexibility to users and allow timely revision of existing text or the inclusion of supplemental material as appropriate. The primary function of the guide is to direct the user toward references and technical support for detailed information on program requirements, technical methods, data requirements and technologies.

The guide is divided into five sections: (I) Collection and Evaluation of Site Information, (II) Remedial Technologies, (III) Technical Assistance Directory, (IV) Annotated Bibliography, and (V) Compendium of Courses, Symposia, Conferences, and Workshops.



Section I is subdivided into Overview, Preliminary Site Assessment, Characterization of Contaminant Sources(s) and Environmental Setting, Assessment of Contaminant Fate and Transport, Selection, Design and Implementation of Remedial Technologies, and Performance Evaluation of Remedial Technologies. Brief discussions and tables are provided under these and other subdivisions to clarify how each phase of assessment/remediation fits into the overall, iterative process of collecting and evaluating site information. The tables, designed as screening tools, relate site information with technologies or methods, or vice versa. Guidance documents, references and other technical support are listed after the preliminary discussions and tables.

Section II contains descriptions of specific remedial technologies that are grouped under four categories: (1) source control, (2) withdrawal, injection and flow control, (3) water treatment, and (4) restoration of contaminated water supplies and utility/sewer lines. Each technology description includes a general description, application/availability, design and construction considerations, costs, and references. In addition, an overview of general references precedes the four categories of remedial technologies.

Section III is a technical assistance directory of EPA program, regional, and research staff that may be contacted to answer specific questions regarding the assessment and remediation of contaminated sites. The directory includes the individual's name, organization within EPA, area of expertise, mailing address, and phone number. The directory is intended to foster communication among scientists and engineers within EPA, other Federal agencies, industry, and state and local governments. Improved access to current scientific advances and data on the application and performance of technologies will likely enhance the effectiveness and efficiency of assessment and remediation programs.

Section IV is an annotated bibliography of guidance documents and references listed under Sections I and II. Brief summaries of each document are provided to assist the reader in selecting the appropriate technical guidance.

Section V is a compendium of existing courses, symposia, conferences, and workshops. Each course, symposium, conference or workshop description includes the title, content, contact, and cost.

### Corrective Measures Implementation (CMI)

CMI includes designing, constructing, operating, maintaining, and monitoring selected corrective measures. As indicated above, selection and implementation of corrective measures will be addressed in future regulations and in separate guidance to be developed by EPA.

#### **1.3 Purpose of the RCRA Facility Investigation (RFI) Guidance**

This document provides guidance to regulatory agency personnel for overseeing facility owners or operators who are required to conduct a RFI to characterize the nature, extent, and rate of migration of contaminant releases to soils, ground water, subsurface gas, air, and surface water. It also provides guidance on the interpretation of results by the regulatory agency to determine if interim corrective measures and/or a CMS may be necessary.

This RFI Guidance is not intended to describe all activities that may be undertaken during the RFI. For example, consideration of community relations and development of a community relations plan are addressed in other EPA guidances. This and other items that may be undertaken during the RFI are outlined in the following document:

U.S. EPA. November 1986. RCRA Corrective Action Plan. Interim Final. OSWER Directive No. 9902.4 Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

This document provides as much procedural specificity as possible to clearly define the owner or operator's responsibilities in the RFI. Each situation, however, is likely to be unique. Site-specific conditions, including the amount and quality of information available at the start of the RFI process, the existence of or potential for actual exposure, and the nature and extent of the release call for a flexible

approach to the release investigation. This RFI Guidance is written in this context. However, some situations may be so complicated and unique that further technical guidance may be necessary. If this is the case, the owner or operator should contact the responsible regulatory agency for assistance. If necessary, the responsible regulatory agency will contact EPA Headquarters.

#### **1.4 Organization of this Document**

This guidance is organized into four volumes containing 15 sections and 8 appendices. Volume I contains eight sections: Section 2 provides direction for preparation of the RFI Work Plan and procedures for submitting this Plan to the regulatory agency for review. Section 3 provides guidance on the general strategy to be employed in performing release investigations. Sections 4, 5, and 6 discuss Quality Assurance/Quality Control (QA/QC), Data Management and Reporting, and Health and Safety Procedures, respectively. Section 7 discusses how information from source (waste and unit) characterization can be used in the RFI process. Section 8 presents guidance on the interpretation of data collected during the RFI process, using health and environmental criteria. Guidance for situations that may require the application of interim corrective measures is also provided in Section 8.

Volumes II and III provide detailed technical guidance on how to perform media-specific investigations. Volume II presents Sections 9, 10 and 11, which discuss the soil, ground water, and subsurface gas media, respectively. Volume III presents Sections 12 and 13, which discuss the air and surface-water media, respectively. Representative case study illustrations of various investigative approaches and techniques described in Volumes I through III are presented in Sections 14 and 15 of Volume IV.

#### **1.5 Reference Information**

This document provides guidance on characterizing known releases and on verification of suspected releases. Applicable field methods (e.g., sampling techniques) and equipment are described or referenced, as appropriate. This document uses, to the extent possible, existing guidances and information developed in various EPA programs (e.g., Office of Emergency and Remedial

Response, Office of Waste Programs Enforcement, Office of Air Quality Planning and Standards, and Office of Water), as well as State material to assist in performing release characterizations for the various environmental media. As such, many references are provided which refer the owner or operator to more complete or detailed information. Where available, identification or ordering numbers have been supplied with these citations. The following describes these identification numbers and provides information on how these documents may be obtained.

**NTIS:** NTIS stands for the National Technical Information Service. NTIS documents may be obtained by calling (703) 487-4650 or by writing to NTIS at the following address:

NTIS  
U.S. Department of Commerce  
Springfield, VA 22161

**EPA:** Environmental Protection Agency (EPA) Reports are available through EPA's Headquarters or Regional libraries, or by writing to EPA at the following address:

U.S. EPA  
Public Information Center  
401 M. Street, S.W.  
Washington, D.C. 20460

Many EPA reports are also available through NTIS. NTIS should be contacted for availability information. The indicated EPA office may also be contacted for information by writing to the above address.

**OSWER:** OSWER stands for EPA's Office of Solid Waste and Emergency Response. Availability information on documents identified by an OSWER Directive Number can be obtained by calling EPA's RCRA/Superfund Hotline, at (800) 424-9346 (toll-free) or (202) 382-3000.

GPO: GPO stands for the U.S. Government Printing Office. Documents available through GPO may be obtained by calling GPO at (202) 275-3648.

## 1.6 Guidance Changes Description

The RFI Guidance has undergone a number of revisions since publication of the initial October 1986 draft. Draft documents were released to the public in July 1987, December 1987 (updated Section 8 - Health and Environmental Assessment only), and of course the current version, May 1989. These revisions were necessitated by both the need to remain consistent with evolving EPA policy with respect to corrective action, and the desire to provide facility owners and operators with sufficient information and guidance to ensure that investigations provide adequate information for confident decisionmaking. Further revision of the RFI Guidance is not anticipated. Following is a brief discussion of how the RFI Guidance has changed since its original release.

October 1986 Draft - This was the first draft of the RFI Guidance. It contained basic information on the conduct of RFIs, but did not go into great detail on media specific investigations, particularly with respect to the air and surface water media. In addition, this first draft contained little guidance pertaining to health and environmental assessment. This draft was circulated mainly to the EPA Regions, in an attempt to obtain comment before further development of the Guidance was initiated. As a result of this activity, the need for major revision was identified.

July 1987 Draft - This version of the RFI Guidance represented the first major revision made to the Guidance. Virtually all sections were restructured for consistency and new sections were added as well. The major changes were as follows:

- Revision of much of the regulatory and procedural aspects of the Guidance (contained in Volume I) to reflect the final RCRA Facility Assessment (RFA) Guidance.

- Introduction of a new, more efficient means of selecting hazardous constituents and parameters to monitor for, based on available information on the unit(s) involved, the waste managed, the media being investigated and any previous data collected.
- Addition of guidance relating to the selection of methods for sampling and analysis, and incorporation of references to available information regarding acceptable methods already published by EPA's Superfund Program.
- Addition of new section on health and environmental assessment (Section 8), including tables of action levels for specific constituents in specific media.
- Major editing of all medium specific sections for consistency in structure and overall content.
- Expansion of all medium specific sections to address the importance of inter-media transport of contamination.
- Expansion of the Soil Section (Section 9) to emphasize the importance of recognizing soil as a key medium for inter-media transfer of contamination, both as a source and as a recipient of contamination.
- Expansion of the Ground Water Section (Section 10) to provide guidance on the use of flow nets and flow cells in defining site hydrogeology and contamination migration pathways.
- Complete rewrite of the Air Section (Section 12) to reflect the special considerations inherent in investigations of releases to air, and evolving Agency policy regarding renewed emphasis on monitoring vs modeling.
- Complete rewrite of Surface Water Section (Section 13) to reflect the importance of understanding the release mechanism (i.e., past vs

intermittent vs continual release), and the type of release (i.e., point source vs area source).

- Addition of new Volume IV - Case Studies.

December 1987 Draft - This revision of the RFI Guidance involved only Section 8 on Health and Environmental Assessment. Hence, only Section 8 was reissued. The major revisions made to Section 8 are summarized as follows:

- Clarification of the hierarchy in which the health and environmental criteria (i.e., action levels) are applied.
- Revision of the criteria tables to reflect new exposure assumptions for the soil medium.
- Revision of the criteria tables to reflect the latest additions and revisions made by EPA to health based exposure levels.
- Addition of new guidance pertaining to evaluation of deep soil and sediment contamination.
- Update in accordance with new MCLs promulgated for volatile organic constituents.

May 1989 Final Draft - The current final draft of the RFI Guidance constitutes significant revision over the previous drafts. Major changes from previous drafts include the following:

- Incorporation of improved graphics and tabular presentations throughout all four volumes of the Guidance.
- Incorporation of an RFI Guidance Feedback Form (at the end of Volume 1) to determine the utility of the Guidance as well as the need for further guidance.

- General revision, where appropriate, to ensure consistency with the forthcoming regulations dealing with RCRA corrective action.
- Revision of the Section 8 criteria tables to reflect revised exposure assumptions for the soil medium.
- Revision of the Section 8 criteria tables to reflect the latest additions and revisions made by EPA to health based exposure levels.
- Incorporation of the concept of using leaching tests (Section 9 - Soil) to predict when soil contamination may affect underlying ground water, including a new appendix (Appendix F) presenting a draft EPA method developed specifically for contaminated soil.
- Addition of a new appendix (Appendix E) illustrating the calculation of basement air contaminant concentrations due to basement seepage of volatile organic contaminants.
- Addition of a new section (Section 8.6.3) pertaining to newly promulgated methods for evaluating ground-water contamination in a statistical manner, and reference to additional guidances and other documents available from EPA for conducting ground-water remediation (Section 10.7).
- Revision of the Air Section of the Guidance (Section 12) to reflect a new phased approach, involving an initial screening assessment, and the incorporation of a new appendix (Appendix G) containing draft Guidance on the screening assessment.
- Revision of the Air Section (Section 12) to reflect a balance between the application of modeling and monitoring approaches, depending on site-specific circumstances.



- Incorporation of the concept of using soil loss equations for determining contaminated soil loading to surface waters (Section 13), including a new appendix (Appendix H) illustrating the soil loss calculation.
- Rearrangement of the Volume IV Case Studies to reflect the order in which the specific points illustrated are presented in Volumes I through III.
- Incorporation of a new Volume IV case study illustrating the use of leaching tests to predict the potential for contaminated soil to contaminate underlying ground water.

## 1.7 Corrective Action Regulations

EPA is in the process of promulgating comprehensive corrective action regulations pursuant to HSWA Section 3004 (u) and (v). These regulations, which will appear primarily in Subpart S of 40 CFR Part 264, will establish requirements for all aspects of RCRA corrective action. Because the RFI Guidance is being released prior to the proposal and promulgation of Subpart S, the potential for differences is significant. Therefore, users of this guidance are advised to review the final Subpart S rule carefully when published. Potential differences are identified below:

- Identification of health and environmental criteria or "action levels" - The RFI Guidance includes tables of the most recent action levels in Section 8, Health and Environmental Assessment. However, these levels are continually being updated by EPA, and the levels presented in the Subpart S rule may differ.
- Development of health and environmental criteria - The RFI Guidance provides information on how action levels are developed (e.g., use of exposure assumptions, risk levels for carcinogens). The Subpart S rule may propose alternate methods for developing actions levels.

- Definition of constituent - The RFI Guidance refers to constituents as those listed in 40 CFR Part 261, Appendix VIII. Use of the term "constituent" in the Subpart S rule is being reviewed.
- Action levels for surface water - The RFI Guidance identifies action levels for surface water to include various Agency-developed criteria (such as MCLs), but indicates that State-developed standards may also be considered. The Subpart S rule may propose a different scheme for establishing action levels for surface water.
- Action levels for soil - The RFI Guidance attempts to differentiate deep from surficial soil contamination, and provide methods (e.g., leaching tests) and action levels for determining the need for corrective action. Surficial soil and deep soil contamination may be addressed differently in the Subpart S rule.
- Influence of detection/quantitation limits on action levels - The RFI Guidance indicates that the detection limit will serve as the action level, where action levels are lower than detection limits. The issue of detection/quantitation limits is under Agency review, and may be changed in the Subpart S rule.
- Evaluation of chemical mixtures - The RFI Guidance provides the rationale and equations for computing adjusted action levels, assuming additive toxicity, when more than one constituent is present in a contaminated medium. The issue of evaluation of chemical mixtures is under Agency review and may be addressed differently in the Subpart S rule.
- Definition of Solid Waste Management Unit (SWMU) - The RFI Guidance definition of SWMU is currently under Agency review and may be changed in the Subpart S rule.
- Notification and Reporting - The RFI Guidance identifies specific reports that may be required throughout the performance of an RFI, and also

identifies specific situations in which the owner or operator is required to submit notifications to the regulatory agency. Notification and reporting requirements are being reviewed by EPA and may be changed in the Subpart S rule.

- Use of specific language - The specific language used in various sections of the RFI Guidance, for example when referring to factors the regulatory agency may consider in determining the need for interim corrective measures, may be changed in the Subpart S rule.

## **SECTION 2**

### **THE RFI WORK PLAN**

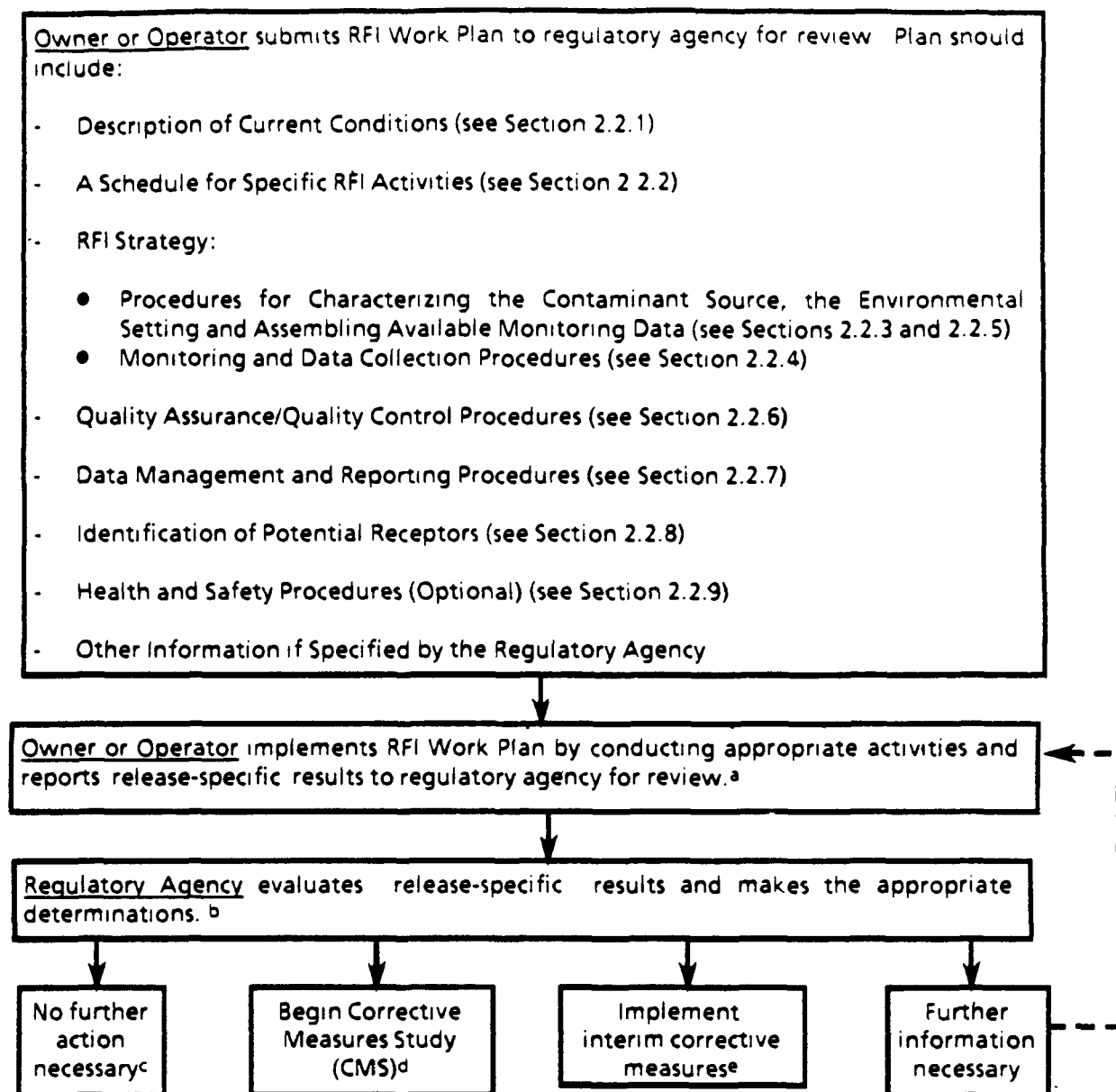
#### **2.1 Introduction**

If notified by the regulatory agency that an RFI must be conducted, the owner or operator should initiate a series of activities aimed at supplying specific information on the identified, suspected, or known releases of concern. Such activities can include release verification and characterization. Conducting the RFI should follow a logical sequence of actions involving the preparation and submittal of an RFI Work Plan, including development of a monitoring approach, performance of investigatory tasks, submission of results, and interactions with the regulatory agency on courses of further action. The overall RFI process is shown in Figure 2-1.

As indicated previously, each RFI situation is likely to be unique in various respects, including the unit or units releasing, the media affected, the extent of the release, the potential for inter-media impacts, the amount and quality of existing information, and other factors. The amount of work that may be involved in the RFI, and therefore the content of the RFI Work Plan, is also likely to vary. This section provides guidance concerning the general content of the RFI Work Plan.

#### **2.2 Preparation of an RFI Work Plan**

The RFI Work Plan is a detailed plan that the facility owner or operator should develop and follow throughout the RFI that will lead to characterization of the nature, extent, and rate of migration of a release of hazardous waste or hazardous constituents. This plan consists of a number of components that may be developed and submitted either concurrently or sequentially in accordance with the schedule specified in the permit or compliance order. These components are shown in the top box of Figure 2-1. Development and, therefore, submittal of specific plan components (e.g., detailed monitoring procedures) may not be required



<sup>a</sup> In some cases, existing information may be adequate to characterize specific releases

<sup>b</sup> The owner or operator also has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures.

<sup>c</sup> No further action will be necessary where a suspected release is shown to not be an actual release based on an adequate amount of monitoring data or where release concentrations are shown to be below levels of concern for a sufficient period of time

<sup>d</sup> Implies release concentrations were observed to be equal to or above health and environmental assessment criteria, or that there was a reasonable likelihood of this occurring.

<sup>e</sup> Interim corrective measures may also be implemented prior to or during the RFI, as necessary.

FIGURE 2-1. RCRA FACILITY INVESTIGATION (RFI) PROCESS.

until adequate information on the contaminant source and environmental setting is gathered and evaluated. Discussion on RFI reporting and schedules between the owner or operator and regulatory agency is encouraged.

The owner or operator should be guided by the information contained in the RFA Report and the conditions specified in the permit or compliance order in developing the RFI Work Plan. These conditions will usually indicate which units and releases are to be addressed in the RFI (based on the findings of the regulatory agency during the RFA), as well as which media are of concern. In most cases, the information contained in the RFA Report and the conditions specified in the order or permit will enable the owner or operator to develop a sufficiently focused RFI Work Plan. However, if additional guidance is needed by the owner or operator, consultation with the regulatory agency is advised.

### **2.2.1 Description of Current Conditions**

As part of the RFI Work Plan, the owner or operator should provide background information pertinent to the facility, contamination, and interim corrective measures as described below. Data gathered during any previous investigations or inspections and other relevant data should be included. The owner or operator should consult with the regulatory agency to determine if any of these information items are irrelevant or have already been submitted in an appropriate format for other purposes (e.g., contained in a RCRA permit application).

#### **2.2.1.1 Facility Background**

The owner or operator should summarize the regional location, pertinent boundary features, general physiography, hydrogeology, and historical use of the facility for the treatment, storage or disposal of solid and hazardous waste. This information should include the following:

- Map(s) depicting:
  - General geographic location;

- Property lines, with the owners of all adjacent property clearly indicated;
- Topography and surface drainage (with an appropriate contour interval and a scale of 1 inch = 100 feet) depicting all waterways, wetlands, floodplains, water features, drainage patterns, and surface-water containment areas;
- All tanks, buildings, utilities, paved areas, easements, rights-of-way, and other features;
- All solid or hazardous waste treatment, storage or disposal areas active after November 19, 1980;
- All known past solid or hazardous waste treatment, storage or disposal areas regardless of whether they were active on November 19, 1980;
- All known past and present product and waste underground tanks or piping;
- Surrounding land uses (residential, commercial, agricultural, recreational);
- The location of all production and ground-water monitoring wells. These wells shall be clearly labeled and ground and top of casing elevations and construction details included (these elevations and details may be included as an attachment); and
- Location of any injection wells onsite or near the facility.

All maps should be consistent with the requirements set forth in 40 CFR §270.14 and be of sufficient detail and accuracy to locate and report all current and future work performed at the site including

- A history and description of ownership and operation, solid and hazardous waste generation, and treatment, storage and disposal activities at the facility;
- Approximate dates or periods of past product and waste spills, identification of the materials spilled, the amount spilled, the location where spilled, and a description of the response actions conducted (local, state, or Federal response units or private parties), including any inspection reports or technical reports generated as a result of the response; and
- A summary of past permits requested and/or received, any enforcement actions and their subsequent responses, and a list of documents and studies prepared for the facility.

#### 2.2.1.2 Nature and Extent of Contamination

The owner or operator should describe any existing information on the nature and extent of releases, including

- A summary of all possible source areas of contamination. This, at a minimum, should include all regulated units, solid waste management units, spill areas, and other suspected source areas of contamination. For each area, the owner or operator should identify the following:
  - Location of unit/area (which should be depicted on a facility map);
  - Quantities of solid and hazardous wastes;
  - Hazardous waste or constituents, to the extent known; and
  - Identification of areas where additional information is or may be necessary.
- A description of the degree and extent of contamination. This should include



- Available monitoring data and qualitative information on locations and levels of contamination at the facility;
- All potential migration pathways including information on geology, pedology, hydrogeology, physiography, hydrology, water quality, meteorology, and air quality; and
- The potential impact(s) on human health and the environment, including demography, ground-water and surface-water use, and land use.

The surface configuration of contaminant sources both on and off the site may impact assessment and remediation by contributing to the complexity of contamination. Technical factors such as contaminant migration potential, the ability to withdraw or treat contaminants, and the effectiveness of treatment trains can be significantly altered by the interaction of releases from different contaminant sources. Well-developed maps showing the number, spacing, and relative positions of contaminant sources are essential to the planning and implementation of assessment and remediation activities. In addition to map and field inspections, remote sensing, surface geophysical methods, and Geographic Information Systems are useful site evaluation tools. Information obtained from these site screening methods will help direct subsequent, more intensive activities to the major areas of concern.

Assessment activities may be subtly affected by the surface configuration of contaminant sources at the site. Figure 2-2 shows an example of overlapping ground-water contamination plumes from adjacent sources that contain different wastes. Organic solvents from Source A may facilitate the movement of otherwise low-mobility constituents from Source B. Contaminants from Source B, that are fairly insoluble in water, dissolve readily when in contact with solvents from Source A. This process is described as co-solvation. Examples of other potential complications in the ground water medium include heavy metal transport by complexation, particle transport, biotransformation, clogging of media pores or filtering devices by particulates, and changes in subsurface adsorptive properties. These and other factors suggest that an approach that focuses only on individual

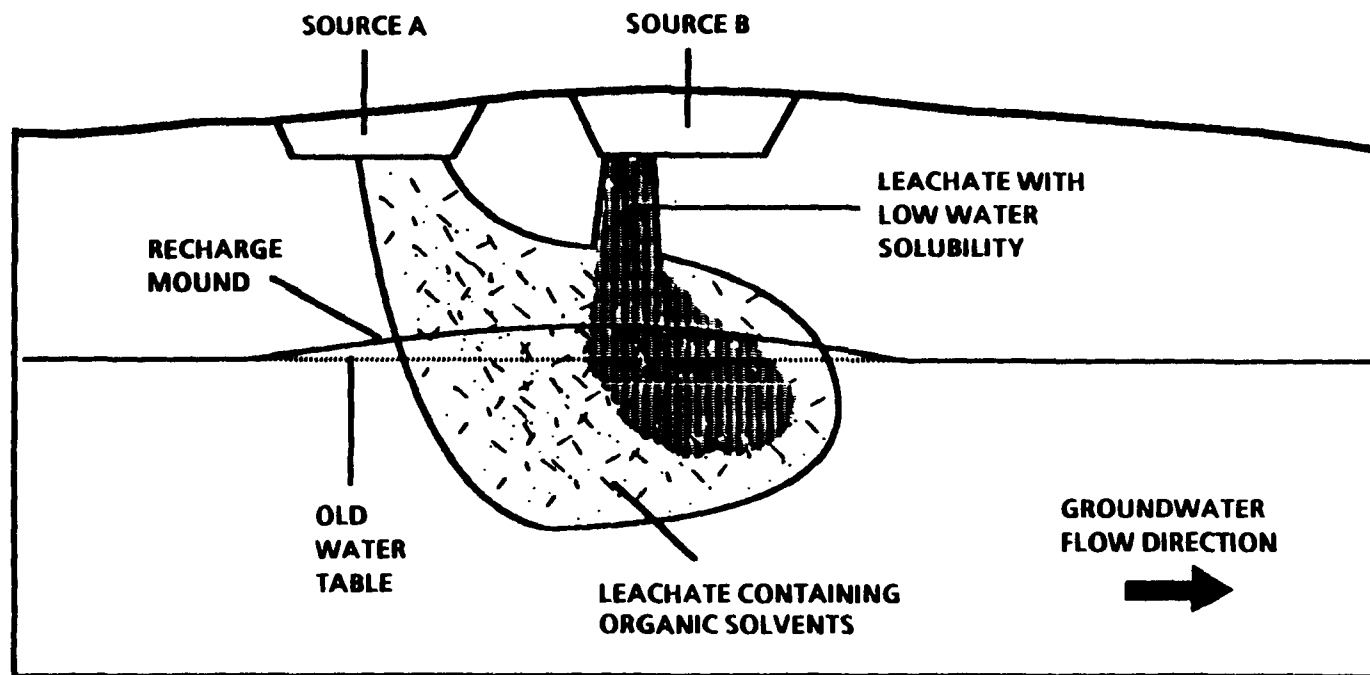


FIGURE 2-2. Overlapping Plumes From Adjacent Sources That Contain Different Wastes

contaminant sources without considering potential interactions between sources may lead to improper assessment and remediation. Additional information on this subject is provided in the following reference:

Keely, J.F. January, 1987. The Use of Models In Managing Ground-Water Protection Programs. EPA/600/8-87/003. EPA Office of Research and Development. Washington, D.C. 20460.

The extent of contamination at a site can be viewed in two ways. First the extent can be examined from a spatial perspective, i.e., where is the contamination located and what are its approximate dimensions? Second, the extent of contamination can be viewed from a toxicity or concentration level perspective, i.e., to what degree is the medium (e.g., soil, aquifer) "damaged" or contaminated? Chemical isopleth maps (discussed in Section 5) can be used to represent both components of contamination over a given area. Each perspective should be considered because both can influence ground-water remedy selection, and on a larger scale, future land use.

Data on the extent of contamination are gathered through a variety of analytical devices and methods, such as monitoring wells, soil gas monitoring, ambient air monitoring, modeling and geophysical techniques. As in all cases, a more extensive monitoring system allows for better delineation of the contaminant release. Economic considerations force investigators to obtain a maximum amount of information from assessment activities. With this in mind, areal photographs, color infrared imagery and other more sophisticated remote sensing imagery may be useful in defining vegetation stress or other environmental indicators that aid in delineating the extent of contamination.

The vertical extent of contamination should also be considered in defining a release. For ground water, the vadose zone, uppermost aquifer, and if affected, other proximal interconnected aquifers and surface-water bodies, should be considered as an integral part of every ground-water decontamination process. The importance of controlling and cleaning up contamination within the vadose zone is well documented. Often, ground-water pollution abatement efforts are inhibited by percolating waters that collect leachate or products in a contaminated vadose zone and advance down to the water table. At this point, the initial ground-water

clean up attempt must be repeated causing additional problems and costs. To prevent continued loss of ground-water quality, vadose zone decontamination should be initiated and regarded as an important component of the ground-water remediation process.

Cross media effects also play an important role in defining the extent of contamination. Air, soil, surface-water, and ground-water quality are all potentially threatened by any contaminant release within the environment. Contaminants transported inconspicuously from a seemingly confined media to another may harm ecosystems or humans simply because the migration was not anticipated. Both natural pathways between media and those created by anthropogenic features (e.g., improperly constructed monitoring wells) may increase the extent of contamination. For these reasons the complex interactions between environmental media should not be overlooked.

#### **2.2.1.3 Implementation of Interim Corrective Measures**

The owner or operator should document interim corrective measures that were or are being undertaken at the facility. This should include

- Objectives of the interim measures, including how the measure is mitigating a potential threat to human health and the environment and/or is consistent with and integrated into any long-term solution at the facility;
- Design, construction, operation, and maintenance requirements;
- Schedules for design, construction and monitoring; and
- Schedule for progress reports.

#### **2.2.2 Schedule for Specific RFI Activities**

In the RFI Work Plan, the owner or operator should propose a schedule for completing the RFI within the time frame of the order or permit schedule of compliance. The schedule should be as specific as possible and should indicate dates

for submittal of the various components of the RFI Work Plan, dates for starting and accomplishing specific tasks associated with the RFI, and dates for reporting information from specific tasks to the regulatory agency.

### **2.2.3 Procedures for Characterizing the Contaminant Source and the Environmental Setting**

Prior to establishing monitoring procedures to provide data on the release, certain information should be acquired to determine constituents of concern and appropriate sampling locations. Two key areas should be addressed: characterization of the source (i.e., waste and unit), and characterization of the environmental setting. These areas are described in general terms below. They are also described in detail in each of the media-specific sections.

#### **2.2.3.1 Contaminant Source Characterization**

Characterization of the unit(s) and associated waste may be necessary to identify applicable monitoring constituents or useful indicator parameters for the release characterization. Design and operational information on the unit, such as unit size and amount of waste managed therein, may be necessary to determine release rates.

In some cases, adequate characterization of the waste in the unit can be made by evaluating existing waste management records or data on the process generating the waste. In other cases, a sampling and analysis effort may be necessary. If so, the owner or operator should define the sampling and analysis effort in regard to:

- Constituents, analytical methods, detection limits, and the rationale for their selection;
- Sampling methods, sampling locations, equipment, and schedule; and
- Pertinent QA/QC procedures to ensure valid waste characterization.

Identification of monitoring constituents and use of indicator parameters are discussed further in Section 3 and supported by Appendix B. Waste and unit characterization methods, including sampling, are described in Section 7. QA/QC procedures are described in Section 4.

Unit characterization should include information such as construction procedures and materials, and liner specifications, if applicable. Such information may be important in evaluating the probable degree of contamination from the unit, and consequently, the probable type and severity of the release.

Waste characterization will not always provide complete information for use in identifying monitoring constituents. This may be especially true for old units, where significant degradation of constituents may have occurred, and for those units that have received many different types of waste, where it is difficult to be sure that all wastes in the unit were sampled and analyzed. The owner or operator should be aware of these possibilities. Further guidance on appropriate procedures in these cases is provided in Sections 3 and 7.

Important data on individual sources also includes the condition of the source, the spatial distribution of the source, and waste management practices. The condition of a source may significantly affect its capacity to contaminate the surrounding environment. Evaluating and controlling contaminant sources early on may significantly reduce the costs of assessment and remediation.

Waste treatment, storage and disposal units (e.g., landfills, surface impoundments, and waste piles, etc.) that do not have containment systems are, of course, more susceptible to the release of contaminants. If there is no cover or liner present, the release of constituents from a unit will largely depend on site characteristics (e.g., infiltration, hydrogeology) and contaminant characteristics (e.g., solubility, specific gravity), which are discussed in later sections. Source control technologies such as cover installation, waste removal, in situ waste treatment, or subsurface barrier construction may be appropriate when no containment system is present.

When a containment system is present, it is appropriate to evaluate the condition of the system to determine if modifications could significantly reduce or

prevent further releases. Table 2-1 presents an outline describing some of the important characteristics of waste treatment, storage and disposal unit containment systems that should be evaluated. The degree of modification to a source will largely depend on contaminant migration potential, exposure potential, and the feasibility of implementing remedial measures, which in turn are affected by site hydrogeology, land use, waste characteristics, and other factors.

The three-dimensional distribution of each source should also be carefully delineated to focus remedial activities on the site's "hot spots" (i.e., those regions with the highest concentrations of contaminants). Cleaning up contaminated sites without identifying, defining and characterizing these hot spots may lead to ineffective, inefficient remediation attempts. Innovative technologies such as specialized coring methods (see Section 9), geophysical methods (see Section 10 and Appendix C), and soil gas sampling devices (see Section 11) may provide better resolution of these hot spots than more conventional methods and devices (e.g., monitoring wells, and split-spoon samplers).

The manner in which wastes are managed may significantly affect the nature and extent of contamination by influencing the spatial and temporal variability of contaminant releases. Important factors to consider when characterizing contaminant sources include the total quantity of wastes, the location and timing of waste management, waste and constituent characteristics, and general waste management practices.

As indicated previously, the total quantity of contaminants within a source is an obvious yet important consideration when assessing or remediating contamination. In general, the potential extent of contamination is proportional to the volume of wastes managed in the source, taking into account other factors such as hydrogeologic setting, exposure potential, and the condition of the source.

In addition, the location of waste treatment, storage, and disposal units may affect the type and degree of remedial measures. In addition to the surface configuration of sources, the location of different quantities and types of waste within a source may affect the potential for release. For instance, low pH liquid waste placed near wastes containing heavy metals may promote the migration of the metal cations by increasing their solubility.

TABLE 2-1. CONTAINMENT SYSTEM EVALUATION

- I. Cover<sup>1</sup>
  - A. Characteristics of the soil to be used in the cover
  - B. Cover and surrounding land topography
  - C. Climate characteristics
  - D. Composition of the cover
    - 1. Component type
    - 2. Component thickness
  - E. Cover design and construction practices
  - F. Cover configuration
  - G. Cover drainage characteristics
    - 1. Material used in drainage system
    - 2. Thickness of drainage system
    - 3. Slope of the drainage system
  - H. Vegetative cover
  - I. Post-closure maintenance
    - 1. Cap system
      - a. Adequate vegetative cover
      - b. Erosion
      - c. Settlement/subsidence
    - 2. Run-on and run-off control system
      - a. Adequate vegetative cover
      - b. Erosion
      - c. Flow obstructions
- II. Liner and Leachate Collection/Detection System
  - A. The number of liners

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<sup>1</sup> Information in this section was in part obtained from EPA's technical resource document, Evaluating Cover Systems for Solid and Hazardous Waste, SW-867, 1982.



**TABLE 2-1. CONTAINMENT SYSTEM EVALUATION (Continued)**

- B. The type and thickness of the liners**
  - 1. The compatibility of the liners with the waste type
  - 2. The structural strength of the liners
  - 3. The liner foundation
- C. The age and installation methods of the liners**
- D. Description of leachate collection system**
  - 1. Thickness of drainage layer
  - 2. Material used in the drainage system
  - 3. Slope of the collection system
  - 4. Method of leachate collection
  - 5. Method of leachate withdrawal
- E. Description of leak detection system**
  - 1. Thickness of detection system
  - 2. Material used in the system
  - 3. Slope of the detection system
  - 4. Method of leak detection
  - 5. Ability to withdraw leachate from the system
- III. Other Factors**
  - A. Compatibility of bottom-most liner with the underlying geology**
  - B. Relationship of the ground-water table to the bottom liner**
  - C. Water content (percent solids and free liquids content)**
  - D. Compatibility of waste with containment system (or underlying soil, if no containment system is present)**
  - E. Waste load on the containment system**

Transportation of wastes on and off site is an equally important consideration. For instance, a buried transmission line may rupture and release contaminants to the subsurface. Vehicles conveying wastes to, from, or within a site may spill or leak substances onto the ground and eventually cause subsurface contamination. Carefully maintained records of waste transportation or field inspections may reveal such potential leaks or spills.

The timing of waste management also is important in assessing and remediating site contamination. Two aspects of timing are important to recognize here: the age of the source and the history of waste management. Both aspects may affect the timing, nature, and degree of assessment and remediation.

Due to the generally slow movement of some types of contamination (e.g., ground water plumes), releases covering a large area are more likely to originate from older sources (i.e., sources that have managed wastes for long periods or at previous times). Older sources are generally harder to define and characterize due the paucity of waste management data and little, if any, containment features. Newer units, on the other hand, are more likely to have accurate management records and improved design features for containment. Remediation for an older source contaminating the ground water, for example, may involve substantial plume control, aquifer restoration, and capping of large areas of contaminated soil. On the other hand, a recently detected leak from a new source may be abated by minor containment system repair, with little or no aquifer restoration and plume control required.

The history of waste management for a specific source affects assessment and remediation by influencing the source's capacity to contaminate over time. In addition to the spatial variability of wastes, the temporal variability of waste management should be considered. Sources may form discrete or continuous plumes, depending on the history of waste management. As shown in Figure 2-3, the configuration of ground-water contamination may be profoundly affected by the timing of releases. Assessment and remediation of contamination are consequently aided by understanding the history of waste management for individual sources.

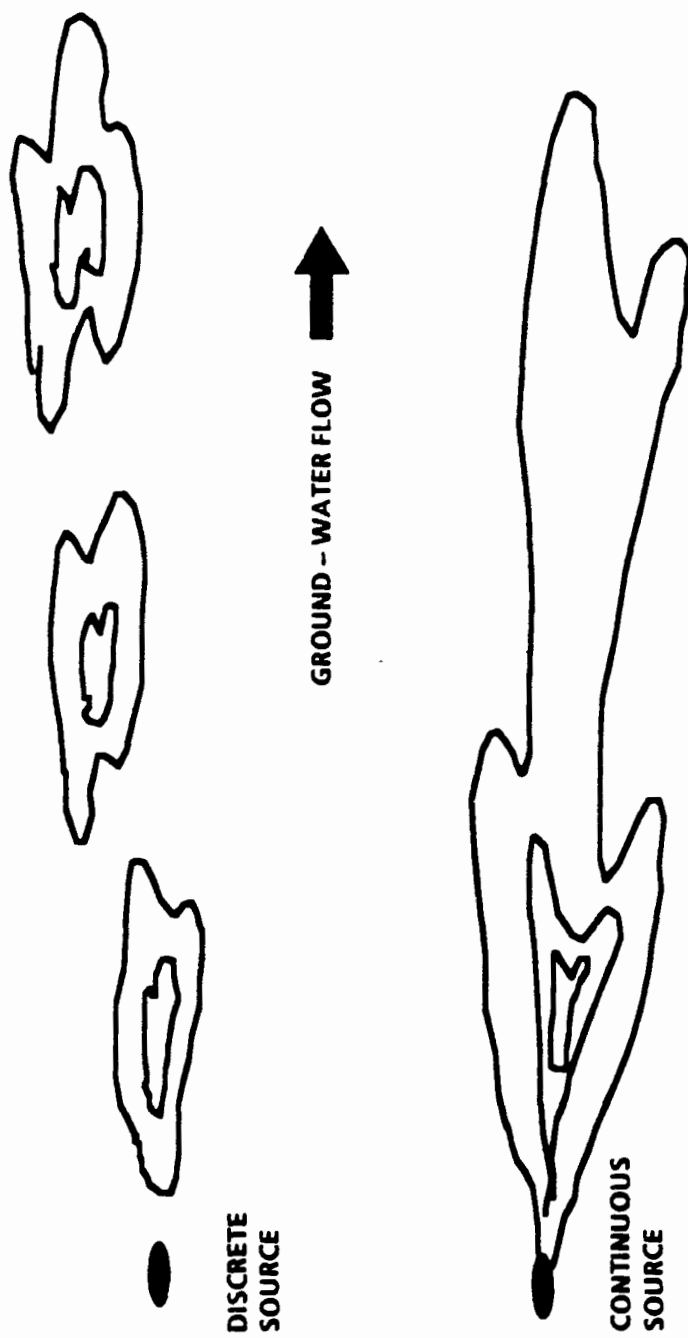


FIGURE 2-3. Discrete versus Continuous Contaminant Sources.

In some cases, altering the timing of waste management may be an effective source control measure. For instance, placement of wastes in landfill cells without covers may be limited to anticipated dry periods. By doing so, the amount of moisture in contact with wastes may be significantly reduced, thus minimizing the potential for contaminant migration.

Specific characteristics of waste and constituents affecting the assessment and remediation of contamination in specific media are discussed in the media specific sections of this guidance. These characteristics include the compatibility of wastes with the unit, the containment system (if any), the underlying geology, and interactions between different wastes and constituents. Assessing the characteristics of wastes and constituents in conjunction with data on the condition of the source and site hydrogeology may aid assessment and remediation by identifying problems related to waste containment or complicated fate and transport mechanisms. If waste/containment system compatibility problems are discovered during a site evaluation, source modification such as liner replacement may be necessary to reduce or prevent further releases. In some cases, modifying waste treatment, storage, and disposal practices (e.g., restricting certain wastes from operating landfills) may be the most appropriate source control measure.

Interactions between wastes and constituents and underlying geology may alter contaminant migration potential and complicate control, recovery and treatment operations. For example, acidic leachate may cause or exacerbate solution cavity development in areas underlain by karst geology, thus promoting the migration of contaminants. In other instances, interactions between contaminants and subsurface materials may reduce the effectiveness and efficiency of remediation technologies; for example, by changing the chemistry of contaminated ground water or by inhibiting fluid flow to and from heavily contaminated areas.

Predicting the interactions between different wastes and constituents is among the most difficult tasks performed during site investigations. Such interactions may affect contaminant migration potential and complicate recovery and treatment operations. One example is the clogging of pore spaces or well screens by precipitates which form by chemical interactions between wastes or constituents. Other examples include co-solvation, particle transport and mobile

transformation products (see Table 2-2). It should be noted that laboratory testing of waste, or constituent interactions may not accurately depict subsurface processes. For this reason, ground-water chemistry and waste treatment, storage, and disposal conditions at the site should be considered when predicting the behavior of certain combinations of wastes or constituents. In some instances, this may mean additional sampling, monitoring, and field testing.

Reviewing waste management records to assess the quality of waste management practices may aid assessment and remediation activities by providing insight into the release potential of a source, and consequently, facilitate remedy selection. For instance, factors such as waste packaging, handling and placement, freeboard maintenance, and waste characterization may indicate how well a waste management unit is operated and maintained. Improvements in such waste management practices may reduce contaminant migration potential and therefore should be considered viable source control measures.

#### **2.2.3.2 Environmental Setting Characterization**

Characterization of the environmental setting may be necessary to determine monitoring locations (i.e., contaminant pathways) and to aid in defining the boundaries of the contaminated area. Techniques for characterizing the environmental setting are media-specific and are described in Volumes II and III of this Guidance. Examples of environmental information that may be required are wind speed and direction, subsurface stratigraphy, and surface-water body volumes and flow rates.

#### **2.2.4 Monitoring and Data Collection Procedures**

Specific monitoring procedures should be identified in the RFI Work Plan to characterize each release of concern. These procedures should indicate the proposed approach for conducting the investigation and should account for the following:

- Historical information and/or information gathered during the characterization of the contaminant source and the environmental setting;

**TABLE 2-2. PHYSICAL, CHEMICAL AND BIOLOGICAL PROCESSES  
AFFECTING CONTAMINANT FATE AND TRANSPORT  
(Keely, 1987)**

**PHYSICAL PROCESSES**

**Advection (porous media velocity)**

**Hydrodynamic Dispersion**

**Molecular Diffusion**

**Density Stratification**

**Immiscible Phase Flow**

**Fractured Media Flow**

**CHEMICAL PROCESSES**

**Oxidation-Reduction Reactions**

**Radionuclide Decay**

**Ion-Exchange**

**Complexation**

**Co-Solvation**

**Immiscible Phase Partitioning**

**Sorption**

**BIOLOGICAL PROCESSES**

**Microbial Population Dynamics**

**Substrate Utilization**

**Biotransformation**

**Adaptation**

**Co-metabolism**

- An approach for implementation, including the type of information to be collected;
- Description of the monitoring network; and
- Description of monitoring activities (e.g., sampling, meteorological monitoring).

Monitoring procedures may include a phased approach for release characterization as described in the media-specific sections of this Guidance. The initial phase may include a limited monitoring effort followed by subsequent phases, if necessary. The design of subsequent monitoring phases may be based on information gathered during a prior phase; therefore, revisions to the monitoring procedures may become necessary as the RFI progresses. A phased approach may be particularly useful in cases where a suspected release was identified by the regulatory agency as a result of the RFA process. In this case, the first monitoring phase may be designed to provide for release verification as well as the first step for release characterization. If revisions to a proposed monitoring approach become necessary, documentation should be submitted to the regulatory agency to support such changes.

#### **2.2.5 Assembling Existing Data to Characterize the Contaminant Release**

The owner or operator should assemble and review existing analytical and monitoring data pertinent to the release(s) and media of concern. This information can be used to determine the need for and to plan the extent of additional monitoring. Only data that have been collected using reliable methods and documented QA/QC procedures should be used as the basis for planning additional efforts. The amount and quality of existing data will determine the need for additional monitoring information on the release. Sources of such data include

- Information supplied by the regulatory agency with the permit conditions or compliance order;
- The RFA report;

- Facility records;
- The facility's RCRA permit application;
- State and local government agency files, and
- CERCLA site reports (e.g., Records of Decisions).

#### **2.2.6 Quality Assurance/Quality Control (QA/QC) Procedures**

The use of properly documented and implemented QA/QC procedures for monitoring activities (including sampling and analysis) is an essential part of the RFI Work Plan. It is important to ensure that data generated during the investigation are valid (i.e., supported by documented procedures) such that they can be used with confidence to support determinations regarding the need for and design of subsequent monitoring, the need for interim corrective measures, and the need for a Corrective Measures Study. These procedures are used to describe and document data quality and include such activities as

- Defining sampling and analytical techniques;
- Confirming and documenting correct sample identity;
- Establishing precision and accuracy of reported data;
- Documenting all analytical steps in determining sample identity and constituent concentrations;
- Establishing detection limits for constituents of concern; and
- Establishing any bias arising from field sampling or laboratory analytical activities.



Another important aspect of QA/QC is to ensure the use of qualified personnel (e.g., licensed or certified) to conduct or oversee various parts of the investigation. QA/QC procedures are described in Section 4.

#### **2.2.7 Data Management and Reporting Procedures**

Data management procedures should be included as part of the RFI Work Plan for organizing and reporting investigation data and results. Satisfactory presentation of investigation results to the regulatory agency is essential in characterizing and interpreting contaminant releases. Guidance on these procedures is presented in Section 5.

#### **2.2.8 Identification of Potential Receptors**

As specified by the regulatory agency in the permit or order, the owner or operator should provide in the RFI Work Plan information describing the human populations and environmental systems that may be susceptible to contaminant releases from the facility. Such information may include

- Existing and possible future use of ground water, including type of use (e.g., municipal and/or residential drinking water, agricultural, domestic/non-potable, and industrial);
- Location of ground-water users, including wells and discharge areas;
- Existing and possible future uses of surface waters draining the facility, including domestic and municipal uses (e.g., potable and lawn/gardening watering), recreational (e.g., fishing and swimming), agricultural, and industrial and environmental (e.g., fish and wildlife populations) uses;
- Human use of or access to the facility and adjacent lands, including recreational, hunting, residential, commercial, zoning, and the relationship between population locations and prevailing wind direction;
- A description of the biota in surface-water bodies on, adjacent to, or which can be potentially affected by the release;

- A description of the ecology on and adjacent to the facility;
- A demographic profile of the human population who use or have access to the facility and adjacent land, including age, sex, sensitive subgroups (e.g., schools, nursing homes), and other factors as appropriate; and
- A description of any endangered or threatened species near the facility.

This information can be used to determine whether any interim corrective measures may be necessary at the facility. If populations are currently being adversely exposed or such exposure seems imminent, interim corrective measures may be necessary. Further information regarding interim corrective measures is provided in Section 8 (Health and Environmental Assessment).

Receptors can be affected by the transfer of a release from one medium to another. Apparent or suspected inter-media transfers of contamination, as identified in the permit or order, should be addressed in the RFI Work Plan. Table 2-3 illustrates some potential inter-media contaminant transfers and pathways. In examining the extent of a release, the owner or operator may be directed to collect sufficient information to allow the identification of potential inter-media transfers.

Situations where inter-media contaminant transfer may be important may arise through common usage of the contaminated medium. For example, drinking of ground or surface waters contaminated with volatile constituents poses an obvious hazard. Less obvious is the inhalation hazard posed by showering with such contaminated waters. Situations such as this should also be considered when determining the need for interim corrective measures.

The guidance presented in the media-specific sections (Volumes II and III) addresses potential areas for inter-media transfer. The guidance also identifies situations in which contamination of more than one media can be characterized, to some extent, using common procedures. For example, soil-gas analyses, such as those conducted using an organic vapor analyzer (OVA), can be used to monitor for subsurface gas (e.g., methane), as well as to indicate the overall extent of certain types of contaminant releases to ground water.

TABLE 2-3. SOME POTENTIAL INTER-MEDIA CONTAMINANT  
TRANSFER PATHWAYS

Release Media	Potential Receiving Media	Transfer Pathways
Air	<ul style="list-style-type: none"> <li>• Soil</li> <li>• Surface Water</li> </ul>	<ul style="list-style-type: none"> <li>- Deposition of particles</li> <li>- Atmospheric washout</li> </ul>
Soil	<ul style="list-style-type: none"> <li>• Ground Water</li> <li>• Subsurface Gas</li> <li>• Surface Water</li> </ul>	<ul style="list-style-type: none"> <li>- Migration through the unsaturated zone</li> <li>- Migration through the soil</li> <li>- Overland runoff</li> </ul>
Ground Water	<ul style="list-style-type: none"> <li>• Surface Water</li> <li>• Subsurface Gas</li> </ul>	<ul style="list-style-type: none"> <li>- Ground-water discharge</li> <li>- Volatilization</li> </ul>
Surface Water	<ul style="list-style-type: none"> <li>• Ground water</li> <li>• Air</li> <li>• Soil</li> </ul>	<ul style="list-style-type: none"> <li>- Ground-water recharge</li> <li>- Volatilization</li> <li>- Deposition of floodplain sediments</li> </ul>
Subsurface Gas	<ul style="list-style-type: none"> <li>• Air</li> <li>• Soil</li> </ul>	<ul style="list-style-type: none"> <li>- Venting through soil</li> <li>- Migration through soil</li> </ul>

### **2.2.9 Health and Safety Procedures**

Health and safety procedures may be included as part of the RFI Work Plan. The owner or operator is advised to understand, use, and document health and safety procedures describing efforts that will be taken to ensure the health and safety of the investigative team and others (e.g., the general public) during the RFI. The owner or operator should also be aware that on December 19, 1986, the Occupational Safety and Health Administration (OSHA) issued an interim final rule on hazardous waste site operations (29 CFR 1910.120) which specifically requires certain minimum standards concerning health and safety for anyone performing activities at CERCLA sites, RCRA sites, or emergency response operations. Further discussion on this topic is provided in Section 6.

### **2.3 Implementation of the RFI Work Plan**

After review of the RFI Work Plan by the regulatory agency, the owner or operator should implement the plan as directed. In some cases, adequate information may exist to characterize specific releases, and an extensive monitoring effort may not be necessary. The extent of monitoring will depend on the amount and quality of existing information and the nature of the release. Results of investigative activities should be submitted to the regulatory agency according to the RFI Work Plan schedule. Further guidance on specific reports that may be required is provided in Section 5.

The owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. Interim corrective measures may be necessary if receptors are currently being exposed to release constituents or if such exposure seems imminent. These situations may become evident at any point in the RFI process. The owner or operator should contact the regulatory agency immediately if any such situation becomes apparent. Further information regarding the evaluation of the results of release characterization is presented in Section 8.

## **2.4 Evaluation by the Regulatory Agency**

The regulatory agency will evaluate reports of release-specific results of the RFI submitted by the owner or operator to make determinations for further action. Such determinations may include

- No further action is necessary at that time;
- Further information on a release is necessary. The owner or operator will be advised to initiate additional monitoring activities;
- Interim corrective measures are necessary; or
- Adequate information is available to conclude that a CMS is necessary.

The regulatory agency may elect to be present at the facility to observe any phase of the release investigation. As indicated previously, close coordination between the owner or operator and the regulatory agency is essential throughout the RFI process. Also, as shown in Figure 2-1, interim corrective measures may be implemented prior to or during the RFI, as necessary.

## **SECTION 3**

### **GENERAL STRATEGY FOR RELEASE INVESTIGATION**

#### **3.1 INTRODUCTION**

An investigation of releases from solid waste management units requires various types of information. This information is specific to the waste managed, unit type, design, and operation, the environment surrounding the unit or facility, and the medium to which contamination is being released. Although each medium will require specific data and methodologies to investigate a release, a general strategy for this investigation, consisting of two elements, can be described:

- Collection and review of data to be used in developing a conceptual model of the release that can be used to plan and develop monitoring procedures. These data may include existing information on the facility/unit or related monitoring data, data which can be gathered from outside sources of information on parameters affecting the release, or the gathering of new information through such mechanisms as aerial photography or waste characterization.
- Formulation and implementation of field investigations, sampling and analysis, and/or monitoring procedures designed to verify suspected releases (if necessary), and to evaluate the nature, extent, and rate of migration of verified releases.

As stated in Section 2, two components of the RFI Work Plan will address these elements. These are

- Procedures to characterize the contaminant source and the environmental setting; and
- Monitoring procedures.

Sections 3.4 and 3.5 provide general guidance on these procedures. Section 3.2 outlines the general strategy suggested for all release investigations, and Section 3.3 briefly discusses concepts concerning data quality that are designed to ensure that data collected during the investigation will adequately support decisions that will eventually be made regarding the need for corrective measures. Section 3.6 provides guidance for formulating methods and monitoring procedures, and addresses monitoring constituents and indicator parameters, use of EPA and other methods, sampling considerations, and analytical methods and detection limits. Section 3.7 provides information concerning various decisions that may be made based on monitoring data and other information collected during the RFI process.

### **3.2 Phased Strategy for Release Investigations**

At the start of the RFI process, varying amounts of information will exist on specific releases and units. In some instances, suspected releases may have been identified based on strong evidence that releases have occurred, but with little or no direct data confirming their presence. On the other end of the spectrum, there may be enough existing data at the start of the RFI to begin considering whether some form of corrective measure may be necessary.

This potentially broad spectrum of situations that may exist at the beginning of the RFI may call for a flexible, phased approach for the release investigation, beginning with an evaluation of existing data and collecting additional data, as necessary to characterize the release source and the environmental setting. From such data, a conceptual model of the release can be formulated in order to design a monitoring program capable of release verification and/or characterization.

The release characterization may be conducted in phases, if appropriate, with each monitoring phase building on the findings and conclusions of the previous phase. The overall level of effort and the number of phases for any given characterization effort depend on various factors including

- The level of data and information available on the site;

- The complexity of the release (e.g., number of units, release pathways, affected media); and
- The overall extent of the release.

As many situations are likely to be unique with respect to the above factors, the number and intensity of each of the phases of the RFI process leading to eventual characterization and to assessment against health and environmental criteria are also likely to be unique. Even though some RFIs may have several phases, it is important to make sure that the establishment of a phased approach does not result in undue delay of the RFI process.

Case Study No. 18 in Volume IV (Case Study Examples) provides an illustration of a phased characterization.

### **3.3 Data Quality and Use**

Throughout the RFI process, it should be kept in mind that the data will be used in making comparisons to health and environmental criteria to determine whether a CMS or interim corrective measures may be necessary. Therefore, the data collected during the investigation must be of sufficient quality to support decisions as to the need for corrective measures. The data can also be used to help establish the scope and types of corrective measures to be considered in the CMS.

Qualitative or quantitative statements that outline the decision-making process and specify the quality and quantity of data required to support decisions should be made early in the planning stages of the RFI. These "data quality objectives" are then used to design sampling and analytical plans, and to determine the appropriate level of quality assurance and control (QA/QC). As this subject is normally considered a QA/QC function, it is presented in more detail in the QA/QC Section (Section 4) of this document. It is briefly discussed here to stress the importance of defining the objectives of the investigation, and of designing data-gathering efforts to meet these objectives throughout the investigation.



### **3.4 Procedures for Characterizing the Contaminant Source and the Environmental Setting**

Before monitoring procedures are established, information on the contaminant source (i.e., waste and unit) and environmental setting may be required. The owner or operator should identify necessary data and formulate procedures to gather these data.

Unit-specific data that may be required for release investigation include such parameters as the physical size of the unit, the amount of waste in the unit, operational schedules, age, operational lifetime, and release controls. Data concerning the environmental setting that may be necessary are specific to the medium affected, and may include such information as climate, hydrogeologic setting, vegetation, and topography. These and other important elements are described below, starting with a discussion of the importance of existing information.

Case Study Numbers 8, 10, 12, 13, 14, and 30 in Volume IV (Case Study Examples) provide examples of the techniques discussed below.

#### **3.4.1 Sources of Existing Information**

Useful existing data may be found in the following sources:

- The RCRA Facility Assessment report. This report should provide information on the unit(s) known to be causing or suspected of causing a release to the environment and the affected media. It may also include data supporting the regulatory agency's release determinations. The owner or operator may wish to obtain the RFA report from the regulatory agency for use in scoping the RFI.
- Facility records and files. Other useful information may be available in facility records and files. This information may include data from required ground-water monitoring activities, results of required waste analyses, and other analytical results (e.g., tests run on wastes to determine such parameters as liner compatibility or free liquid

composition). The owner or operator may have information on the characteristics of the waste in the units of concern from other in-house sources, such as waste reduction and engineering studies on the process(es) feeding the units, or from analyses performed in conjunction with other regulatory programs, such as the National Pollutant Discharge Elimination System (NPDES) permitting process or Clean Air Act Standards. Design and construction information may also be contained within facility files. For example, design and construction information for advanced wastewater treatment systems may contain information on inactive units.

- **RCRA Permit Application.** Under current requirements, a RCRA permit application should include a description of the waste being managed at the facility (although not necessarily for all the units of concern), descriptions of the units relevant to the permit, descriptions of the general environment within and surrounding the facility (including descriptions of the subsurface stratigraphy), and design and operating information such as runoff/runoff controls. A companion rule (promulgated December 1, 1987) to the July 15, 1985, codification rule for Section 3004(u) expands the information requirements under §270.14(d) for all solid waste management units to be located on the facility topographic map, and to contain information on unit type, dimensions and design, dates operated, and waste managed, to the extent available.
- **State Construction Permit (e.g., industrial wastewater) files.**
- **Environmental or other studies conducted in conjunction with ownership changes.**
- **Interviews with facility personnel (current or retired).**
- **Environmental audit reports.**
- **Investigations for environmental insurance policies.**

### **3.4.2 Waste and Unit Characterization**

In addition to obtaining waste data on general parameters such as pH, density, and viscosity, which may be needed to characterize a release to specific media (and which may also be useful in evaluating corrective-measure technologies), the owner or operator should characterize the unit's waste to the compound-specific level. This characterization may serve as a basis for identifying monitoring constituents and indicator parameters for the media of concern. It should be noted that the owner or operator may be required to characterize all potential constituents of concern for a given medium, unless it can be shown that only certain constituents could be released from the waste source. A detailed waste characterization, through the use of facility records and/or additional waste sampling and analysis, can be utilized to limit the number of constituents for which release monitoring must be performed during the RFI. (See also Section 3.6.1.)

Waste and unit characterization procedures should address the following:

- Existing sources of information on the unit and waste and their utility in characterizing the waste source; and
- Methods for gathering data on the waste and unit that are not presently available.

In some cases the location of disposal areas (units) may not be obvious. Some of these disposal areas or units may have been buried, overgrown by trees, or covered by structures such as buildings or parking lots. In such cases, use of geophysical techniques (e.g., ground-penetrating radar - see Appendix C) may be useful in locating former disposal areas containing materials such as discarded drums or buried tanks.

After evaluating existing data, the owner or operator may propose to collect additional waste and unit characterization information. In such cases, the owner or operator should propose procedures in the RFI Work Plan for

- Sampling--This should include sampling locations, schedules, numbers of samples to be taken, and methods for collecting and storing samples.

- **Analysis**--This should include a listing of analytical constituents or parameters and the rationale for their selection, analytical methods, and identification of detection limits.
- **QA/QC**--This should include specific steps to be taken to ensure the viability and validity of data produced during a waste sampling effort.
- **Data management**--The owner or operator should describe data management procedures, including the format(s) by which data on the contaminant source will be presented to the regulatory agency and the various reports that will be submitted.

Further guidance on the types of information and methods to be used in gathering waste and unit data is given in Section 7. Case Study Numbers 3, 4, 7, 8, 9, and 10 in Volume IV (Case Study Examples) illustrate some of the activities discussed above.

### **3.4.3 Characterization of the Environmental Setting**

Data on the environmental setting will generally be necessary for characterizing the release, and may also be helpful for evaluating various corrective-measure technologies. The information necessary is specific to the site and medium receiving the release and is described in the media-specific sections (Sections 9 through 13). Some examples of the methods and techniques that may be used are as follows:

- **Direct media measurements**--Direct media measurements can provide important information that can be used to determine the rate and extent of contaminant release. For example, hydraulic conductivity measurements are essential in determining ground-water flow rates. Wind roses and patterns can be used in determining how far air contamination may migrate and are essential input for air dispersion models. Specific measurements helpful for investigating the rate and extent of releases are discussed in the media-specific sections (Sections 9 through 13) of this Guidance.

- **Aerial photography--**Aerial photography can provide information that can be helpful in determining the extent of contamination at a site. Interpretation of aerial photographs can aid in describing past and present contaminant sources, pathways, and effects. Information obtained can include ecological impacts (e.g., decaying vegetation), topography, drainage patterns, fracture traces, and other erosional features. The usefulness of aerial photography is discussed further in Appendix A.
  
- **Geophysical techniques--**Geophysical techniques can aid in characterizing subsurface conditions fairly rapidly with minimal disturbance of the site. Such characterization can provide information on physical (e.g., stratigraphic) and chemical (e.g., contaminant extent) conditions and can also be used to locate buried drums, tanks, and other wastes. Geophysical techniques include electromagnetic induction, seismic refraction, electrical resistivity, ground-penetrating radar, magnetic borehole methods, and other methods. These techniques can be particularly useful in determining appropriate sampling locations. However, these geophysical techniques are not always applicable at a particular site and do not provide detailed contaminant concentration data. Therefore, sampling will generally be necessary to provide data needed for adequately characterizing the release. Further details on these techniques are available in Section 10 on Ground Water, and in Appendix C (Geophysical Techniques).
  
- **Surveying and mapping--**According to the 40 CFR Part 270 requirements for RCRA permit applications, the owner or operator must provide a topographic map and associated information regarding the site. If an adequate topographic map does not exist, a survey may be necessary to measure and plot land elevations. Site-specific surveying and mapping can provide an effective means of expressing topographic features (e.g., subtle elevation changes and site drainage patterns) of an area useful in characterizing releases. Surveying and mapping are discussed in further detail in Appendix A.

The owner or operator should describe the following in the RFI Work Plan:

- Specific techniques to be used in defining the environmental setting for the releases of concern at the facility;
- A rationale for the use of these techniques;
- Specific QA/QC procedures applicable to the proposed techniques;
- Procedures for managing and presenting the data; and
- Potential uses of the information obtained from this characterization.

#### **3.4.4 Assembling Available Monitoring Data**

The owner or operator should compile and assess available media-specific monitoring data as a means of determining additional data needs. It is conceivable, in certain instances, that available data will be sufficient to characterize a release and provide the basis for making a determination on the need for corrective measures. However, this conclusion would be valid only if available data are current, comprehensive, accurate, and supported by reliable QA/QC methods. Otherwise, the use of available data should be limited to planning additional monitoring efforts.

### **3.5 Use of Models**

#### **3.5.1 General Applications**

Mathematical and/or computer modeling may provide information useful to the owner or operator during the RFI and in the design of corrective measures. The information may prove useful in refining conceptualizations of the environmental setting, defining likely contaminant release pathways, and designing corrective measures (e.g., pumping and treating contaminated ground water).

Because a model is a mathematical representation of an often-complex physical system, simplified assumptions must be made about the physical system, so

that it may fit into the more simplistic mathematical framework of the model. Such assumptions are especially appropriate because the model assumes a detailed knowledge of the relevant input parameters (e.g., permeability, porosity, etc.) everywhere in the area being modeled.

Because a model uses assumptions as to both the physical processes involved and the spatial and temporal variations in field data, the results produced by the model may provide only a qualitative assessment of the nature, extent, and rate of migration of a contaminant release. Because of the assumptions made, a large degree of uncertainty may arise from some modeling simulations. Such modeling results should not be unduly relied on in selecting precise monitoring locations or in designing corrective measures.

Use of predictive models during the RFI may be appropriate for guiding the general development of monitoring networks. Each of the media-specific sections identify where and how such predictive models may be used, and identify references containing specific models. For example, models are identified in the Surface Water Section (Section 13) for use in determining the extent of a monitoring system which may be necessary in a stream. Modeling results are generally not acceptable for expressing release concentrations in an RFI. An exception to this is the air medium (Section 12). Atmospheric dispersion models are suggested for use (especially when downwind monitoring is not feasible) in conjunction with emission-rate monitoring or modeling in order to predict downwind release concentrations and to define the overall extent of a release.

Where a model is to be used, site-specific measurements should be collected and verified. The nature of the parameters required by a model varies from model to model and is a function of the physical processes being simulated (e.g., ground-water flow and/or contaminant transport), as well as the complexity of the model. In simulating ground-water flow, for example, hydrogeologic parameters that are usually required include hydraulic conductivity (vertical and horizontal); hydraulic gradient; specific yield (unconfined aquifer) or specific storage (confined aquifer); water levels in wells and nearby surface-water bodies; and estimates of infiltration or recharge. In simulating contaminant transport in ground water, physical and chemical parameters that are usually required include ground-water velocity; dispersivity of the aquifer; adsorptive characteristics of the aquifer (retardation);

degradation characteristics of the contaminants; and the amount of each contaminant entering the aquifer (source definition).

Model input parameters that can be determined directly should be measured, with consideration given to selecting representative samples. Because the parameters cannot be measured continuously over the entire region but only at discrete locations, care should be taken when extrapolating over regions where there are no data. These considerations are especially important where the parameters vary significantly in space or time. The sensitivity of the model output both to the measured and assumed input parameters should be determined when evaluating modeling results. In addition, the ability of the model to be adequately calibrated (i.e., the ability of the model to reproduce current conditions), and to reproduce past conditions should be carefully evaluated in assessing the reliability of model predictions. Model calibration with observed physical conditions is critical to any successful modeling exercise.

Many models exist that may be applicable for use in the RFI. Because EPA is a public agency and models used by or for EPA may become part of a judicial action, EPA approval of model use should be restricted to those models that are publicly available (i.e., those models that are available to the public for no charge or for a small fee). The subset of models that are publicly available is quite large and should be sufficient for many applications. Publicly available models include those models developed by or for government agencies (e.g., EPA, U.S. Geological Survey, U.S. Department of Energy, U.S. Nuclear Regulatory Commission, etc.) and national laboratories (e.g., Sandia, Oak Ridge, Lawrence Berkeley, etc.), as well as models made publicly available by private contractors. Any publicly available model chosen should, however, be widely used, well-documented, have its theory published in peer-reviewed journals, or have some other characteristics reasonably ensuring its credibility. For situations where publicly available models are not appropriate, proprietary models (i.e., models not reasonably accessible for use or scrutiny by the public) should be used only where the models have been well-documented and have undergone substantial peer review. If these minimal requirements have not been met, the model will not be considered reliable.

*The Graphical Exposure Modeling System (GEMS) may be particularly useful for various aspects of the RFI. GEMS is an interactive computer system, developed*



by EPA's Office of Pesticides and Toxic Substances, which provides a simple interface to environmental modeling, physiochemical property estimation, statistical analysis, and graphic display capabilities, with data manipulation which supports all these functions. Fate and transport models are provided for soil, ground water, air, and surface water, and are supported by various data sets, including demographic, hydrologic, pedologic, geologic, climatic, economic, among others. Further information on GEMS may be obtained by calling EPA at (202) 382-3397 or (202) 382-3928 or by writing to EPA at the following address:

U.S. EPA  
Office of Pesticides and Toxic Substances  
Exposure Evaluation Division (TS-798)  
401 M Street, S.W.  
Washington, D.C. 20460

If the use of a model is proposed to guide the development of a monitoring network, the owner or operator should describe how the model works, and explain all assumptions used in calibrating and applying the model to the site in question. In addition, the model and all related documentation should be made available to the regulatory agency for review.

Case Study Numbers 20, 24, 25, and 31 in Volume IV (Case Study Examples) illustrate the use of various models that may be applied during the RFI.

### **3.5.2 Ground-Water Modeling**

Ground-water modeling is often used for site characterization, remedy selection and design, and prediction of site-specific cleanup levels and time requirements. As with other models, a ground-water model is a simplified representation of reality, usually expressed with mathematics, that aids in understanding and predicting subsurface contaminant fate and transport. As such, models may include flow nets, ground-water flow models, simple analytical solute transport models, method of characteristics models, or complex multi-phase finite element models.

Perhaps the most important role of ground-water models for assessment and remediation programs is their application in selecting, collecting and analyzing field data on subsurface contaminant fate and transport. Model development and site characterization should be combined in an iterative process of fate and transport simulation and data collection. For instance, after examining several cross-sections and water level data sets, the investigator may develop several flow nets to better understand the ground-water flow regime beneath a site. Following this, a series of simulations using a simple analytical solute transport model can roughly estimate the range of concentrations with respect to distance and time for various contaminants. These results could then be compared with actual concentrations of samples collected from monitoring wells. Discrepancies between observed and predicted concentrations may suggest that additional site characterization is required or that the model does not adequately simulate actual field conditions.

Ground-water models may be used to some extent in predicting contaminant migration, selecting and designing remedial systems, evaluating the performance of technologies, and projecting cleanup levels. For instance, assuming a pump and treat alternative is appropriate, analytical or numerical ground-water flow models could be used to estimate the placement of recovery wells and plume control wells. Such models could also be used in planning the timing of ground-water withdrawals. However, these types of applications should only be used in concert with actual data collection (e.g., collecting ground-water samples) and field demonstrations (e.g., pilot studies). Exclusive model use for the above applications without adequate data collection and field demonstration may lead to incorrect and inefficient remedy selection.

The following documents provide information on the uses of models and point out many of their limitations and underlying assumptions:

Keely, J.F. January 1987. The Use of Models in Managing Ground Water Protection Programs. EPA/600/8-87/003. EPA Office of Research and Development. Washington, D.C. 20460.

U.S. EPA. January 1989. Resolution on Use of Mathematical Models by EPA for Regulatory Assessment and Decision-Making. Report of the Environmental

These documents emphasize the importance of using ground-water models that are commensurate with the extent and quality of collected field data. Matching the model with the type of contamination problem is equally important. Certain instances may arise where more sophisticated models may be appropriate. For example, a finite element model simulating multi-phase flow of a hydrocarbon release in a well-characterized area may contribute to both defining the problem and selecting the remedy. The key rule to follow is to match the model with the type of contamination problem and the level and quality of data. In addition, every modeling exercise should include a sensitivity analysis to determine the relative impact of different variables on modeling results. The following presents excerpts from the above identified EPA Science Advisory Board report on mathematical models which are particularly relevant for regulatory assessment and decision-making:

- The use of mathematical models for environmental decision-making has increased significantly in recent years. The reasons for this are many, including scientific advances in the understanding of certain environmental processes, the wide availability of computational resources, the increased number of scientists and engineers trained in mathematical formulation and solution techniques, and a general recognition of the power and potential benefits of quantitative assessment methods. Within the U.S. Environmental Protection Agency (EPA) environmental models which integrate release, transport, fate, ecological effects and human exposure are being used for rule making decisions and regulatory impact assessments.
- The realistic characterization of an environmental problem requires the collection of laboratory and field data - the more complex the problem, the more extensive and in-depth are the required studies. In some cases involving more complex issues, future projections of environmental effects, larger geophysical regimes, inter-media transfers, or subtle ecological effects, mathematical models of the phenomena provide an essential element of the analysis and understanding. However, the

models cannot stand alone; adequate data are required. Indeed, a major function of mathematical models is as a tool to design field studies, interpret the data and generalize the results.

- Mathematical models should ideally be based on a fundamental representation of the physical, chemical and biological processes affecting environmental systems.
- An improperly formulated model can lead to serious misjudgements concerning environmental impacts and the effectiveness of proposed regulations. In this regard, a bad model can be worse than no model at all.
- There are a number of steps needed to confirm the accuracy and utility of an environmental model. As a preliminary step, the elements of the basic equations and the computational procedures employed to solve them should be tested to ensure that the model generates results consistent with its underlying theory. The confirmed model should then be calibrated with field data and subsequently validated with additional data collected under varying environmental conditions.
- The stepwise procedure of checking the numerical consistency of a model, followed by field calibration, validation and *a posteriori* evaluation should be an established protocol for environmental quality models in all media, recognizing that the particular implementation of this may differ for surface water, air and ground water quality models.
- A number of methods have been developed in recent years for quantifying and interpreting the sensitivity and uncertainty of models. These methods require careful application, as experience with uncertainty analysis techniques is somewhat limited, and there is a significant potential for misuse of the procedures and misinterpretation of the results. Potential problems include the tendency to confuse model uncertainty with temporal or spatial variation in environmental systems, the tendency to rely on model uncertainty analysis as a low-cost substitute for actual scientific research, and the tendency to ignore

important uncertainties in model structure when evaluating uncertainties in model parameters.

- Peer review is an essential element of all scientific studies, including modeling applications. Peer review is appropriate in varying degrees and forms at different stages of the model development and application process. The basic scientific representation incorporated in the model should be based on formulations which have been presented in the peer reviewed scientific literature. Ideally, the model itself and initial test applications should also be presented in peer-reviewed papers.

### **3.6 Formulating Methods and Monitoring Procedures**

The RFI Work Plan should describe monitoring procedures that address the following items on a release-specific basis:

- Monitoring constituents of concern and other monitoring parameters (e.g., indicators);
- Sampling locations and frequency;
- Sampling methods;
- Types of samples to be collected;
- Analytical methods; and
- Detection limits.

These items are discussed below.

#### **3.6.1 Monitoring Constituents and Indicator Parameters**

Selection and use of reliable and useful monitoring constituents and indicator parameters is a site-specific process and depends on several factors, including the following:

- The phase of the release investigation (e.g., verification, characterization);
- The medium or media being investigated;
- The degree to which verifiable historical information exists on the unit or release being investigated;
- The degree to which the waste in the unit(s) has been characterized through sampling and analysis;
- The extent of the release;
- The concentration of constituents within the contaminated media; and
- The potential for physical, chemical, or biological transformations (e.g., degradation) of waste or release constituents.

The general strategy for the selection of specific monitoring constituents starts with a large universe list of constituents (i.e., 40 CFR Part 261, Appendix VIII). (It should be noted that the definition of constituent may also include components of 40 CFR Part 264, Appendix IX that are not also on Appendix VIII, but are normally monitored for during ground-water investigations.) Based on site-specific considerations (e.g., the contaminated media, sampling and analysis of waste from the unit, or industry-specific information), this list may be shortened to an appropriate set of monitoring constituents. Constituents initially deleted as a result of this process may have to be analyzed at selected locations during and/or following the RFI, especially if a CMS is found necessary. The discussion below explains the use of the four lists presented in Appendix B for selecting monitoring constituents and supplemental indicator parameters.

List 1 in Appendix B identifies indicator parameters recommended for release verification or characterization for the five environmental media discussed in this Guidance. This list was developed based on a review of RCRA and CERCLA guidances, as well as on information obtained during RCRA and CERCLA site

investigations. These indicator parameters should be used in the RFI unless the owner or operator can show that their use will not be helpful. For example, although total organic carbon and total organic halogen are listed as indicator parameters for ground water, their use may not be warranted for releases consisting primarily of inorganic (e.g., heavy-metal) contamination. In addition, as indicated in the footnote in List 1, although TOC and TOX have historically been used as indicator parameters for site investigations, the latest data suggests that use of these parameters may not provide an adequate indication of contamination, primarily due to precision and accuracy problems.

At most sites, however, the use of indicator parameters will be appropriate, especially for ground-water monitoring. In general, any constituent not expected to be contained in or derived from the waste or the contaminated area may not serve as a reliable or practical indicator of a release. Studies have examined the frequency of occurrence of analytes in ground-water at hazardous waste sites throughout the country (Garman, Jerry, Tom Freund and Ed Lawless. 1987. Testing for Ground-water Contamination at Hazardous Waste Sites: Journal of Chromatographic Science, Vol. 25, pp. 328-337). These studies indicate that metals and volatile organic compounds (VOCs) are two sets of analytes that generally provide a reliable and practical way of detecting and monitoring a release to ground water.

In addition, investigations by EPA's Environmental Monitoring Systems Laboratory in Las Vegas, Nevada, and others have shown that most of the compounds being released from hazardous waste facilities (as high as 70%) are volatile organics. These compounds have a low molecular weight and are fairly water soluble, which accounts for their high mobility in ground water. Furthermore, volatiles are produced in relatively large quantities in the United States and wastes containing them are managed in significant quantities at most permitted hazardous waste facilities.

Metals, particularly those that are amenable to the ICP (Inductively Coupled Plasma) scan, are the second most common set of contaminants that are released at hazardous waste management facilities, and therefore are also expected to be excellent indicators of releases to ground water, as alluded to earlier.

A list of those 40 CFR 264 Appendix IX constituents commonly found in contaminated ground water and amenable to analysis by volatile organics and ICP (metals) methods is provided in List 2.

List 3 in Appendix B is a master list of potential hazardous constituents that may, at one time or another, have to be monitored during an RFI. It contains the 40 CFR Part 261, Appendix VIII list of hazardous constituents in the left-hand column. The five environmental media columns contain X's where there is a reasonable probability, based on physical or chemical characteristics, of a particular constituent being present in the given medium. However, constituents not containing an X for a particular medium may still be present in that medium, despite a relatively low probability of their presence. Therefore, the regulatory agency may add such constituents for monitoring when appropriate. List 3 was derived through consultation with various EPA program offices and through examination of existing regulations. The rationale for identifying specific Appendix VIII constituents for the various media is explained below:

- **Reactivity with water.** Those constituents that react with or decompose in water were not marked with an X in the water-related columns.
- **Existence of viable analytical techniques for a constituent in a specific medium.** In many cases, constituents were not included for a specific medium because valid analytical methodologies are not currently available for that particular constituent/medium combination. In some cases, standard reference materials are not available for the analysis.

[Note that the above two criteria describe the primary rationale used to develop the 40 CFR Part 264, Appendix IX list of ground-water monitoring constituents. Hence, the ground-water and surface-water columns in List 3 are based on the final Appendix IX constituent list.]

- **Recommendations from other EPA program offices.** Offices concerned with the release of hazardous constituents to various media were consulted for recommendations on the analytes of primary concern. Appendix VIII hazardous constituents regarded by EPA's Office of Air



Quality Planning and Standards (OAQPS) as being of primary concern for release to air are identified in the air column in List 3.

- Background information. Analytes recommended for subsurface gas releases were chosen due to their predominance in past studies of this problem. The primary sources used for the subsurface gas medium are:

U.S. EPA. Technical Guidance for Corrective Measures -Subsurface Gas. Prepared by SCS Engineers for U.S. EPA, Office of Solid Waste. Washington, D.C. 20460.

South Coast Air Quality Management District. December 1986. Hazardous Pollutants in Class II Landfills. U.S. EPA, Region IX. San Francisco, CA 94105.

- The soil column includes constituents that may be present in both saturated and unsaturated soil. The column generally identifies constituents that are also identified for the ground-water and surface-water media, but contains additional constituents that are normally analyzed during soil contamination investigations (e.g., hydrogen sulfide and other gases), and certain other compounds that can be highly attenuated in soil (e.g., polyaromatic hydrocarbons).

An RFI may involve the investigation of waste which is hazardous by characteristic, as well as containing specific hazardous constituents. For example, methane, which is not an Appendix VIII hazardous constituent, is shown as an indicator parameter in List 1 for releases of subsurface gas. Because methane at sufficient concentrations possesses explosive or reactive properties, it can be hazardous based on the reactivity characteristic (40 CFR 261.23). Hence, subsurface gas may be the subject of an RFI even if specific hazardous constituents are not identified in the release.

List 4 in Appendix B is an industry-specific list. This list identifies categories of constituents, based on the classification presented in the 3rd Edition of EPA's Test Methods for Evaluating Solid Waste (EPA/SW-846), that may be present if wastes from a given industry are contained in the releasing unit. The EPA/SW-846 chemical

classifications for these categories are reprinted as a supplement to List 4. List 4 applies to all media and may be used in conjunction with List 3 to identify industry-specific constituents that have a reasonable probability of being present in a particular medium. List 4 was derived from a review of the Development Documents for Effluent Guidelines Limitations prepared for various industries under EPA's NPDES program, information received from several EPA Regional Office Hazardous Waste Programs, and other references, as indicated in Appendix B. It does not cover all industries that may be subject to an RFI. The Development Documents for Effluent Guidelines Limitations are available for the 30 industries identified in List 4, and may be obtained from the National Technical Information Service (NTIS).

[Note that the chemical categories upon which List 4 are based are not mutually exclusive. If a category is identified as being appropriate for an industry, all constituents within the category should be monitored regardless of whether the constituent is contained in other categories.]

The use of the Appendix B lists in developing and implementing the general investigation strategy is described below.

The phase of the release investigation is a very important consideration. For example, the use of indicator parameters (List 1) along with specific hazardous constituents, can be helpful in verifying the presence of a suspected release. However, indicators alone are not adequate in showing the absence of a release, partially because of their relatively high detection limits (i.e., generally 1000 µg/l versus 10 to 20 µg/l for specific constituent analyses), and because indicator parameters do not account for all classes of constituents that may be present. Verification of the absence of a release should therefore always be supported by specific hazardous constituent analyses.

For the same reasons, indicator parameters should not form the sole basis for release characterization, especially at locations in the release where indicator concentrations are close to detection limits. Indicator parameters may be particularly useful in mapping large releases, but should always be used in conjunction with specific monitoring constituents.

Specific monitoring constituents and indicator parameters may also need to be modified as the investigation progresses, because physical, chemical, and biological degradation may transform constituents as the release ages or advances. When chemicals degrade, they usually degrade into less toxic, more stable species. However, this is not always the case. For example, one of the degradation products of trichloroethylene is vinyl chloride. Both of these chemicals are carcinogens. Information on degradation can be found in the environmental literature. Particular references include:

U.S. EPA. 1985. Atmospheric Reaction Products from Hazardous Air Pollutant Degradation. NTIS PB85-185841. Washington, D.C. 20460.

U.S. EPA. 1984. Fate of Selected Toxic Compounds Under Controlled Redox Potential and pH Conditions in Soil and Sediment Water Systems. NTIS PB84-140169. Washington, D.C. 20460.

This topic is discussed in more detail later in this section and in each of the media-specific sections.

After a release is adequately characterized in terms of concentrations of hazardous constituents (or hazardous characteristics), a comparison of these concentrations to EPA health and environmental-based criteria will be made (see Section 8). Although this comparison may involve a shortened list at this stage of the RFI, all potential monitoring constituents (even those deleted earlier in the process) may need to be analyzed at selected monitoring locations to verify their presence or absence.

The use of ICP spectroscopy (for metals) and gas chromatography/mass spectrometry for volatile organic compounds (List 2) can be particularly helpful in delineating releases where little or no information is available on the source. These methods are relatively cost-effective because they address a number of constituents in a single analysis.

The medium or media being investigated is also an important consideration in identifying monitoring constituents. For example, non-volatile constituents may be poor candidates for monitoring of an air release, unless wind-blown particulates are

of concern. List 3 in Appendix B has been developed to aid in identifying constituents most likely to be measurable in each medium of concern.

Historical information (e.g., records indicating the industry from which wastes originated) may be useful in selecting monitoring constituents. List 4 in Appendix B may be helpful in identifying classes of constituents that may be of concern if a particular industry can be identified.

Waste sampling and analysis (see Section 7) may be performed to tailor the initial list of monitoring constituents. Although complete waste characterization is recommended in most cases, this may not always be possible or desirable (e.g., for a large unit in which many different wastes were managed over a long period or in cases where wastes have undergone physical and/or chemical changes over a long period). A complete historical waste characterization in such cases would not be possible. Other cases where waste sampling and analysis would generally be inadvisable are those where the waste is highly toxic (e.g., nerve gas) or explosive (e.g., disposed munitions). In these cases, it may be more appropriate to sample the environmental medium of concern at locations expected to indicate the highest release concentrations. Such sampling activities should be performed following appropriate health and safety procedures (see Section 6).

The extent of the release may also dictate, to some degree, the selection of monitoring constituents. For apparently small releases (e.g., 5 square yards of contaminated soil), it may be reasonable to base all analyses on specific monitoring constituents. For larger releases, the use of indicator parameters along with specific monitoring constituents may be a better approach. In this case, an appropriate balance between indicator parameters and monitoring constituents is advisable.

In addition, the potential for physical, chemical, or biological transformations (e.g., degradation) of constituents should also be considered in identifying monitoring constituents. Biodegradation may be of particular importance for the soil and surface-water media. For example, trichloroethylene in a waste unit or medium can degrade over time to vinyl chloride and other products. Such products may be present at higher concentrations than the parent trichloroethylene and may also be more toxic. Therefore, the selection of monitoring constituents should consider the potential for constituents to be transformed over time. Each of the media-specific

sections contains a discussion of physical, chemical, and biological transformation mechanisms.

Another approach that may be taken in selecting monitoring constituents for a particular medium is to use physical and chemical property data, such as the octanol/water partition coefficient or solubility, to predict which constituents may be present in a given medium. Further guidance on the use of this approach, including tables presenting data on relevant physical and chemical properties of various constituents, is presented in the following reference:

U.S. EPA. October, 1986. Superfund Public Health Evaluation Manual. EPA 540/1-86/060. NTIS PB87-183125. Office of Emergency and Remedial Response. Washington, D.C. 20460.

Case Study Numbers 1, 2, 4, 9, and 10 in Volume IV (Case Study Examples) illustrate application of the concepts discussed above.

### **3.6.2 Use of EPA and Other Methods**

As described in the preceding sections, and in the media-specific sections (Sections 9 through 13), many different types of methods may be employed in conducting the RFI. These include methods for sampling, QA/QC, and field operations, as well as methods for physical, biological, and chemical analyses. These methods were developed by various organizations, including EPA, other Federal and State agencies, and by "standard-setting" organizations [e.g., ASTM, (American Society for Testing and Materials)]. Some of these methods are final, while others are in draft or proposed status. As discussed previously, the RFI Work Plan should propose methods that best suit the needs of the situation under investigation. Guidance in the following sections, and in the media-specific sections, is given on methods recommended in certain situations, including appropriate references. The following discussion highlights some general guidelines to follow in the selection of methods:

- **Use of EPA Methods:**

EPA recently published the 3rd Edition of its testing manual for solid waste (U.S. EPA. 1986. Test Methods for Evaluating Solid Waste. EPA/SW-846, GPO No. 955-001-00000-1), generally known as SW-846. This manual provides QA/QC methods, analytical methods, physical and chemical property test methods, and sampling and monitoring methods. These methods are acceptable for the RFI and contain guidance on unique problems that may be encountered during solid and hazardous waste investigations. Where possible, it is recommended that SW-846 (or equivalent) methods be used over other available methods. SW-846, however, may not provide all methods applicable in certain situations. In such cases, other EPA methods manuals (including EPA Regional Office methods manuals) may be used. One such document that should be particularly useful is EPA's Compendium of Field Operations Methods, developed by the Office of Emergency and Remedial Response (OSWER Directive No. 9355.0-14, EPA 540/P-87/001A, August 1987). This document provides discussions of various methods that can be applied in field investigations, and includes general considerations for project planning, QA/QC, and sampling design. Specific methods presented include:

- Rapid field screening procedures (e.g., soil gas surveys using portable field instruments);
- Drilling in soils;
- Test pits and excavation;
- Geological reconnaissance;
- Geophysics;
- Ground-water monitoring;
- Physical and chemical properties;
- Surface hydrology;

- Meteorology;
  - Biology and Ecology/Bioassay and Biomonitoring; and
  - Surveying, Photography, and Mapping.
- Use of Other Federal or State Methods:

The Occupational Safety and Health Administration (OSHA), the Food and Drug Administration (FDA), and several other Federal agencies have developed methods and methods manuals for specific applications. In addition, State and EPA Regional Offices have also developed methods and methods manuals. These methods may also be used during release investigations, if appropriate. The media-specific sections of this Guidance identify where such methods may be particularly applicable.

- Use of Other Methods:

Several "standard-setting" organizations are involved in the development of test methods for various applications. One such organization, the ASTM, publishes test methods and other standards in its Annual Book of ASTM Standards, which is updated yearly. Many of ASTM's methods may be applicable for use in the RFI; however, if comparable EPA methods exist, they are preferred because they often contain important information necessary for regulatory purposes.

Many ASTM and EPA methods are similar and some are identical. The primary reason for this is that many EPA methods are derived from ASTM methods. Some of ASTM's methods are adopted by EPA in toto. EPA's Compendium of Field Operations Methods, for example, contains many ASTM methods that can be used during an RFI.

Although ASTM's Committee D-34 on Waste Disposal has only published several final methods (ASTM. 1986 Annual Book of ASTM Standards. Volume 11:04), it has many other methods currently in various stages of development.

Several methods under development that may be applicable to the RFI process are expected to be finalized and available soon.

Other organizations are also involved in the development and standardization of test methods. Many industrial and environmental association methods can also be used during an RFI. EPA's Compendium of Field Operations Methods identifies several of these.

All methods proposed for use by the owner or operator should be clearly described and adequately referenced.

### **3.6.3 Sampling Considerations**

This section discusses several considerations important in designing a sampling plan, including sample types, and pertains to sampling of the waste source and the affected environmental media. Section 7 contains additional guidance on waste source sampling. A general discussion of sampling equipment and procedures is presented in EPA's SW-846. Other guidances containing general information that can be used in designing a sampling plan include the following:

U.S. EPA. August, 1987. Compendium of Field Operations Methods. Office of Emergency and Remedial Response. OSWER Directive No. 9335.0-14. EPA 540/P-87/001A. Washington, D.C. 20460.

U.S. EPA. 1985. Practical Guide for Ground-Water Sampling. Robert S. Kerr Environmental Research Laboratory. EPA/600/2-85/104. Ada Oklahoma.

U.S. EPA. 1986. RCRA Ground-Water Monitoring Technical Enforcement Guidance Document. OSWER Directive No. 9950.1. Office of Waste Programs Enforcement. Washington, D.C. 20460.

U.S. EPA. July 24, 1981. RCRA Inspection Manual. Section V. Office of Solid Waste. Washington, D.C. 20460.



U.S. EPA. June, 1985. Guidance on Remedial Investigations Under CERCLA. Office of Emergency and Remedial Response. NTIS PB85-238616. Washington, D.C. 20460.

U.S. EPA. May, 1984. Soil Sampling Quality Assurance Users Guide. CR810550-01. NTIS PB84-198621. Washington, D.C. 20460.

#### **3.6.3.1 General Sampling Considerations**

Various methods exist for obtaining acceptable samples of waste and for each medium described in this document. Each of the media-specific sections (Sections 9 through 13) describes appropriate methods. The RFI Work Plan should propose methods that best suit the needs of the sampling effort. The following criteria should be considered in choosing such methods:

- **Representativeness**--The selected methods should be capable of providing a true representation of the situation under investigation.
- **Compatibility with Analytical Considerations**--Sample integrity must be maintained to the maximum extent possible. Errors induced by poorly selected sampling techniques or equipment can result in poor data quality. Special consideration should be given to the selection of sampling methods and equipment to prevent adverse effects during analysis. Materials of construction, sample or species loss, and chemical reactivity are some of the factors that should receive attention.
- **Practicality**--The selected methods should stress the use of simple, practical, proven procedures capable of being used in or easily adapted to a variety of situations.
- **Simplicity and Ease of Operation**--Because of the nature of the material to be sampled, the physical hazards that may be encountered during sampling, and the wearing of safety equipment, the proposed sampling procedures should be relatively easy to follow and equipment simple to operate. Ideally, equipment should be portable, lightweight, and rugged.

- **Safety**--The risk to sampling personnel and others, intrinsic safety of instrumentation, and safety equipment required for conducting the sampling should be carefully evaluated.

#### **3.6.3.2 Sample Locations and Frequency**

Because conditions in the unit or in the contaminant release will change both temporally and spatially, the design of the monitoring network should be developed accordingly. Spatially, sufficient samples should be collected to adequately define the extent of the contamination. Temporally, the plan should address spreading of the release with time and variation of concentrations due to factors such as changes in background concentrations, waste management practices, unit operations, the composition of the waste, and climatic and environmental factors. For example, sampling and supplemental measurements (e.g., wind speed) should be conducted when releases are most likely to be observed, when possible.

Selection of specific sampling locations and times will be site- and release-dependent. Three general approaches can be used in selecting specific sampling locations. Selection of a particular approach depends on the level of knowledge regarding the release. Judgmental sampling generally involves selection of sampling locations based on existing knowledge of the release configuration (e.g., visual evidence or geophysical data). A systematic approach involves taking samples from locations established by a predetermined scheme, such as a line or grid. Such samples can help to establish the boundaries of a contaminated area. Random sampling involves use of a "randomizing scheme," such as a random number table, to select locations within the study area. Random sampling can be useful when contaminant spatial distribution is expected to be highly variable. Regardless of the sampling approach taken, it is recommended that a coordinate (grid) system be established at the site to describe and record sampling locations accurately. As a release investigation progresses, and as more information regarding a release is gathered, the sampling approach may be varied as appropriate. Application of judgmental, systematic, and random sampling is discussed below.

### 3.6.3.3 Judgmental Sampling

Judgmental sampling is appropriate when specific information exists on the potential configuration of a release. Many releases are likely to fall into this category, because site layout or unit characteristics will often indicate areas of potential contamination. Examples of judgmental sampling include:

- Taking air samples at areas generally downwind of a unit;
- Taking grab samples of surface soils from a drainage channel that receives surface runoff from a known contaminated area; and
- Obtaining soil cores downslope from a known waste burial site.

Judgmental sampling will generally bias the data obtained toward higher contaminant concentrations. For example, samples taken only from areas of suspected contamination would generally be biased toward higher concentrations. In many cases, this approach will suit the needs of the RFI.

### 3.6.3.4 Systematic or Random Grid Sampling

Systematic or random grid sampling allows the collection of a set of unbiased samples at the area of concern. These samples can be used for detection of contamination, for calculation of averages (e.g., for characterizing the contents of a surface impoundment when it is expected to be fairly homogeneous), and for modeling purposes. The size and shape of the grid should consider site-specific factors. However, some general recommendations can be made for effective grid planning. The following steps are recommended in establishing a grid system:

- (1) Choose the study area to be included in the grid. To define the full extent of the contaminated area, this area should be larger than the suspected extent of contamination.
- (2) Select the shape and spacing of the grid. The shape may vary (e.g., rectangular, triangular, or radial), depending on the needs of the investigation. The grid spacing should be based on consideration of the

appropriate density of sampling points. For example, an initial sampling effort in an area of widespread, homogeneous contamination may use a 200-foot grid, whereas a search for "hot spots" in a poorly defined contaminated area might require a 50-foot or smaller spacing.

- (3) Draw (or overlie) the sampling grid on a plan of the site. To minimize sampling bias, a random number table may be used to choose sampling cells.
- (4) Transfer the grid onto the study area by marking grid line intersections with wooden stakes. The exact location of the sample within each grid cell may be chosen systematically (e.g., at each node) or randomly (i.e., anywhere within each cell).

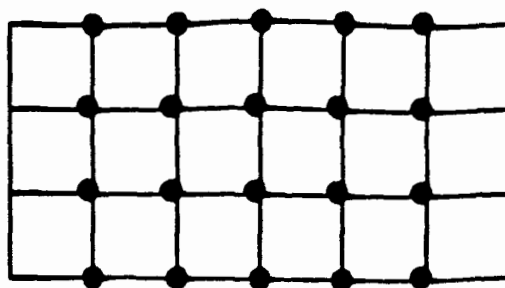
Figure 3-1a shows a systematic grid with samples taken at each node. Random grid sampling produces a sampling distribution such as that shown in Figure 3-1b. A possible limitation of systematic grid sampling is that if contaminants are distributed in a regular pattern, the sampling points could all lie within the "clean" areas (Figure 3-1c). This possibility should be considered when proposing a sampling approach.

#### 3.6.3.5 Types of Samples

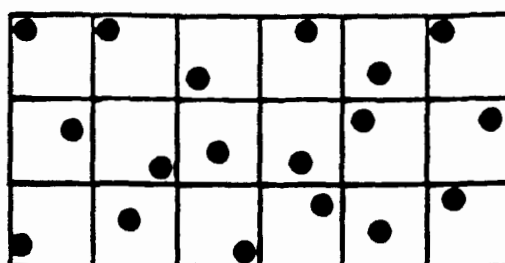
The owner or operator should propose the types of samples to be collected with the monitoring procedures. In general, there are three basic sample types: grab, composite, and integrated, as discussed below.

- **Grab sampling**--A grab sample is an individual sample taken at a specific location at a specific time. If a contaminant source or release is known to be fairly constant in composition over a considerable period of time or over substantial distances in all directions, then the sample may serve to represent a longer time period or a larger volume (or both) than the specific point and time at which it was collected.

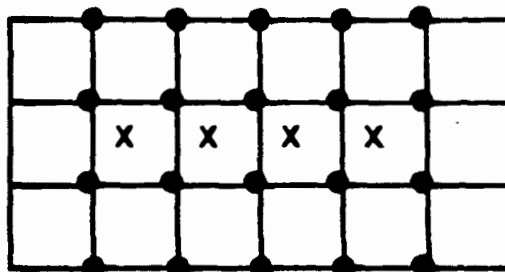
When a contaminant source or release is known to vary with time, grab samples collected at suitable intervals and analyzed separately can



a) SYSTEMATIC GRID SAMPLING



b) RANDOM GRID SAMPLING



X = BURIED WASTE

c) CASE IN WHICH SYSTEMATIC GRID SAMPLING MISSES  
WASTES BURIED IN A REGULAR PATTERN

FIGURE 3-1. GRID SAMPLING.

indicate the magnitude and duration of variations. Sampling intervals should be chosen on the basis of the frequency with which variations may be expected. It may not always be desirable to take samples at equal intervals (e.g., subsurface gas releases are sensitive to seasonal influences). If sample composition is likely to show significant variation with time and space, grab samples from appropriate locations are recommended.

- **Composite samples**--Composites are combinations of more than one sample collected at various sampling locations and/or different times. Analysis of composites generally yields average values which may not accurately describe the distribution of release concentrations or identify hot spots. Compositing does not reflect actual concentrations and can reduce some concentrations to below detection limits. Composites may, in limited instances, be used to reduce the number of individual grab samples (e.g., when calculating an average value is appropriate). For example, compositing waste samples from a surface impoundment may be performed to determine an average value over several different locations. Compositing may also be useful in determining the overall extent of a contaminated area, but should not be used as a substitute for characterizing individual constituent concentrations. Therefore, compositing should be limited and should always be done in conjunction with an adequate number of grab samples.
- **Integrated samples**--An integrated sample is typically a continuously collected single sample taken to describe a population in which one or more parameters vary with either time or space. An integrated sampling technique can account for such variations by collecting one sample over an extended time period, such that variations can be averaged over that period. The most common parameter over which sampling periods are integrated is time. Time-integrated samples can provide an average of varying concentrations over the period sampled.

Integrated sampling may be appropriate under limited circumstances. For example, process stream flows often change with variations in the process itself or with environmental conditions, such as wind speed. A

flow-integrated sampling device can collect a sample over a period of time as the sampling rate increases or decreases with the rise and fall of the stream flow. The device automatically biases sample collection toward those periods of high flow, with sampling rates decreasing during low-flow periods.

Integrated samples can be particularly useful for air and surface-water investigations where continuous changes in environmental conditions can affect constituent concentrations. See Sections 12 and 13 (air and surface water, respectively) for more information.

#### **3.6.4 Analytical Methods and Use of Detection Limits**

Analytical methods should be appropriate for the constituents and matrices being sampled. As indicated previously, the EPA publication Test Methods for Evaluating Solid Waste (EPA/SW-846), should be used as the primary reference for analytical methods. This document contains analytical methods that can be applied to solid, liquid, and gaseous matrices, and also presents detection limits generally associated with these methods. It is important to understand that detection limits can vary significantly depending on the medium (e.g., air, water, or soil) and other matrix-specific factors (e.g., presence of multiple contaminants). In addition to SW-846, the following reference provides detection limit information for water and soil matrices:

U.S. EPA. March, 1987. Data Quality Objectives for Remedial Response Activities. Volume 1 (Development Process) and Volume 2 (Example Scenario). Office of Emergency and Remedial Response and Office of Waste Programs Enforcement. EPA 540/G-78/003a. OSWER Directive No. 9335.0-7b. Washington, D.C. 20460.

Detection limits should be stated along with the proposed analytical methods in the RFI Work Plan. Analytical values determined to be at or below the detection limit should be reported numerically (e.g.,  $\leq 0.1$  mg/l).

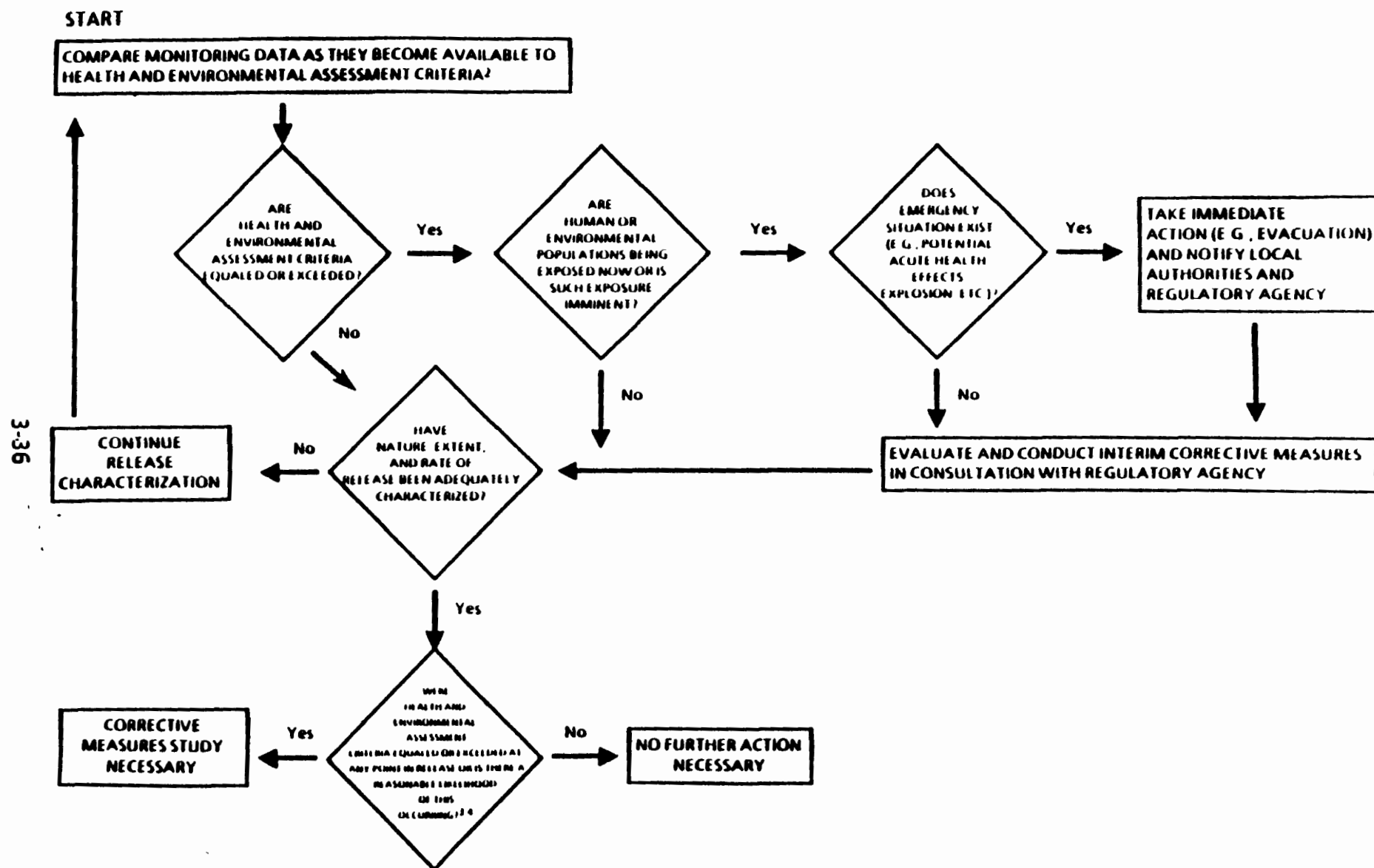
### **3.7 RFI Decision Points**

As monitoring data become available, both within and at the conclusion of discrete investigative phases, they should be reported to the regulatory agency as directed. The regulatory agency will compare the monitoring data to applicable health and environmental criteria to determine the need for (1) interim corrective measures; and (2) a CMS. In addition, the regulatory agency will evaluate the monitoring data with respect to adequacy and completeness to determine the need for any additional monitoring efforts. The health and environmental criteria and a general discussion of how the regulatory agency will apply them are supplied in Section 8. A flow diagram illustrating RFI decision points is provided in Figure 3-2.

Notwithstanding the above process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For these situations, the owner or operator is directed to follow the RCRA Contingency Plan requirements under 40 CFR Part 264, Subpart D.



**(See Following Page for Footnotes)**



### FOOTNOTES FOR FIGURE 3-2

- 1 Although the health and environmental assessment is conducted by the regulatory agency, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures.
- 2 If sufficient monitoring data indicate that a release identified as "suspected" by the RFA has actually not occurred, no further action is necessary unless the regulatory agency determines that the occurrence of a release is or may be imminent.
- 3 For the air medium, the health and environmental assessment criteria are applied at actual receptor locations. For all other media, these criteria are applied at the unit or waste management area boundary and beyond.
- 4 A Corrective Measures Study or interim corrective measures may still be required based on qualitative criteria. (See Section 8 for discussion).

## **SECTION 4**

### **QUALITY ASSURANCE/QUALITY CONTROL PROCEDURES**

#### **4.1 Overview**

Quality assurance (QA) is a management system for ensuring that all information, data, and decisions resulting from the RFI are technically sound and properly documented. Quality control (QC) is the functional mechanism through which quality assurance achieves its goals. Quality control programs, for example, define the frequency and methods of checks, audits, and reviews necessary to identify problems and dictate corrective action to resolve these problems, thus ensuring data of high quality. Thus, a QA/QC program pertains to all data collection, evaluation, and review activities that are part of the RFI.

Data generated during the RFI will provide the basis for decisions on corrective measures; therefore, the data should present a valid characterization of the situation. Utilization of erroneous or poor-quality data in reporting RFI results may lead to unnecessary repetition of sampling and analysis or, more importantly, to faulty decisions based on poor results. The owner or operator should develop adequate QA/QC procedures for the RFI. Implementation of these procedures will allow the owner or operator to monitor and document the quality of the data gathered.

The next portion of this section (4.2) describes the general design of a QA/QC program. The following portions of this section (Sections 4.3 and 4.4) outline and describe important QA/QC considerations that should be accounted for in the performance of sampling and analysis.

Section 4 is not intended to constitute a complete guide to constructing QA project plans or QC programs. EPA has established, through the issuance of various documents, guidance describing the development and implementation of QA/QC programs that can be used to design effective QA/QC procedures for the RFI. The

final portion of this section (Section 4.5) presents references that provide additional guidance in constructing appropriate QA/QC procedures for the RFI.

When selecting field personnel and analytical services to perform any RFI activity, the owner or operator is encouraged to evaluate available QA/QC programs and procedures in light of the information and references provided in this section. Participation in internal and/or external (e.g., Federal or State) laboratory validation/certification programs may be particularly important in selecting laboratory services.

Case Study No. 5 in Volume IV (Case Study Examples) provides an example of an effective QA/QC program.

## **4.2 QA/QC Program Design**

The initial step for any sampling or analytical work should be to strictly define the program goals. Once these goals have been defined, a program can be designed to meet them. QA and QC measures are used to monitor the program and to ensure that all data generated are suitable for their intended uses. The responsibility of ensuring that the QA/QC measures are properly employed should be assigned to a knowledgeable person (i.e., a QA/QC specialist) who is not directly involved in the sampling or analysis.

One approach found to provide a useful structure for a QA/QC program is preparing both program and project-specific QA/QC plans. The program plan sets up basic policies, including QA/QC, and may include standard operating procedures (SOPs) for specific methods. The program plan serves as an operational charter for defining purposes, organizations, and operating principles. Thus, it is an orderly assemblage of management policies, objectives, principles, and general procedures describing a plan for producing data of known and acceptable quality. The elements of a program plan and its preparation are described in the following reference:

U.S. EPA. September 20, 1980. Guidelines and Specifications for Preparing Quality Assurance Program Plans. Office of Monitoring Systems and Quality Assurance. EPA/QAMS-004/80. NTIS PB83-219667. Washington, D.C. 20460.

Project-specific QA/QC plans differ from program plans in that specific details of a particular sampling/analysis program are addressed. For example, a program plan might state that all equipment will be calibrated according to a specific protocol given in written SOPs, while a project plan would state that a particular protocol will be used to calibrate the equipment for a specific set of analyses that have been defined in the plan. The project plan draws on the program plan for its basic structure and applies this management approach to specific determinations. An organization or laboratory would have only one QA program plan, but would have a QA project plan for each of its projects. The elements of a project plan and its preparation, presented in Table 4-1, are described in detail in the following reference:

U.S. EPA. December 29, 1980. Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans. Office of Monitoring Systems and Quality Assurance. EPA/QAMS-005/80. NTIS PB83-170514. Washington, D.C. 20460.

#### **4.3 Important Considerations for a QA/QC Program**

The use of qualified personnel for conducting various portions of the RFI is of paramount importance to an effective QA/QC program. This pertains not only to qualified QA/QC specialists, but also to specialists in other fields, including hydrogeologists, air quality specialists, soil scientists, analytical chemists and other scientific and technical disciplines. The owner or operator should ensure that qualified specialists, primarily individuals with the proper education, training, and experience, including licensed or certified professionals, are directing and performing the various RFI activities. The same general principles apply to selection of contractors and/or outside laboratories.

##### **4.3.1 Selection of Field Investigation Teams**

The owner or operator should consider the following factors when selecting any field investigation team:

- Level of expertise and/or training required (e.g., experience, references);

**TABLE 4-1**  
**ESSENTIAL ELEMENTS OF A QA PROJECT PLAN**

1. Title Page
2. Table of Contents
3. Project Description
4. Project Organization and Responsibility
5. QA Objectives
6. Sampling Procedures
7. Sample Custody
8. Calibration Procedures and Frequency
9. Analytical Procedures
10. Data Reduction, Validation, and Reporting
11. Internal Quality Control Checks
12. Performance and System Audits
13. Preventive Maintenance
14. Specific Routine Procedures Used to Assess Data Precision, Accuracy, and Completeness
15. Corrective Action
16. Quality Assurance Reports to Management

- Available workforce; and
- Time and equipment constraints.

#### **4.3.2 Laboratory Selection**

The owner or operator should consider the following factors when selecting a laboratory:

- Capabilities (facilities, personnel, instrumentation), including:
  - Participation in interlaboratory studies (e.g., EPA or other Federal or State agency sponsored analytical programs);
  - Certifications (e.g., Federal or State);
  - References (e.g., other clients); and
  - Experience (RCRA and other environmentally related projects).
- Service:
  - Turnaround time; and
  - Technical input (e.g., recommendations on analytical procedures).

The owner or operator is encouraged to gather pertinent laboratory-selection information prior to extensively defining analytical requirements under the RFI. A request may be made to a laboratory to provide a qualifications package that should address the points listed above. Once the owner or operator has reviewed the various laboratory qualifications, further specific discussions with the laboratory or laboratories should take place. In addition, more than one laboratory should be considered. For large-scale investigations, selection of one laboratory as a primary candidate and one or two laboratories as fall-back candidates should be considered.

The quality of the laboratory service provided is dependent on various factors. The owner or operator should be able to control the quality of the information (e.g., samples) provided to the laboratory. It is extremely important that the owner or operator communicate to the laboratory all the requirements attendant to the RFI. This includes the identification of the number of samples and their matrices, sampling schedule, parameters and constituents (analytes) of interest, required analytical methodologies, detection limits, holding times, deliverables, level of QA/QC, and required turnaround of analytical results.

#### **4.3.3 Important Factors to Address**

A major element in release characterization is to define the QA/QC measures that will be followed to ensure the validity of data generated during the investigation. These measures should ensure that data generated are suitable for their intended uses. QA/QC procedures should address the following factors:

- (1) Intended use(s) for the data, and the necessary level of precision and accuracy for these intended uses (See Section 4.4.1).
- (2) Procedures for representative sampling, including:
  - Selecting appropriate sampling locations, depths, etc.;
  - Providing a sufficient number of samples and sampling sites;
  - Obtaining all necessary ancillary data;
  - Determining conditions (e.g., weather) under which sampling should be conducted;
  - Determining which media are to be sampled (e.g., ground water, air, soil, sediment, etc.);
  - Determining which constituents are to be measured;
  - Selecting appropriate sample containers;



- **Selecting the frequency of sampling and duration of the sampling period;**
  - **Selecting the types of samples (e.g., composites and grabs) to be collected;**
  - **Detailing methods of sample preservation; and**
  - **Detailing methods of sample chain-of-custody.**
- (3) Documentation of field sampling operations and procedures, including:**
- **Documentation of procedures for preparation of reagents or supplies that become an integral part of the sample (e.g., filters and adsorbing reagents);**
  - **Documentation of procedures and forms for recording the exact location and specific considerations associated with sample acquisition;**
  - **Documentation of specific sample preservation methods;**
  - **Calibration of field devices;**
  - **Collection of replicate samples;**
  - **Submission of field blanks, where appropriate;**
  - **Detailing of potential interferences present at the facility;**
  - **Listing of construction materials and techniques associated with monitoring wells, piezometers, and other monitoring equipment;**
  - **Listing of field equipment and sample containers;**
  - **Copy of sampling order; and**

- Documentation of decontamination procedures.
- (4) Analytical procedures, including:
- Appropriate analytical methods;
  - Appropriate sample storage;
  - Appropriate sample preparation methods;
  - Appropriate calibration procedures; and
  - Data management (e.g., review, reporting, and recordkeeping) procedures.
- (5) Planning for the inclusion of proper and sufficient QA/QC activities, including the use of QC samples, throughout the study is necessary to ensure that the quality of the sampling and analytical data will meet the objectives of the RFI.

The factors and considerations described above are important for any environmental monitoring and measurement project. If these factors are adequately addressed (i.e., appropriate procedures are developed, tasks are assigned to qualified personnel, and sufficient QA/QC steps are employed), the goals of the RFI should be met. If the QA/QC procedures are sound, problems will be detected early, enabling the appropriate corrective actions to be taken.

[Note that the term "corrective action," in the context of a QA/QC program pertains to actions taken as a result of problems (e.g., sample contamination) uncovered by an effective QA/QC program. This should not be confused with the corrective measures that may be applied as a result of the RFI. Corrective actions as a result of QA/QC are discussed in Section 4.4.10.]

#### **4.4 QA/QC Objectives and Procedures**

The following describes the general components of QA/QC objectives and procedures. Specific references regarding recommended procedures are presented in Section 4.5.

##### **4.4.1 Data Quality and Use**

Throughout the RFI process, it is important that the owner or operator keep in mind the eventual use to which data will be put; that is, comparison of data to health and environmental criteria to determine whether some form of corrective measure may be necessary to correct the release. Therefore, data collected during the investigation needs to be of sufficient quality to support decisions regarding whether interim corrective measures and/or a CMS may be necessary.

Qualitative or quantitative statements that outline the decision-making process and specify the quality and quantity of data required to support decisions should be made early in the planning stages of the RFI. These data quality objectives (DQOs) are then used to design sampling and analysis plans and to determine the appropriate level of QA/QC.

The following discussion concerning DQOs is summarized from the following document:

U.S. EPA. March, 1987. Data Quality Objectives for Remedial Response Activities. Volume 1: Development Process. Volume 2: Example Scenario. EPA 540/G-87/003a. OSWER Directive No. 9335.0-7B. Office of Emergency and Remedial Response and Office of Waste Programs Enforcement. Washington, D.C. 20460.

This document may be reviewed for more detailed information. The Example Scenario (Volume 2) may be particularly helpful in understanding the overall DQO process.

The first step in the process of developing DQOs involves defining the decisions to be made based on the data and the objectives of the investigation. The

second step is defining a set of objectives (DQOs) that can be used to design the sampling and analysis plan and determining the appropriate level of QA/QC. Ultimately, these DQOs are also used to determine the adequacy of the data in terms of whether their quality and quantity are sufficient to enable confident decision-making. This process of defining the objectives of the investigation and designing data-gathering efforts to meet these objectives, should be initiated prior to starting the investigation. Refinements or revisions to these objectives may also be necessary as the investigation progresses.

The criteria most commonly used to specify DQOs and to evaluate available sampling, analytical, and QA/QC options are known collectively as the Precision, Accuracy, Representativeness, Completeness, and Comparability (PARCC) parameters. A brief description of these follows:

- Precision - a measure of the reproducibility of analyses under a given set of conditions.
- Accuracy - a measure of the bias in a measurement system.
- Representativeness - the degree to which sampling data accurately and precisely represent selected characteristics.
- Completeness - a measure of the amount of valid data obtained from a measurement system compared to the amount that could be expected to be obtained under "normal" conditions.
- Comparability - the degree of confidence with which one data set can be compared to another.

When using these parameters to assess data quality, only precision and accuracy can be expressed in purely quantitative terms. The other parameters are best expressed using a mixture of quantitative and qualitative terms. All these parameters are interrelated in terms of overall data quality and may be difficult to evaluate separately due to these interrelationships. The relative significance of each parameter depends on the type and intended use of the data being collected. Each parameter is addressed in further detail below.

Precision is a measure of the scatter of a group of measurements made at the same specified conditions around their average. Values calculated should demonstrate the reproducibility of the measurement process. Determination of precision in relation to the RFI deals primarily with sampling and analytical procedures. The sample standard deviation and sample coefficient of variation are commonly used as indices of precision. The smaller the standard deviation and coefficient of variation, the better the precision.

Precision is stated in units of measurement or as a percentage of the measurement average, as a plus and minus spread around the average measured value. There are many sources of variation or error within any measurement system. Depending on the nature of the investigation, variation or error may be introduced at various stages. Examples of these are sample collection, handling, shipping, storage, preparation, and analysis. When summarizing precision determinations, the component or components of the measurement system that are included should be noted. The stage at which a replicate is placed within the measurement system, for example, generally dictates the components that affect the precision determination.

Accuracy is defined as the agreement of a measurement with an accepted reference or true value. This is normally expressed as the difference between measured and reference or true values or the difference as a percentage of the reference or true value. It may also be expressed as a ratio of the measurement to the true value. Accuracy is a measurement of system bias.

The determination of accuracy or bias within the measurement system is generally accomplished through the analysis of the neat sample (e.g., distilled water as opposed to pond or local water) and the analysis of the sample spiked at a known concentration utilizing a standard reference material. As in the case of the precision determination, the point at which the sample is spiked determines which components of the measurement system have an effect on the accuracy of the analysis. The three sample spiking points are sample acquisition (field matrix spike); preparation (lab matrix spike); and analysis (analysis matrix spike). The field matrix spike provides a best-case estimate of bias based on recovery. It includes matrix effects associated with sample preservation, shipping, preparation, and analysis.

The lab matrix spike provides an estimate of recovery incorporating matrix effects associated with sample preparation and analysis only. The analysis matrix spike provides an indication of matrix effects associated with the analysis process only. In addition to the above sample spiking points, the analysis of a known concentration of a standard reference material into the appropriate method solvent (e.g., deionized water, methanol, 2 percent nitric acid, etc.) provides an indication of the accuracy of the analytical system calibration.

Completeness is defined as the measure of the amount of valid data obtained from a measurement system compared to the amount that could be expected to be obtained under "normal" conditions. The completeness goals should be identified, to the extent possible, at the beginning of the RFI to ensure that sufficient valid data are collected to meet the RFI objectives and to provide a measurement whereby the progress of the RFI may be monitored during data collection.

QA/QC procedures may benefit through tabular presentations of the precision, accuracy, and completeness goals for the work performed under the RFI.

Representativeness expresses the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. QA/QC procedures should address all data gathering with regard to representativeness. All RFI data compilation should reflect as precisely and as accurately as possible the conditions that existed at the time of measurement. Examples of factors that should be considered include:

- Environmental conditions at the time of sampling;
- Fit of the modeling or other estimation techniques to the event(s);
- Appropriateness of site file information versus release conditions;
- Appropriateness of sampling and analytical methodologies;
- Number of sampling points;

- Representativeness of selected media; and
- Representativeness of selected analytical parameters.

Comparability is defined as an expression of the confidence with which one data set can be compared to another. In terms of the RFI, comparability may be applied to:

- RFI data generated by the owner or operator over a specific time period;
- Data generated by an outside laboratory over a specific time period;
- RFI data generated by an outside laboratory versus data generated by the owner or operator; and
- Data generated by more than one outside laboratory.

The utilization of standard methodologies for the various data generation categories (e.g., sampling, analysis, geological, and meteorological) should ensure data comparability. The owner or operator should take the appropriate measures to ensure the comparability of data compiled under the RFI.

The PARCC parameters are indicators of data quality. Ideally, the end use of the measurement data should define the PARCC parameters necessary to satisfy that end use. Ideally, numerical precision, accuracy, and completeness goals should be established to aid in selecting measurement methods to be used. However, RFI work may not fit this ideal situation. RFI sites are likely to differ substantially from one another, and information on overall measurements (e.g., sampling and analysis) may be limited such that it may not be practical to initially set meaningful PARCC goals. In such cases, the historical precision and accuracy achieved by different sampling and analytical techniques should be reviewed to aid in selecting the most appropriate technique. Only those techniques that have been adequately evaluated (e.g., precision and accuracy studies), and which therefore have a documented history of acceptable performance, should be proposed for use.

Precision and accuracy statements and detection limit information for analytical methods can be found in the DQO document referenced earlier in this section, as well as the following reference:

U.S. EPA. November, 1986. Test Methods for Evaluating Solid Wastes. EPA/SW-846. GPO No. 955-001-00000-1. Office of Solid Waste. Washington, D.C. 20460.

Each of the PARCC parameters should be considered in evaluating sampling and analysis options. To the extent possible, they should be defined as goals to be achieved by the data collection program. It should be recognized, however, that DQOs can be developed for RFI work without strictly defined PARCC goals.

Whenever measurement data are reviewed, the PARCC parameters should be included in the review. Precision and accuracy data may be expressed in several ways and are best evaluated by an analytical chemist or a statistician. The data reviewer should keep the action levels (health and environmental criteria) and the end use of the data in mind when reviewing precision and accuracy information. In some cases, even data of poor precision and/or accuracy may be useful. For example, if all the results are far above an action level, the precision and accuracy are less important. However, close to the action level, precision and accuracy are much more important and should be carefully reviewed. If results have very good precision but poor accuracy, correcting the reported results using the percent recovery or percent bias data may be acceptable.

#### **4.4.2 Sampling Procedures**

To ensure that sample collection will provide high quality and representative data, the owner or operator is advised to carefully select appropriate sampling procedures that will meet the objectives of the investigation. Some factors to consider in choosing the best sampling methodologies include the following:

- Physical and chemical properties of the medium to be sampled;
- Relative and absolute concentrations of analytes of concern;



- Relative importance of various analytes to RFI objectives;
- Method performance characteristics;
- Potential interferences at the site; and
- Time resolution requirements.

QA/QC procedures relevant to sampling activities should also be formulated and followed during any site environmental characterization. These procedures should include a description of the techniques to be utilized in performing tasks such as well drilling, stratigraphic analysis, meteorological measurements, and surface water flow measurements. More information can be found in the references identified in Section 4.5, and in the media-specific sections (Sections 9 through 13).

#### **4.4.3 Sample Custody**

An essential part of any program that requires sampling and analysis is ensuring sample integrity from collection to data reporting. This includes the ability to trace the possession and handling of samples from collection through analysis and final disposition. The documentation of the history of the sample is referred to as chain-of-custody.

Chain-of-custody procedures should identify the components that will be utilized for all sampling and analysis under the RFI, including a transfer in custody and how the chain-of-custody procedures and documents will effectively record that transfer. The following sample custody procedures should be addressed:

##### **(1) Field sampling operations:**

- Documentation of procedures for preparation of reagents or supplies that become an integral part of the sample (e.g., filters and adsorbing reagents);

- Provision of procedures and forms for recording the exact location and specific considerations associated with sample acquisition;
- Documentation of specific sample preservation methods;
- Provision of pre-prepared sample labels containing all information necessary for effective sample tracking; and
- Establishment of standardized field tracking reporting forms to establish sample custody in the field prior to shipment.

**(2) Laboratory operations:**

- Identification of a responsible party to act as sample custodian at the laboratory facility authorized to sign for incoming field samples, obtain documents of shipment, and verify the data entered onto the sample custody records;
- Provision for a laboratory sample custody log consisting of serially numbered standard lab-tracking report sheets; and
- Specification of laboratory sample custody procedures for sample handling, storage, and dispersement for analysis.

#### **4.4.4 Calibration Procedures**

Another important consideration in any environmental measurement is the calibration of the measurement system. An improperly and/or infrequently calibrated system may have a serious negative impact on the precision and accuracy of the determinations. The result will be erroneous data and the need to repeat the measurements. The calibration procedures utilized should therefore be defined. Points that should be addressed include:

- For each measurement parameter, including all contaminant measurement systems, reference the applicable SOP or provide a written description of the calibration procedure(s) to be used;

- List the frequency planned for recalibration and/or the criteria utilized to dictate the frequency of recalibration; and
- List the calibration standards to be used and their source(s), including traceability procedures.

#### **4.4.5 Analytical Procedures**

The owner or operator should select analytical procedures that will meet the objectives of the RFI. Factors to consider in choosing appropriate analytical methodologies include:

- Scope and application of the procedure;
- Sample matrix;
- Potential interferences;
- Precision and accuracy of the methodology; and
- Method detection limits.

EPA-approved methodologies, such as those identified in the 3rd edition of Test Methods for Evaluating Solid Wastes (EPA/SW-846) or equivalent, should be utilized when available.

For each measurement parameter, including all contaminant measurement systems, the owner or operator should reference the SOP or provide a written description of the analytical procedure(s) to be used in support of the RFI. If any method modifications are anticipated due to the nature of the sample(s) being investigated, these modifications should be explicitly defined.

An important factor to consider in any analytical procedure is holding time. Samples have a limited shelf life. Analysis should occur within the time specified by the method. This is especially important for organic contaminants. For example,

volatile organic compound (VOC) analysis should occur within 2 weeks of sampling. Acceptable sample holding times for all classes of Appendix VIII constituents are discussed in Test Methods for Evaluating Solid Waste (EPA/SW-846).

#### **4.4.6 Data Reduction, Validation, and Reporting**

This portion of the QA/QC procedures applies to all measurements performed in support of the RFI. The owner or operator should identify the data reduction scheme planned for collected data and include all equations and reporting units used to calculate the concentration or value of the measured parameter.

Data validation is the process of reviewing data and accepting or rejecting it on the basis of sound criteria. Validation methods may differ for various measurements but the chosen validation criteria must be appropriate to each type of data and the purpose of the measurement. Records of all data should be maintained, even those judged to be "outlying" or spurious values. Personnel assigned the responsibility of data validation should have sufficient knowledge of the particular measurement system to identify questionable values.

The owner or operator should identify the principal criteria that will be applied to validate data integrity during collection and reporting. In addition, the methods that will be utilized to identify and treat outliers should be addressed. The validation process should include mechanisms whereby data reduction is verified. In the case of computerized data reduction, this may include subjecting a surrogate data set to reduction by the software to ensure that valid results are produced.

#### **4.4.7 Internal Quality Control Checks**

Quality control checks are performed to ensure that the data collected is representative and valid data. Internal QC refers to all data compilation and contaminant measurements. Quality control checks are the mechanisms whereby the components of QA objectives are monitored. Examples of items to be considered are as follows:

**(1) Field Activities:**

- **Use of standardized checklists and field notebooks;**
- **Verification of checklist information by an independent person;**
- **Strict adherence to chain-of-custody procedures;**
- **Calibration of field devices;**
- **Collection of replicate samples; and**
- **Submission of field blanks, where appropriate.**

**(2) Analytical Activities:**

- **Method blank(s);**
- **Laboratory control sample(s);**
- **Calibration check sample(s);**
- **Replicate sample(s);**
- **Matrix-spiked sample(s);**
- **"Blind" quality control sample(s);**
- **Control charts;**
- **Surrogate samples;**
- **Zero and span gases; and**
- **Reagent quality control checks.**

The owner or operator should consider those checks that will meet the QA objectives of the RFI. In addition, the owner or operator should present, in tabular format, the frequency with which each control check will be used.

#### **4.4.8 Performance and Systems Audits**

A systems audit is a qualitative evaluation of all components of the measurement systems to determine their proper selection and use. This audit includes a careful review of all data-gathering activities and their attendant QC procedures. Systems audits are normally performed before or shortly after systems are operational. However, such audits should be performed at sufficiently regular intervals during the lifetime of the RFI or continuing operation. Systems audits should be conducted by an individual who is technically knowledgeable about the operation(s) under review and who is independent of any other contribution to the RFI. The primary objective of the systems audit is to ensure that the QA/QC procedures are being adhered to.

After systems are operational and generating data, performance audits are conducted periodically to determine the accuracy of the total measurement system(s) or component parts thereof. Performance audits are quantitative evaluations of the measurement system(s). QA/QC procedures should include a schedule for conducting performance audits for each measurement parameter where all measurement systems are included. Examples of performance auditing mechanisms for analytical activities would be the inclusion of "blind" samples into the normal sample flow, an analyst performing the analysis of a sample previously analyzed by another analyst, and the results of any appropriate interlaboratory study samples analyzed during the term of the RFI. Performance audit checks relative to data handling operations might be the insertion of erroneous parameters into field records. This should trigger the validation procedures by entering unreasonable combinations of responses.

#### **4.4.9 Preventive Maintenance**

Preventive maintenance schedules ensure the maximum amount of active time for analytical instrumentation, field devices and instrumentation, and computer

hardware over the course of the RFI program. The following types of preventive maintenance should be considered:

- A schedule of important preventive maintenance tasks that must be carried out to minimize downtime of all measurement systems; and
- A list of any critical spare parts that should be on hand to minimize downtime.

#### **4.4.10 Corrective Action for QA/QC Problems**

Corrective actions are those measures taken to rectify a measurement system that is out of control. [Note that the term "Corrective Action," as used in this section, is a common QA/QC term applied to problem-solving activities. It should not be confused with the RCRA Corrective Action Program.] Corrective action may be initiated by any person performing work in support of the RFI at any time. For example, an analyst should be familiar with the precision and accuracy of the analysis that is being performed. If the results of the analysis are not within the anticipated limits, there are appropriate corrective actions that should be initiated by the analyst. There are, however, other checks within the measurement system that only the person assigned QA/QC responsibilities would be in a suitable position to evaluate and take action upon if required. A "blind" sample inserted in the normal sample flow would be an example of such a check.

The corrective action procedures to be utilized in the accomplishment of the RFI objectives should be contained in the QA/QC procedures and should include the following elements:

- The predetermined limits for data acceptability beyond which corrective action is required; and
- For each measurement system, the identity of the individual responsible for initiating the corrective action and also the individual responsible for approving the corrective action, if necessary.

In addition to routine corrective actions taken by all personnel contributing to the RFI, performance and systems audits may result in the necessity of more formal corrective action.

#### **4.4.11 Quality Assurance Reports to Management**

Another important aspect of the QA/QC program is the communication between the QA/QC organization and the management organization. Regular appraisal by management of the quality aspects related to the ongoing RFI data-gathering efforts provides the mechanism whereby the established objectives may be met.

QA/QC procedures should provide details relating to the schedule, information to be provided, and the mechanism for reporting to management. Reports to management should include:

- Periodic assessment of measurement data accuracy, precision, and completeness;
- Results of performance audits;
- Results of system audits;
- Significant QA/QC problems and recommended solutions; and
- Resolutions of previously stated problems.

The individual(s) responsible for preparing the periodic reports should be identified. These reports should contain a separate QA/QC section that summarizes data quality information.

#### **4.5 References**

Following is a list of the major references, including EPA guidances, recommended for use in designing effective QA/QC programs for RFIs:



- U.S. EPA. September 20, 1980. Guidelines and Specifications for Preparing Quality Assurance Program Plans. Office of Monitoring Systems and Quality Assurance. QAMS-004/80. NTIS PB83-219667. Washington, D.C. 20460.
- U.S. EPA. December 29, 1980. Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans. Office of Monitoring Systems and Quality Assurance. QAMS-005/80. NTIS PB83-170514. Washington, D.C. 20460.
- U.S. EPA. 1986. Test Methods for Evaluating Solid Wastes. 3rd Edition. Office of Solid Waste. EPA/SW-846. GPO No. 955-001-00000-1. Washington, D.C. 20460.
- U.S. EPA. August, 1987. Compendium of Field Operations Methods. OSWER Directive No. 9355.0-14. EPA/540/P-87/001A. Office of Emergency and Remedial Response. Washington, D.C. 20460.
- U.S. EPA. July, 1981. RCRA Inspection Manual. Office of Solid Waste. Washington, D.C. 20460.
- U.S. EPA. June, 1985. Guidance on Remedial Investigations Under CERCLA. Office of Emergency and Remedial Response. NTIS PB 85-238616. Washington, D.C. 20460.
- U.S. EPA. May, 1984. Soil Sampling Quality Assurance Users Guide. EPA 600/4-84-043. NTIS PB84-198621. Washington, D.C. 20460.
- U.S. EPA. 1985. Sediment Quality Assurance Users Guide. EPA 600/4-85-048. NTIS PB85-233542. Washington, D.C. 20460.
- U.S. EPA. March, 1987. Data Quality Objectives for Remedial Response Activities. Volume 1: Development Process. Volume 2: Example Scenario. EPA 540/G-87/003a. OSWER Directive No. 9335.0-7B. Office of Emergency and Remedial Response and Office of Waste Programs Enforcement. Washington, D.C. 20460.

## **SECTION 5**

### **DATA MANAGEMENT AND REPORTING**

#### **5.1 Data Management**

Release characterization studies may result in significant amounts of data, including results of chemical, physical, or biological analyses. This may involve analyses of many constituents, in different media, at various sampling locations, and at different times. Data management procedures should be established to effectively process these data such that relevant data descriptions (e.g., sample numbers, locations, procedures, methods, and analysts) are readily accessible and accurately maintained.

In order to ensure effective data management, the owner or operator should develop and implement a data management plan to document and track investigation data and results. This plan should address data and report processing procedures, project file requirements and all project-related progress reporting procedures and documents. The plan should also provide the format(s) to be used to present the data, including data reduction.

Data presentation, reduction and reporting are discussed in Sections 5.2, 5.3, and 5.4, respectively.

#### **5.2 Data Presentation**

RFI data should be arranged and presented in a clear and logical format. Tabular, graphical, and other visual displays (e.g., contaminant isopleth maps) are essential for organizing and evaluating such data. Tables and graphs are not only useful for expressing results, but are also necessary for decision-making during the investigation. For example, a display of analytical results for each sampling location superimposed on a map of the site is helpful in identifying data gaps and in selecting future sampling locations. Graphs of concentrations of individual constituents plotted against the distance from the source can help to identify patterns, which can be used to design further monitoring efforts.

Various tabular and graphic methods are available for data presentation, as illustrated in Table 5-1. Particular methods most applicable to the RFI may vary with the type of unit, the type of data, the medium under consideration, and other factors. The owner or operator should propose methods in the RFI Work Plan that best illustrate the patterns in the data.

Often, certain types of data, such as stratigraphy and sampling location coordinates, are more effectively displayed in graphic form. Such data may be presented in tabular form but should also be transformed into graphic presentations. For example, stratigraphy might be effectively illustrated on a two-dimensional (or possibly three-dimensional) cross-sectional map. Three-dimensional data presentation is particularly relevant to the RFI, as three-dimensional characterization is generally required to adequately characterize the nature, extent, and rate of release migration.

Sampling locations may be effectively illustrated on a topographic map, as shown in Figure 5-1. Topographic maps and the regulatory requirements for their preparation (40 CFR Part 270.14(b)) are also discussed in Appendix A. Table 5-2 provides some useful data presentation methods. In addition, many of the Case Studies presented in Volume IV illustrate effective data presentation techniques. Case Study No. 6 is of particular relevance to data presentation techniques. Specific data presentation techniques are discussed below.

### **5.2.1 Tables**

Tabular presentations of both raw and sorted data are useful means of data presentation. These are discussed below.

#### **5.2.1.1 Listed (Raw) Data**

Simple lists of data alone are not adequate to illustrate trends or patterns resulting from a contaminant release. However, such lists serve as a good starting point for other presentation formats. These lists are also valuable for sample validation and auditing. Therefore, such lists are highly recommended for reporting results during the RFI. Each data record should provide the following information:

**TABLE 5-1**  
**USES OF TABLES AND GRAPHICS IN AN RFI**

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**Tabular Displays**

1. **Display site information and measurements**
  - Water table elevations
  - Sampling location coordinates
  - Precipitation and temperature data
  - Lists of site fauna and flora
2. **Display analytical data**
  - List of constituents of concern and other monitoring parameters with associated analytical measurements
  - Display sorted results (e.g., by medium, sampling date, soil type)
  - Compare study and background area data
  - Report input data, boundary conditions, and output values from mathematical modeling

**Graphic Displays**

1. **Display site features**
    - Layout and topography (equivalent to the required RCRA permit application map)
    - Sampling locations and sampling grids
    - Boundaries of sampling area
    - Stratigraphy and water table elevations (profile, transect, or fence diagram)
    - Potentiometric contour map of ground water
    - Ground-water flow net
    - Population plot and/or local residential map
    - Features affecting inter-media transport
  2. **Illustrate the extent of contamination**
    - Geographical (areal) extent of contamination
    - Vertical distribution of contaminant(s)
    - Contamination values, averages, or maxima at sampling locations
  3. **Demonstrate patterns and trends in the data**
    - Change in concentration with distance from the source
    - Change in concentration with time
    - Display estimates of future contaminant transport derived from modeling
-



**Table 5-2**  
**Useful Data Presentation Methods**

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**Tables**

Unsorted (raw) data

Sorted tables

**Graphic Formats and Other Visual Displays**

Bar graphs

Line graphs

Area or plan Maps

Isopleth (contour) plots

Ground-water flow nets

Cross-sectional plots, transects, or fence diagrams

Three-dimensional graphs

- Unique sample code;
- Sampling location and sample type;
- Sampling date;
- Laboratory analysis identification number;
- Property or component measured;
- Result of analysis (e.g., concentration);
- Detection limits; and
- Reporting units.

Analytical data will generally be reduced at the laboratory before they are reported (i.e., the owner or operator does not have to report instrument readings or intermediate calculations, although this information should be maintained for ready access, if needed). The owner or operator should report all data to the regulatory agency, including suspected outliers or samples contaminated due to improper collection, preservation, or storage procedures. The rejected data should be marked as such in the data tables, and explanations of rejected data should be presented in footnotes.

In addition to analytical data, the owner or operator may be required to provide sampling logs for all samples obtained during the investigation. Sampling logs are records of procedures used in taking environmental samples, and of conditions prevailing at the site during sampling. Information in the log should include:

- Name and address of sampler;
- Purpose of sampling;
- Date and time of sampling;

- Sample type (e.g., soil) and suspected contaminants;
- Sampling location, description, and grid coordinates (including photos);
- Sampling method, sample containers, and preservation (if any);
- Sample weight or volume;
- Number of samples taken;
- Sample identification number(s);
- Amount purged (for ground water);
- Field observations;
- Field measurements made (e.g., pH, temperature);
- Weather conditions; and
- Name and signature of person responsible for observation.

The owner or operator should also describe any unusual conditions encountered during sampling (e.g., difficulties with the sampling equipment, post-sampling contamination, or loss of samples).

#### **5.2.1.2 Sorted Summary Tables**

Presentation of results grouped according to data categories is one of the simplest formats used to display trends or patterns in data. Examples of categories of data include medium tested, sampling date, sampling location, and constituent or property measured. Table 5-3 shows an example of a sorted table; data are sorted by medium (ground water), sampling date, and constituent measured.



**TABLE 5-3**  
**SORTED DATA**  
 (Concentration of Volatile Organic  
 Compounds in Monitoring Well #32)

		Concentration (µg/l)			
Date	Sample Identification Number	Methylene Chloride	Acetone	Trichloroethylene	Benzene
1/3/82	MW-32-1/3A	20	120	20	30
2/12/82	MW-32-2/12A	≤ 10	220	NA	≤ 10
4/24/82	MW-32-4/24A	≤ 10	140	20	20

NA - Not analyzed.

In Table 5-4, the data are sorted by medium, location, depth, and constituent analyzed. Inclusion of the sample identification number allows the reader to cross-reference the data and look up any information not listed in the table.

Preparation of data summary tables can be simplified by use of a computer spreadsheet program. These programs can perform sorting operations, perform simple calculations with the data, and display results in a number of tabular and graphical formats.

### **5.2.2 Graphic Presentation of Data**

The graphic methods of data presentation will often illustrate trends and patterns better than tables. Some graphic formats useful for environmental data include bar graphs, line graphs, areal maps, and isopleth-plots. These graphic methods of data presentation are discussed below.

#### **5.2.2.1 Bar Graphs and Line Graphs**

Bar graphs and line graphs may be used to display changes in contaminant concentrations with time, distance from a source, or other variables. For example, Figure 5-2 compares two methods of displaying changes in concentrations over distance. Bar graphs are generally preferable to line graphs in instances where there is not enough information to assume continuity between data points. However, line graphs generally can display more information in a single graph.

Attention to the following principles of graphing should provide clear and effective line and bar graphs:

- Do not crowd data onto a graph. Plots with more than three or four lines or bar subdivisions become confusing. Different symbols or textures should be used to distinguish each line or bar;
- Choose the scale of the x and y axes so that data are spread out over the full range of the graph. If one or two data points are far outside the range of the rest of the data, a broken line or bar may be used to indicate

**TABLE 5-4**  
**SOIL ANALYSES: SAMPLING DATE 4/26/85**

Sample Identification, Location, and Depth			Concentration (mg/kg)		
Sample ID Number	Location	Depth	Lead	Arsenic	Chromium
SB-1	N of lagoon	surface	240	55	1,200
SB-2	N of lagoon	6 inches	40	15	220
SB-3	N of lagoon	18 inches	15	15	36
SB-4	SE corner	surface	360	84	5,300
SB-5	SE corner	6 inches	170	29	430
SB-6	SE corner	18 inches	22	≤1.0	47

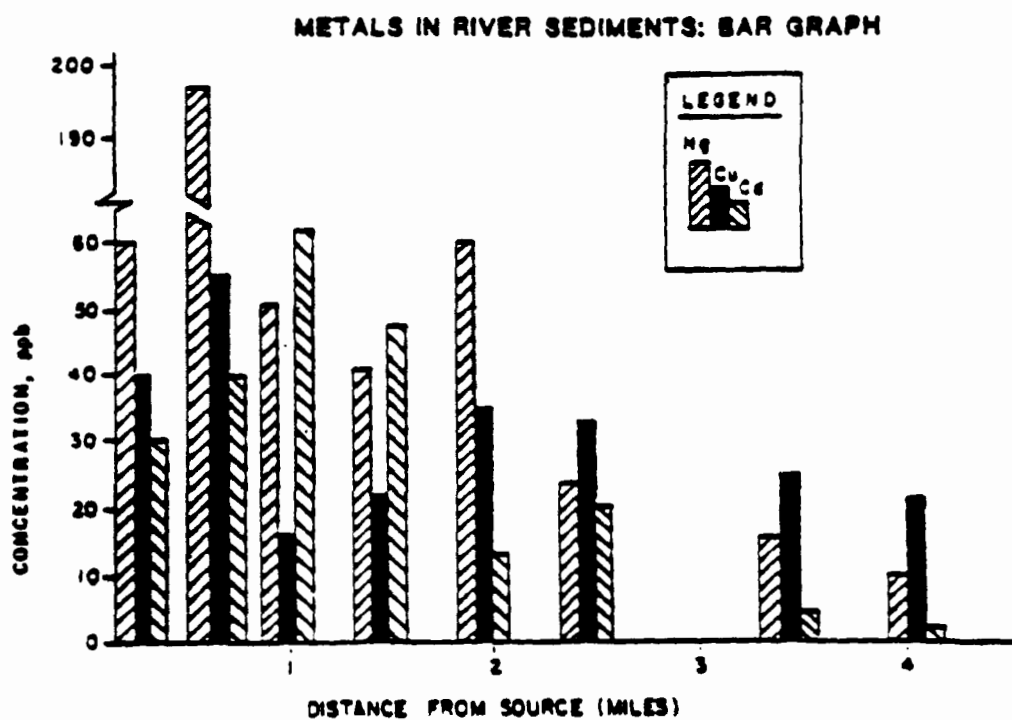
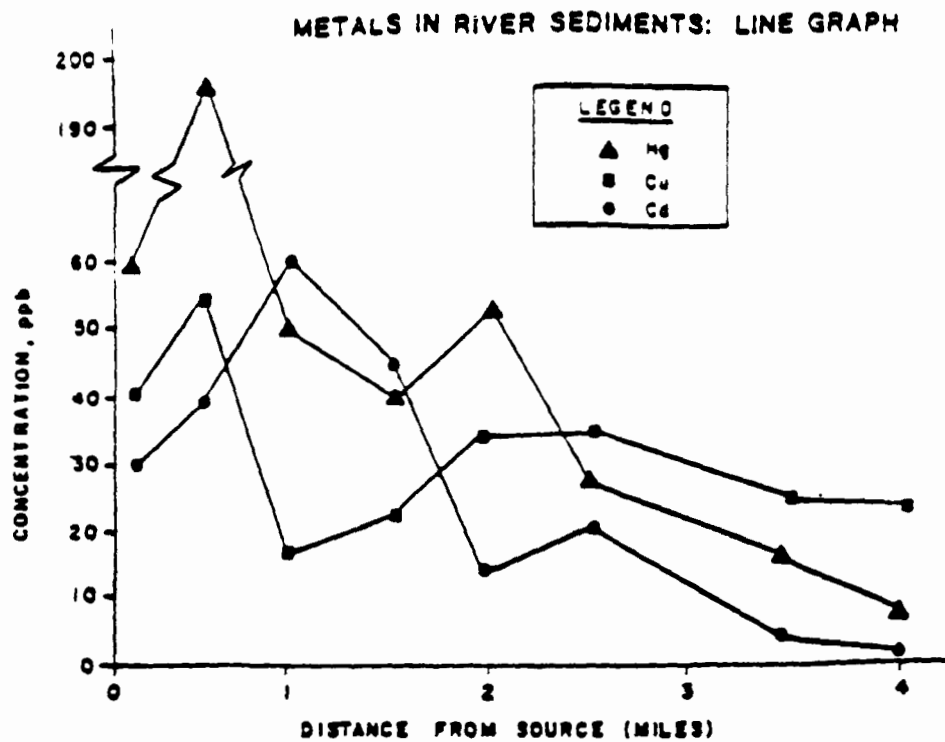


Figure 5-2. Comparison of line and bar graphs

a discontinuous scale. If the data range exceeds two orders of magnitude, the owner or operator may choose to plot the logarithms of the data;

- The x and y axes of the plot should be clearly labeled with the parameter measured and the units of measurement; and
- The x axis generally represents the independent variable and the y axis the dependent variable.

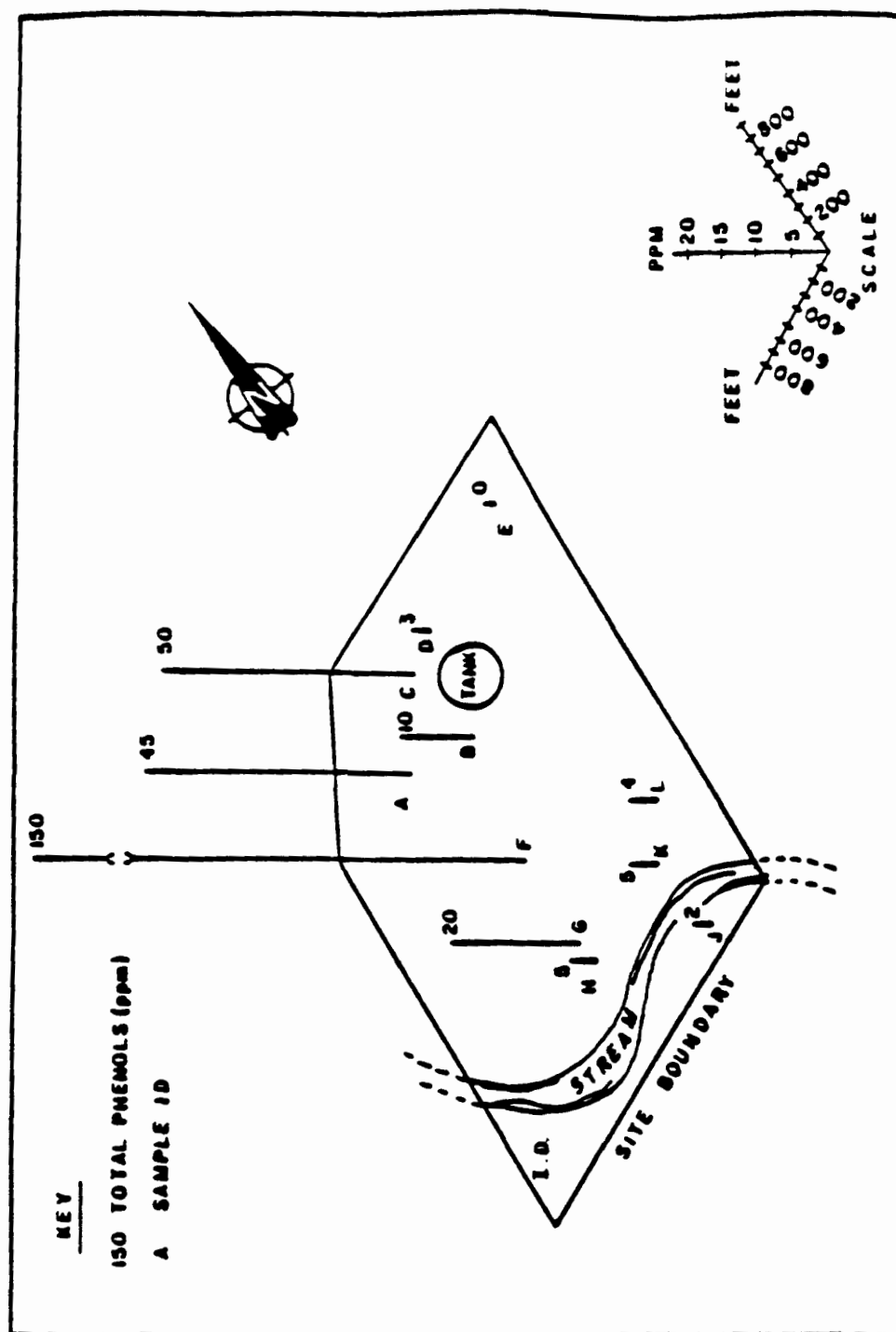
#### 5.2.2.2 Area or Plan Views (Maps)

The distribution of hazardous constituents at a site may be represented by superimposing contaminant concentrations over a map of the site. Distributions may be shown by listing individual measurements, or by contour plots of the contaminant concentrations. Individual techniques are discussed below:

Contamination shown at discrete points--In this format, no assumptions are made concerning contamination outside the immediate sampling area. For example, in Figure 5-3, soil phenol concentrations are shown by the height of the vertical bar at each sampling site. Soil samples indicated on this map were taken from approximately the same depths. Note that one bar is discontinuous so as to bring the lower values to a height that can be seen on the graph. Other possible representations of the same information could use symbols of different shapes, sizes, or colors to represent ranges of concentration. For example, a triangle might represent 0 to 10 ppm; a circle 10 to 100 ppm, etc.

Display of average concentrations--Shadings or textures can be used to represent average contamination concentrations within smaller areas at a site. Shading represents estimated areas of similar concentration only and should not be interpreted as implying concentration gradients between adjacent points.

Contaminant isopleth maps--Lines of equal concentration are called isopleths. Construction of a contaminant isopleth map generally requires a relatively large number of sampling locations spaced regularly across the study area. An isopleth map is prepared by marking the site map with the concentrations detected at each



sampling location. Lines are drawn to connect data points of the same concentration, similar to contours of elevation, as shown in Figure 5-4. Figure 5-5 demonstrates the use of an isopleth plot to show the distribution of an air release.

#### 5.2.2.3 Isopach Maps

A technique that is useful for displaying certain types of geological data is the isopach map. Isopachs are contour maps in which each line represents a unit of thickness of a geologic material (e.g., the soil layer) as shown in Figure 5-6. This format would be useful if, for example, oil is known to be contained within a highly permeable sand layer of varying thickness, confined between low-permeability clay layers. The isopach map displays thickness only and does not provide information on absolute depth or slope.

#### 5.2.2.4 Vertical Profiles or Cross-Sections

Vertical profiles are especially useful for displaying the distribution of a contaminant release in all media. For soil and ground water, the usual approach is to select several soil cores (or monitoring wells) that lie in approximately a straight line through the center of the contaminant release. This cross-section represents a transect of the site. A diagram of the soil (or ground water) profile should be prepared along the length of the transect, displaying subsurface stratigraphy, location of the waste source, and the location and depth of boreholes, as shown in Figure 5-7. Concentrations may also be indicated on the plot as discrete measurements or isopleths and may be drawn as in Figure 5-8. Figure 5-9 presents a plan view of Figure 5-7, showing the offset in cross-section. If the sampling points do not fall in a straight line, an alternate display called a fence diagram can be used. Figure 5-10 shows a fence diagram of subsurface stratigraphy, which also includes analytical data.

To characterize the three-dimensional distribution of a subsurface contaminant release, the owner or operator will generally need to prepare several transects crossing the plume in different directions.

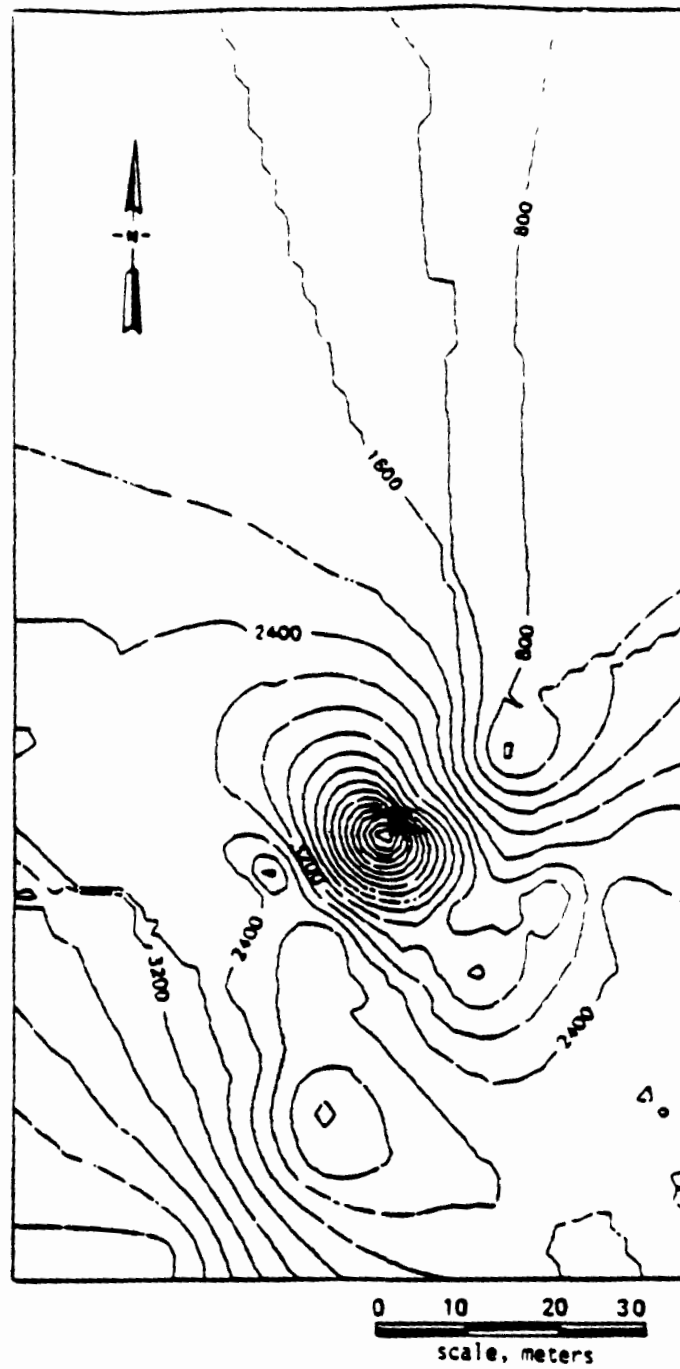
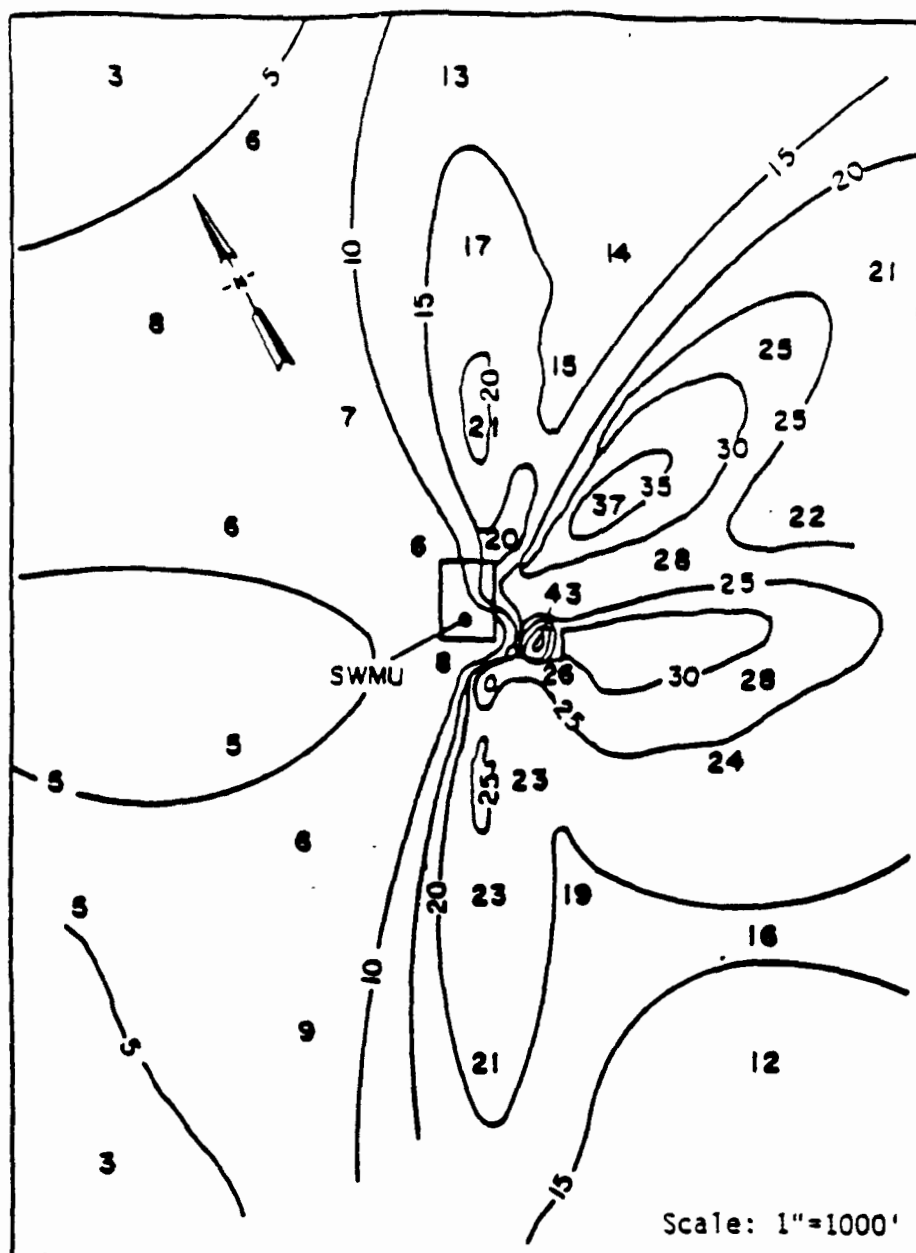


Figure 5-4. Isopleth Map of Soil PCB Concentrations (µg/kg)





ISOPLETHS ARE IN MICROGRAMS PER CUBIC METER

Figure 5-5. Isopleth Map of Diphenylamine Concentrations in Ambient Air in the vicinity of a SWMU.

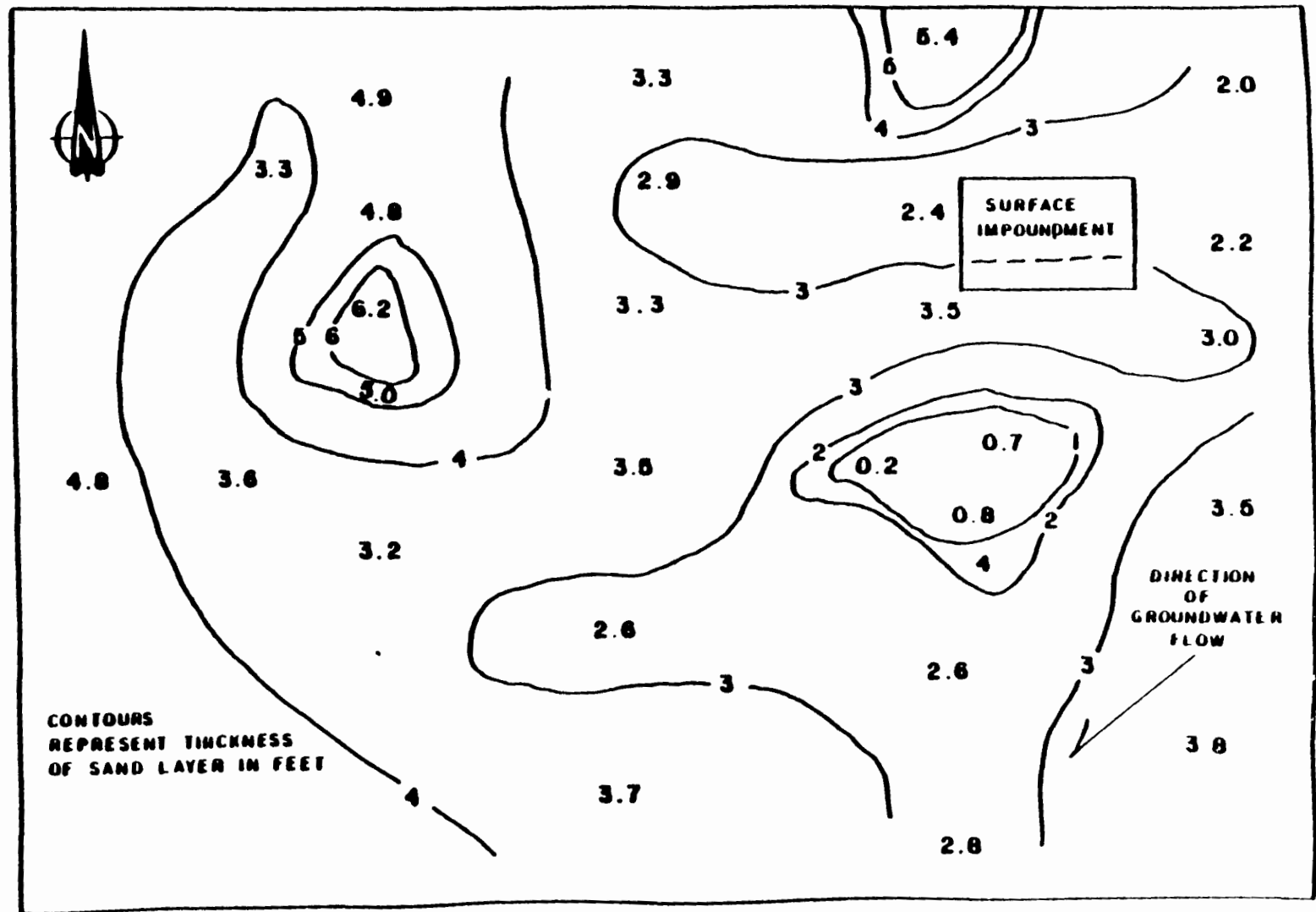
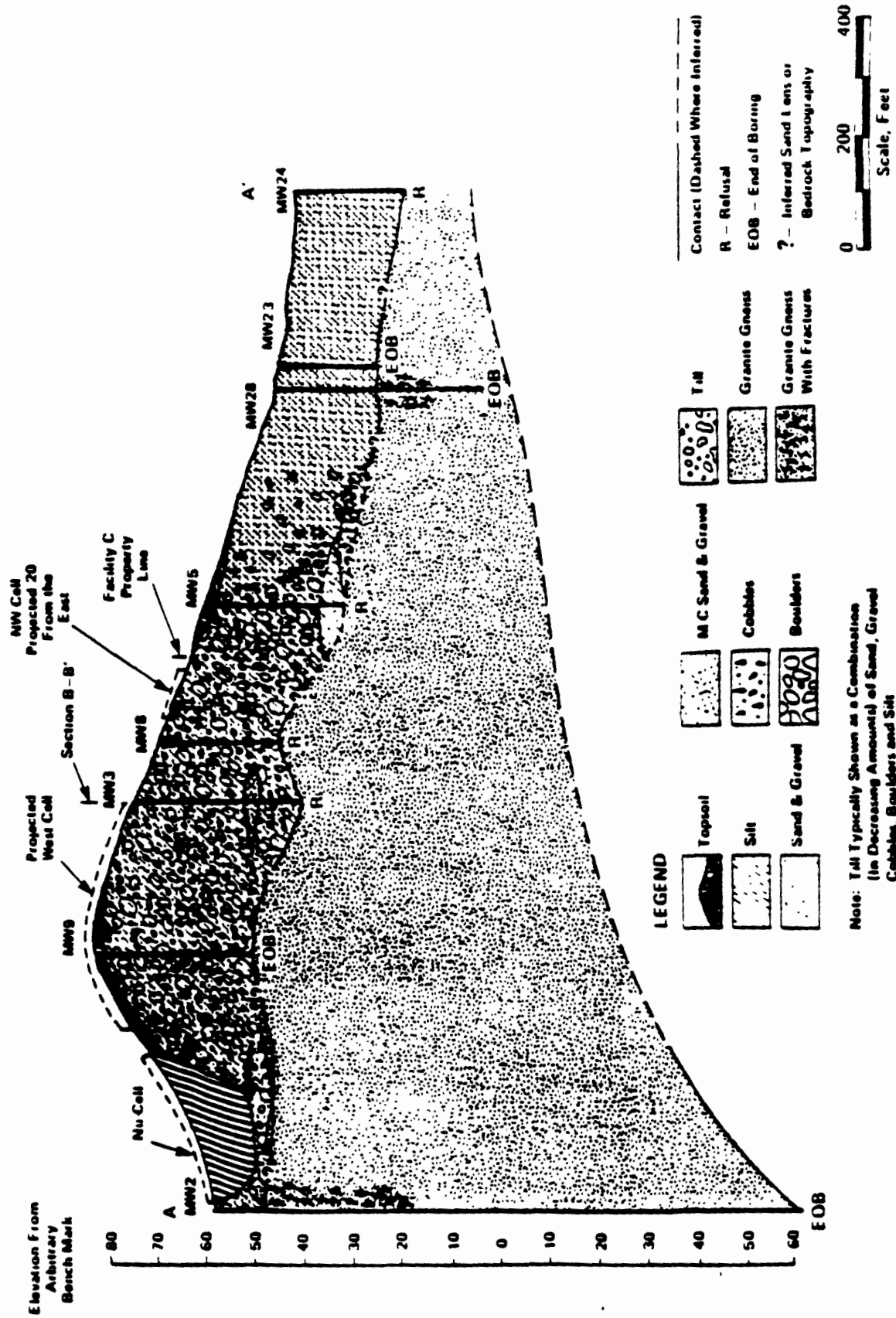


Figure 5-6. Sand Isopach Map Showing Contours (Isopleths)



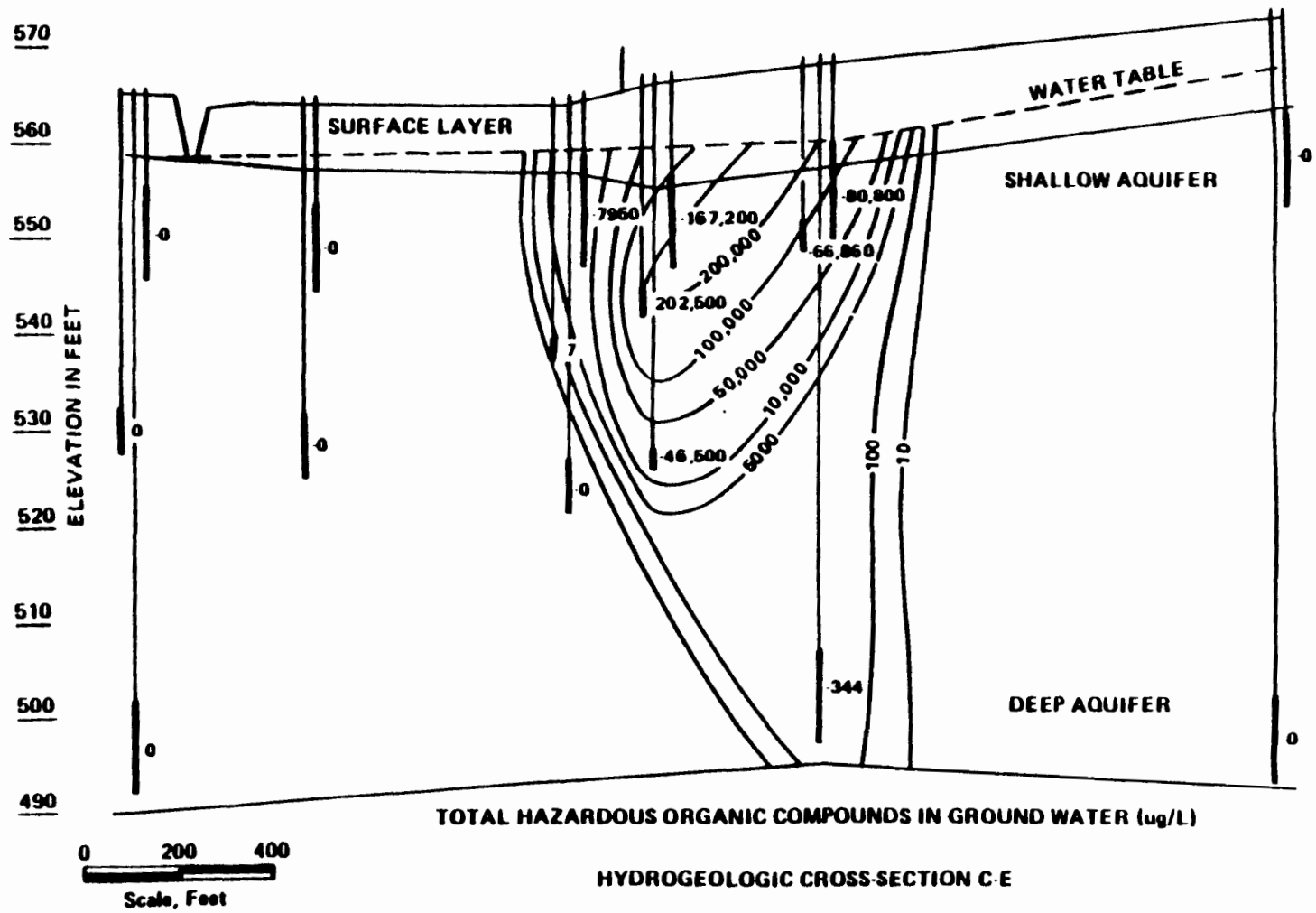


Figure 5-8. Transect Showing Concentration Isopleths ( $\mu\text{g/l}$ )

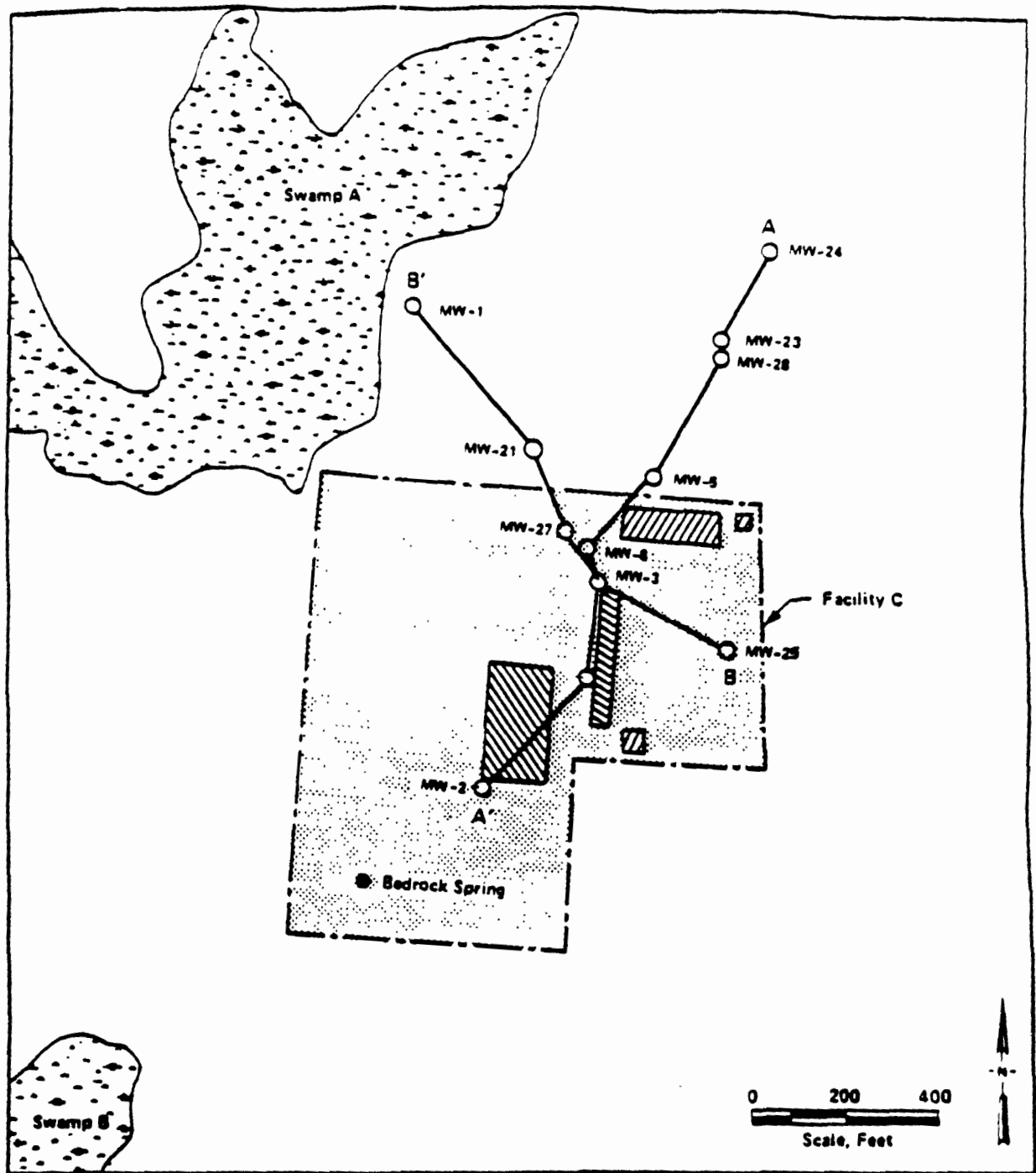


Figure 5-9. Plan View of Figure 5-7 Showing Offsets in Cross Section

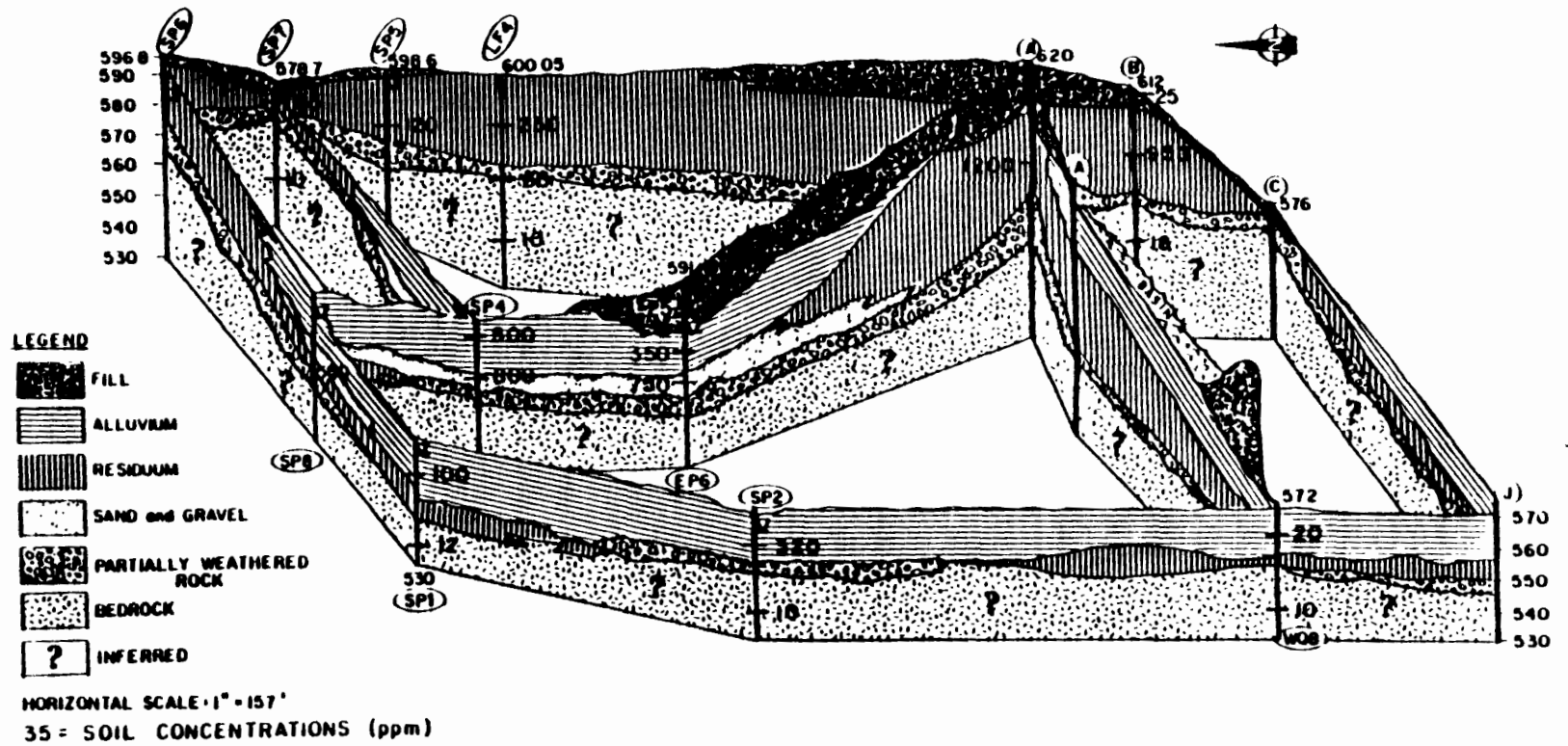


Figure 5-10. Fence Diagram of Stratigraphy Showing Lead (Pb) Concentrations (ppm = mg/kg)

### 5.2.2.5 Three-Dimensional Data Plots

Computer graphics packages are available from several commercial suppliers to produce three-dimensional data plots. A common use of this technique is to represent contaminant concentrations across the study area as a three-dimensional surface, as shown in Figure 5-11. The information provided by this approach does not differ greatly from that of Figure 5-4. The primary difference is that the smoothing of the concentration dissimilarities between adjacent sampling locations in Figure 5-11 makes patterns in the data easier to visualize. Precise concentrations, however, cannot be displayed in this format because the apparent heights of the contours change as the figure is rotated.

## 5.3 Data Reduction

Data should be reported according to accepted practices of QA and data validation. All data should be reported. Considerations, however, include treatment of replicate measurements, identification of outlier values, and reporting of results determined to be below detection limits.

### 5.3.1 Treatment of Replicates

Replicate measurements of a single sample should be averaged prior to further data reduction. For example, Table 5-5 shows how to calculate an overall mean when replicate analyses for a single sample have been performed. The three "B" values are averaged before the mean is calculated. This removes bias from the overall mean. The number of analyses is indicated by "n".

### 5.3.2 Reporting of Outliers

Any program of environmental measurement can produce numbers that lie outside the "expected" range of values. Because field variability of environmental measurements can be great, deciding whether an extreme (outlier) value is representative of actual contaminant levels may be difficult. Outlier values may be the result of:

- A catastrophic unnatural (but real) occurrence such as a spill;

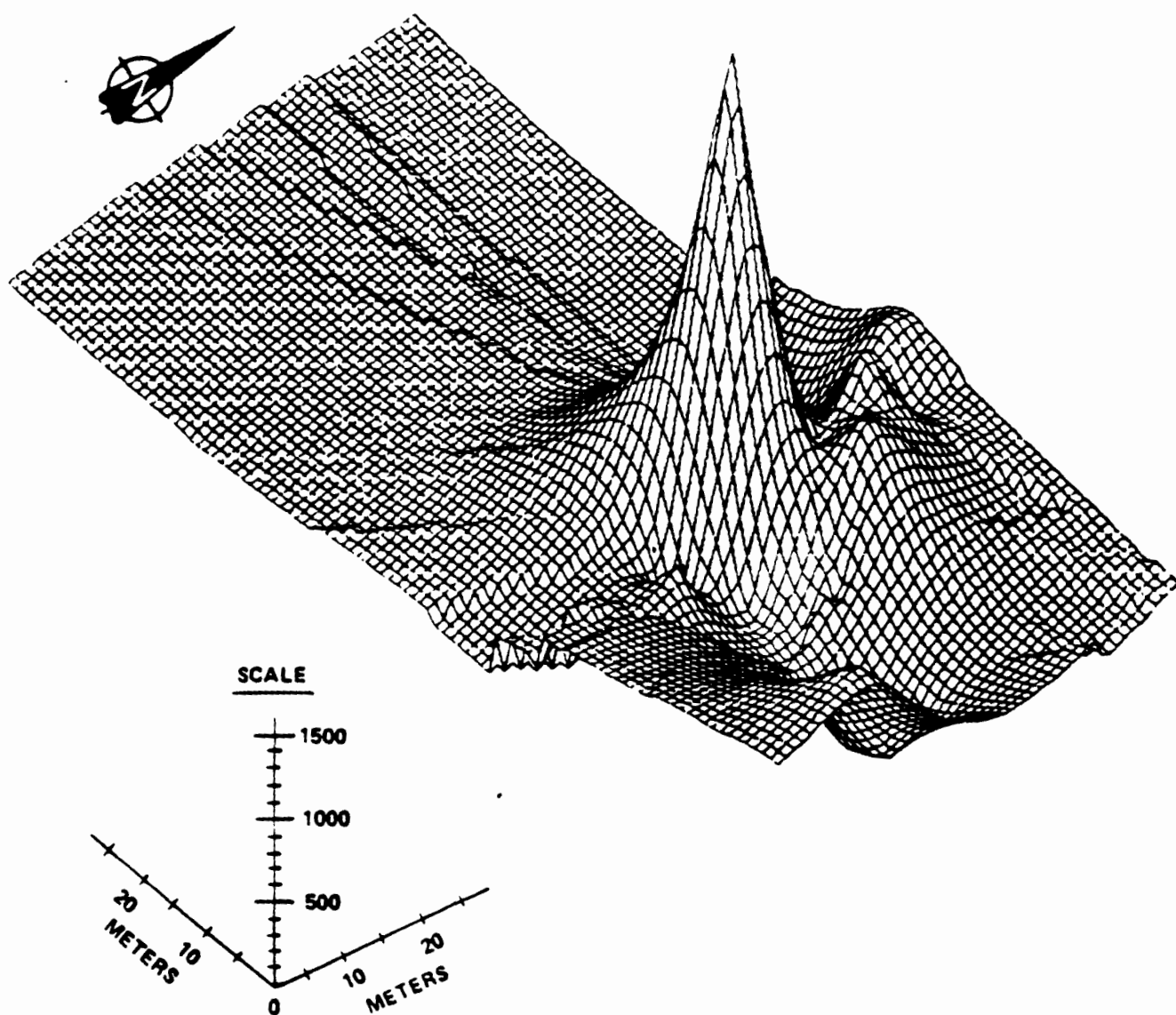


Figure 5-11. Three-Dimensional Data Plot of Soil PCB Concentrations ( $\mu\text{g/kg}$ )



**TABLE 5-5**  
**CALCULATION OF MEAN VALUES FOR REPLICATES**

Raw Data		Data Summary		
Sample	Concentration	Sample	Concentration	n
A	4.3	A	4.3	1
B	1.8	B	1.8	3
B	2.0	C	7.6	1
B	1.6	D	6.3	1
C	7.6			
D	6.3	mean	5.0	6
[(A + B + C + D)/4]				

- Inconsistent sampling or analytical chemistry methodology;
- Errors in the transcription of data values or decimal points; and
- True but extreme concentration measurements.

The owner or operator should attempt to correct outlying values if the cause of the problem can be documented. The data should be corrected, for example, if outliers are caused by incorrect transcription and the correct values can be obtained and documented from valid records. Also, if a catastrophic event or a problem in methodology occurred that can be documented, data values should be reported with clear reference. Documentation and validation of the cause of outliers must accompany any attempt to correct or delete data values, because true but extreme values must not be altered. Statistical methods for identifying outliers require that the analytical laboratory have an ongoing program of QA, and that sufficient replicate samples be analyzed to account for field variability.

Outlier values should not be omitted from the raw data reported to the regulatory agency; however, these values should be identified within the summary tables.

#### **5.3.3 Reporting of Values Below Detection Limits**

Analytical values determined to be at or below the detection limit should be reported numerically (e.g.,  $\leq 0.1$  mg/l). The data presentation procedures should cite analytical methods used including appropriate detection limits.

#### **5.4 Reporting**

As indicated in Section 3.7, the owner or operator should respond to emergency situations and identify to the regulatory agency priority situations that may require interim corrective measures. Such reporting should be done immediately. In addition, results of various activities conducted during the RFI should be reported to the regulatory agency, as required in the compliance order or by the permit conditions.

Various reports may be required. These may include interim, draft, and final reports. In addition, periodic progress reports (e.g., bimonthly) may also be required. Progress reports should generally include the following information:

- A description and estimate of the percentage of the RFI completed;
- Summaries of all findings;
- Summaries and rationale for all changes made in the RFI Work Plan during the reporting period;
- Summaries of all contacts with representatives of the local community, public interest groups, or government representatives during the reporting period;
- Summaries of all problems or potential problems encountered during the reporting period;
- Actions being taken to rectify problems;
- Changes in personnel during the reporting period;
- Projected work for the next reporting period; and
- Copies of daily reports, inspection reports, laboratory/monitoring data, etc.

Reports, including interim, progress, draft, and final reports may also be required for specific activities that may be performed during an RFI. Examples of specific reports or components that may be required include:

- RFI Work Plan;
- Description of Current Situation;
- Geophysical Techniques;

- Waste and Unit Characterization;
- Environmental Setting Characterization;
- Selection of Monitoring Constituents/Indicator Parameters;
- Results of "Phases" of the Investigation;
- QA/QC results;
- Interim Corrective Measures; and
- Identification of Potential Receptors.

In addition, a draft and final RFI report that incorporates the results of all previous reports will generally be required. This report should be comprehensive and should be sufficiently detailed to allow decisions to be made by the regulatory agency regarding the need for interim corrective measures and/or a CMS. It should be noted that these decisions may also be made by the regulatory agency on the basis of results of progress reports and/or other reports as described above.

## **SECTION 6**

### **HEALTH AND SAFETY**

#### **6.1 Overview**

Protecting the health and safety of the investigative team, as well as of the general public, is a major concern during hazardous waste RFIs. Hazards to which investigators may be exposed include known and suspected chemical substances, heat stress, physical stress, biological agents, equipment-related injuries, fire, and explosion. Many of these hazards are encountered in any type of field study, but exposure to chemical hazards is a major concern for the investigative team at hazardous waste facilities.

In addition to the protection of team members, the public's health and safety should also be considered. RFIs may attract the attention and presence of the news media, public officials, and the general public. Not only is the safety of these observers a concern, but their actions should not hinder the operations and safety of the investigative team. Other public health concerns include risks to the surrounding community from unanticipated chemical releases, and events such as fires and explosions.

The facility owner or operator should develop and update as necessary health and safety plans and procedures to address the needs of the RFI. The health and safety plan should, in particular, establish requirements for protecting the health and safety of the investigative team, facility workers, and the general public throughout the investigation.

Health and safety plans should be reviewed and approved by qualified (via education and work experience) safety and health professionals. While professional certifications such as Certified Industrial Hygienists or Certified Safety Professionals are highly regarded, such certifications are not required under the OSHA standard for plan review/approval, nor do they inherently guarantee proficiency in hazardous materials operations. In addition, health and safety plans should be

discussed thoroughly with the investigative team prior to initiating field activities. Other appropriate parties (e.g., local emergency services) should also be involved, as necessary.

Compliance with health and safety regulatory requirements is the ultimate responsibility of the employer, who, for purposes of the RFI, is the facility owner or operator. Development and implementation of health and safety procedures is therefore the responsibility of the owner or operator. Although these procedures may be presented as part of the RFI Work Plan and reviewed by the regulatory agency, ultimate responsibility and liability rest with the owner or operator. Section 6.2 presents general health and safety regulations and guidance that should be reviewed prior to developing health and safety procedures, Section 6.3 outlines basic elements of health and safety procedures which should be addressed, and Section 6.4 reviews application of zones of operation or work zones.

## **6.2 Applicable Health and Safety Regulations and Guidance**

On December 19, 1986, the Occupational Safety and Health Administration (OSHA) issued, in the Federal Register (29 CFR 1910.120), an interim final rule on hazardous waste site operations and emergency response, which specifically requires certain minimum standards concerning health and safety for anyone performing activities at CERCLA sites, RCRA sites, emergency response operations, sites designated for remediation by a state or local agency, or any other operation where employees' operations involve dealing with hazardous waste. The following discussion provides details on the major requirements of the interim final rule.

### **Development and implementation of a safety and health program:**

The development and implementation of a formal, written safety and health program has long been recognized as a foundation for successful occupational risk minimization. In recent years, this recognition has been receiving increased emphasis from the Occupational Safety and Health Administration (OSHA). For example, as stated in the July 15, 1988 Federal Register (53 FR 26791):

. . . OSHA has become increasingly convinced of the relationship between superior management of safety and health programs - which address all safety

and health hazards, whether or not covered by OSHA standards - and low incidence and severity of employee injuries.

As a result, OSHA has intensified its focus on management practices in its evaluation of workplaces. One primary area of this focus has been on documented safety and health programs. This increased emphasis is evidenced in several other OSHA standards that have been promulgated (e.g., Respiratory Protection - 29 CFR 1910.134, Occupational Noise Exposure - 29 CFR 1910.95, Hazard Communication - 29 CFR 1910.1200, and Subpart C of the Construction Industry Standards - 29 CFR 1926).

In addition to these individual subject area requirements, OSHA has released for comment and information a proposed rule on General Safety and Health Programs (previously-referenced Federal Register - 53 FR 26791). In that proposal, suggested guidelines for establishing and implementing new safety and health programs - or evaluating/modifying existing programs - are provided. The proposed rule advises employers to "institute and maintain...a program which provides policies, procedures and practices that are adequate to recognize and protect their employees from occupational safety and health hazards."

Specific elements of the program proposed by OSHA are addressed under four subject headings. These headings include management commitment, worksite analysis, hazard prevention and control, and safety and health training.

It is of no small consequence that management commitment is the first issue addressed in this proposed rule. A strong commitment from top management representatives is critical to the success of any program. Additionally, this commitment needs to be highly visible to employees. Clear program goals and objectives need to be specified, as well as identification and assignation of appropriate levels of authority, responsibility and accountability. Finally, at least annual program reviews and evaluations are necessary to identify the effectiveness of the program, and incorporate any necessary program modifications.

The second program area recommended for inclusion is worksite analysis. The intent of this part of the program is to identify methods and practices to be utilized for recognizing potential hazards. Examples of methods that can be used to achieve

these objectives include: periodic, comprehensive worksite surveys; analysis of new processes, materials and equipment; and performance of routine job or phase hazard analyses. Other recommended methods include the conduct of regular site inspections, and accident (or near-accident) investigations.

The third program area addresses hazard prevention and control. These efforts should include identifying appropriate engineering, administrative, and/or personnel protective equipment and hazard controls. Additionally, emergency preparedness and a medical program should be elements of this portion of the overall program.

The final topic identified in the proposed rule addresses safety and health training. Employee education and training needs should be provided so that employees are fully aware and capable of handling potential hazards in the performance of their work. Additionally, safety and health training of supervisors and managers needs to be addressed and performed to ensure that they are aware of their responsibilities in regard to health and safety.

To summarize, a written, comprehensive health and safety program, that has visible top-management support, is an important element of a safe and healthful work environment. However, the written program itself must be effectively implemented, periodically evaluated - and modified as necessary, in order to achieve its objectives.

#### Performance of site characterization and analysis:

In addition to the general items of worksite analysis identified above, specific requirements for this type of analysis are presented under OSHA regulation 29 CFR 1910.120. Performance of site characterization and analysis is specifically addressed in paragraph (c) of this regulation.

A site characterization and analysis addressing each site task and operation planned to be performed needs to be conducted. This effort generally proceeds in three phases. Initially (prior to any actual site entry), a data-gathering phase is performed to collect any relevant information that may identify potential site hazards. This activity may include such items as obtaining shipping/disposal



manifests or other such records, including newspaper/media reports, and interviewing persons with potential knowledge of past operations (e.g., previous employees, nearby residents). This initial phase may also consist of the conduct of an offsite reconnaissance (e.g., around the perimeter of the site), and characterization based on all of the collected data. The second phase of this process is the conduct of an onsite survey. Finally, the third phase involves site entry, with a continuance of monitoring efforts to provide current information for evaluating potential site hazards.

In view of this phased approach, it is clearly intended that site characterization and analysis is a continuous process. It is initiated prior to any actual onsite involvement, and continues throughout the performance of onsite activities.

#### Development and implementation of a site control program:

Site control elements need to be established to minimize potential for employee contact with contamination, and the transfer of contaminants into non-contaminated areas. These program elements need to be clearly defined in the employer's site safety and health plan. As stated in the preamble of the rule establishing 29 CFR 1910.120, (December 19, 1986 Federal Register), the establishment of a site control program should be performed "in the planning stages of a project and modified based on new information and site assessments developed during site characterization." The preamble further states that the "appropriate sequence for implementing these measures should be determined on a site-specific basis."

The primary intent of this requirement is that the site control program must be addressed on a site-specific basis. However, employers should develop a general program that identifies minimum performance requirements in order to establish overall uniformity for all projects. For each specific project, the OSHA regulations specify that the site control program include - at a minimum - the following:

- A map of the site;
- Designation of site work zones;

- The practice of using what the regulation refers to as a "buddy system" (defined as a "system of organizing employees into work groups in such a manner that each employee of the group is designated to observe the activities of at least one other employee in the work group. The purpose of the buddy system is to provide quick assistance to those other employees in the event of an emergency.");
- Establishment and maintenance of site communications;
- Establishment and implementation of site standard operating procedures or safe work practices; and
- Identifying the nearest medical facility that would be contacted in the event of a site incident resulting in a need for such services.

**Compliance with employee training requirements (specified in paragraph (e) of the standard) and the development and implementation of an employee training program:**

An employee training program must be developed and implemented, meeting (at a minimum) the training requirements specified in paragraph (e) of the hazardous waste regulation. The program must include provisions for both initial and refresher training of employees on matters of health and safety. All involved employees must receive effective training prior to performing any operations that could result in their exposure to potential safety and health hazards.

The training requirements specified in this regulation are categorized into several subject areas. While the majority of the requirements address CERCLA (Superfund)-related operations, RCRA-related projects and emergency response operations, general training requirements are also specified. The intention of this categorization is to recognize that varying degrees of risk potential exist, thereby requiring different types of health and safety training.

Additionally, for CERCLA-type operations, the program must be further subdivided to address health and safety training program elements for employees and onsite management and supervisors. All individuals must receive introductory

training (40 hours in duration) prior to their initial assignment. This is to be supplemented by 8-hours of annual refresher training, and the conduct of site-specific training for each assignment. Onsite managers and supervisors who will be assigned responsibility for direct, onsite supervision, must receive an additional 8-hours of specialized training for operations management upon job assignment.

Employees involved in normal RCRA operations are required to receive a lesser amount of initial training (24-hours) and 8-hours of annual refresher training. These requirements are applicable for employees who will be involved in hazardous waste operations involving storage, disposal and treatment. However, major corrective actions under RCRA would need to be addressed in a manner similar to the previously - identified CERCLA training requirements.

The final category specifying employee training requirements addresses individuals who participate in (offsite) emergency response operations (e.g., HAZMAP team personnel). Any employees involved in such operations are required to receive at least 24 hours of training annually.

The development and implementation of an employee training program must be initiated by first identifying which of the requirements are applicable, and identifying the employees who need to be included. The overall program also needs to address other types of required employee health and safety training applicable to the work site(s) and job tasks. Examples of other types of required training may include:

- Hazard Communication Training (29 CFR 1910.1200);
- Hearing Conservation Training (29 CFR 1910.95);
- Respiratory Protection Training (29 CFR 1910.134); and
- Others-based on types of equipment, processes, etc.

After all training needs have been identified and the program has been developed and implemented, it must be periodically reviewed and evaluated to determine its effectiveness, with appropriate modifications made where necessary.

Finally, appropriate records of employee training must be maintained to satisfy applicable recordkeeping requirements.

Development and implementation of a medical surveillance program:

A comprehensive medical surveillance program must be established for employees engaged in hazardous waste operations. Employees who have been, or are expected to be, exposed to hazardous substances or health hazards must be participants in such a program. Therefore, one of the first tasks in program development should be to define how many (and which) employees need to be covered.

A second critical element in the development of the program is the selection of a physician (or physicians) who will be utilized to perform the examinations. The selected physician must be licensed, should be knowledgeable in occupational medicine, and familiar with the nature of the work tasks that the employees that he/she will be examining will be performing.

The program needs to provide examinations to employees prior to their first hazardous materials job assignment, at least once every twelve months following the initial examination, upon job termination or reassignment, as soon as possible for any employee demonstrating symptoms of overexposure to hazardous substances, and at more frequent times - as determined to be necessary by the examining physician.

The extent of the examination is at the discretion of the examining physician. However, in order for the physician to appropriately determine the necessary parameters, protocols, tests, etc., he/she must be made very familiar with the nature of the patient's job duties. Therefore, the regulation requires that the physician be provided with a copy of the standard-in its entirety, a description of the employee's duties relative to potential exposures, a description of known or anticipated exposure levels that have been - or may be - encountered by the employee, a description of personal protective equipment that the employee has used or may use, and the employee's previous medical history.

The established medical program should be developed to address medical concerns specified by other regulations as well as hazardous waste operations (e.g., respiratory protection usage, audiometry, asbestos exposures, and other applicable regulations). Therefore, it should have a mechanism incorporated to provide for periodic program review and evaluation to determine effectiveness, and the need for modification as deemed necessary. Finally, medical surveillance recordkeeping must be performed and maintained in accordance with OSHA 29 CFR 1910.20.

Incorporation of engineering controls, administrative controls, and the development and implementation of a personal protective equipment program:

To protect employees from potential hazards that may be encountered in hazardous materials operations (e.g., chemical, physical, biological hazards), employers are required to implement appropriate control efforts. In order of preference, such approaches are to employ engineering and administrative controls where feasible, and (as a last resort), personal protective equipment. However, these control efforts are not mutually-exclusive. The regulation provides for the employer to utilize appropriate combinations of these three types of controls in protecting his/her employees. However, where items of personal protective equipment (PPE) are used, a PPE program must be developed and implemented.

In the developmental stages of the program, the employer must define the types of PPE that will or may be necessary for employee usage. Examples include respiratory protection (with considerations given to the types necessary - e.g., air-supplied vs air-purifying, half-face masks, full facemasks, etc.), hearing protection, head protection, foot protection, dermal protection, eye/face protection, etc. Many of these types of PPE are regulated under specific OSHA standards. Therefore, upon identification of the types of PPE to be used, the regulations must be consulted in developing and implementing the program to ensure overall compliance and program adequacy.

The program must also provide for proper selection of equipment on the basis of the known or suspected hazards to be encountered, proper maintenance, cleaning, servicing, storage of equipment, and, proper training of employees in the correct use and recognition of the limitations of the selected equipment. As with

other programs, provisions for review and evaluation for effectiveness must be incorporated, enabling necessary modifications to be made.

Development and implementation of an air monitoring program:

The establishment of an air monitoring program is essential. The purpose of the program is to gain accurate information on employee exposures in order to implement the correct PPE, engineering controls, and work practices. Airborne contaminants can present a significant threat to employee safety and health. Thus, identification and quantification of these contaminants through air monitoring is an essential component of a safety and health program.

The intent of this requirement is that the air monitoring program be addressed on a site-specific basis. After the site characterization and analysis phase has been completed, personnel should be cognizant of possible contaminants on each specific site. With this information, proper air sampling and analytical methods can be chosen.

Reliable measurements of airborne contaminants are useful in selecting proper personal protective equipment, determining whether engineering controls can achieve permissible exposure limits and which controls to use. Also, this information is used in delineating areas where protection is needed and in assessing potential health effects of exposure. Knowledge of potential health effects will further aid in determining the need for specific medical monitoring.

In view of this approach, air monitoring is a continuous process. It should be initiated prior to any actual onsite involvement, and should continue throughout the performance of onsite activities.

The developed program needs to contain elements identifying the types of monitoring equipment available for employee use, proper selection, maintenance and calibration procedures, employee training, and provisions for equipment cleaning and storage.

Development and implementation of an employee informational program:

The Occupational Safety and Health Administration is requiring under 29 CFR 1910.120, that employers, as part of their safety and health program, develop and implement a site-specific health and safety plan (HASP) for each hazardous waste site operation.

The site health and safety plan must be developed by the employer, utilizing the other parts of the organizational plan and the employer's safety and health program. The HASP must address the anticipated health and safety hazards associated with each work operation or task, and the means to eliminate the hazards or to effectively control them to prevent injury or illness.

The minimum requirements that a HASP must include is the following:

- The names of those responsible for assuring that safe and healthful practices and procedures are followed throughout all work operations;
- Risk analysis or systems analysis for specific work tasks or operations on the site;
- Employee training assignments both offsite and on-the-job training onsite;
- A list of personal protective equipment needed for each work task and operation onsite;
- The employers medical surveillance program for the site;
- The methods for identification and characterization of safety and health hazards on the site including the air monitoring procedures that will be performed throughout the work onsite;
- Site control measures including those for establishing work zones on the site;

- The necessary decontamination procedures which are matched to the kinds of anticipated contaminants to be cleaned from personnel and equipment;
- The general safe work practices to be adhered to by personnel onsite;
- The contingency plan for emergencies and confined space entry procedures;
- Site-specific training and site inspections and procedures to be followed in changing or modifying the plan; and
- All emergency numbers of local authorities (e.g., ambulance, police), as well as directions to the nearest hospital and a map to the hospital.

As a separate section, an emergency response plan must also be included. This plan is discussed in greater detail in a latter section of this subsection of the guidance document.

Adherence to proper procedures for handling drums and containers:

The handling of drums and containers at hazardous waste sites poses one of the greatest dangers to hazardous waste site employees. Hazards include detonation, fire, explosion, vapor generation, and physical injury resulting from moving heavy containers by hand and working in the proximity of stacked drums, heavy equipment and deteriorated drums. The employer must implement procedures and provide proper work practices in order to minimize the risks to site personnel.

The appropriate procedures for handling drums depend primarily upon the drum contents. Thus, prior to handling, drums should be visually inspected to gain as much information as possible about their contents. The inspection crew should look for symbols, words, or other marks on the drum indicating that its contents are hazardous, e.g., radioactive, explosive, corrosive, toxic and/or flammable. The crew should also look for signs of deterioration (such as rust, corrosion, and leaks), and whether the drum is under pressure.



Conditions in the immediate vicinity of the drums may also provide information about drum contents and their associated hazards. Monitoring should be conducted in the area around the drums using instruments such as a radiation survey meter, organic vapor monitors, and combustible gas indicators.

As a precautionary measure, personnel should assume that unlabeled drums contain hazardous materials until their contents are characterized. Also, they should bear in mind that drums are frequently mislabeled - particularly drums that are reused.

Employers must ensure that any personnel involved with handling drums are aware of all pertinent regulations. OSHA regulations (29 CFR Parts 1910 and 1926) include general requirements and standards for storing, containing, and handling chemicals and containers, and for maintaining equipment used for handling drums and containers. EPA regulations (40 CFR Part 265) stipulate requirements for types of containers, maintenance of containers, and design and maintenance of storage areas. DOT regulations (49 CFR Parts 171 through 178) also stipulate requirements for containers and procedures for shipment of hazardous wastes.

Development and implementation of a decontamination procedure:

Decontamination procedures must be developed on a site- and/or task-specific basis, and be implemented prior to performing any site entrance activities. These methods must be specifically matched to the hazardous substance(s) of concern at the site in order to be effective. Procedures for both personnel and equipment decontamination must be developed and implemented in order to minimize potential for:

- Employee exposure to substances of concern;
- Transferring contaminants offsite or to previously non-contaminated areas; and
- Exposing the environment and/or offsite receptors to hazard potential.

The standard requires that upon implementation of these procedures, the site safety and health officer must conduct monitoring for effectiveness on a continuous basis.

Decontamination procedures must be supplemented by incorporation of and adherence to standard operating procedures that are developed to minimize potential for personnel and equipment to come into contact with contaminated substances and surfaces. Additionally, the developed decontamination procedures must incorporate provisions for controlling, collecting, and disposing generated wastes in a proper manner. These materials will typically include items of personal protective equipment, decontamination (wash and rinse) fluids, as well as materials generated during site activities (e.g., drill cuttings, pumped monitoring well fluids, etc.).

#### Development and implementation of an Emergency Response Plan:

Prior to any onsite work, the employer must develop and implement an emergency response plan that is site-specific, and all involved employees must be made aware of the provisions of this plan. This is to be incorporated as a separate section of the site safety and health plan, and it must include provisions for: recognition of emergency situations; methods for alerting onsite personnel of emergency situations; site evacuation procedures; provisions for emergency medical treatment; lines of authority in emergency situations; emergency decontamination procedures; and methods for evaluating the effectiveness of the emergency response plan.

The regulations require that the role of individual employee's in emergency situations be reflected in the plan. Two categories of employee activities are also discussed. One is from the standpoint of onsite emergency response, while the other addresses offsite response activities. In addition, the greater the roles and responsibilities of the employee in a response situation, and the greater the risk potential that may be presented, the more detailed and comprehensive the emergency response plan will need to be. It is also common that both on- and offsite response efforts may be necessary, depending on the nature and extent of the specific situation. Therefore, the emergency response plan needs to address both onsite and offsite activities.

The emergency response plan must include provisions for the following elements, at a minimum:

- Pre-emergency planning;
- Personnel roles, lines of authority, training, and communication;
- Emergency recognition and prevention;
- Safe distances and places of refuge;
- Site security and control;
- Evacuation routes and procedures;
- Decontamination;
- Emergency medical treatment and first aid;
- Emergency alerting and response procedures;
- Critique of response and follow-up;
- Personal protective equipment and emergency equipment;
- Establishment of an Incident Command System;
- Procedures for incident reporting to appropriate local, state, and/or Federal agencies;
- Regular rehearsal and employee training of the elements of the plan; and
- Periodic plan review, with necessary modifications, for plan effectiveness.

Compliance with the requirements for both illumination, and sanitation at temporary workplaces:

Minimum requirements for illumination and sanitation (potable and non-potable water supplies and toilet facilities) are specified in the regulation, incorporating the requirements of Subpart C of the Construction Industry standards (29 CFR Part 1926).

Illumination requirements are specified by site areas or operations. Generally, lower levels of illumination are necessary in areas where employee presence is incidental or nonfrequent, and where activities involve low risk potential. Greater amounts of illumination are required in general site areas, indoor site facilities, and in personnel facilities. The highest illumination intensity requirements are specified for areas including first aid stations, infirmaries, and offices.

Sanitation requirements address procedures for providing, identifying, and dispensing potable water and nonpotable water. Additionally, if appropriate, provisions must be made for toilet facilities, food handling, sleeping quarters, and washing facilities.

Compliance with the requirements specified under paragraph (o) of the standard for certain operations conducted under RCRA, including developing and implementing a hazard communication program (meeting the requirements of OSHA 29 CFR 1910.1200):

The OSHA regulation contains less extensive requirements for normal (e.g., non-corrective action type) RCRA operations (vs CERCLA operations) in recognition that, by comparison, hazards should be "better controlled and more routine and stable" (51 FR 45661, December 9, 1986). Employers conducting operations on RCRA facilities must develop and implement the following programs and procedures:

- Hazard Communication Program in conformance with the requirements of OSHA 29 CFR 1910.120;

- A medical surveillance program;
- A health and safety program;
- Decontamination procedures; and
- An employee training program.

Following is a list of other regulations that should be considered when developing health and safety programs and procedures:

<u>Citation</u>	<u>Title</u>
29 CFR 1910.134	Respiratory Protection
29 CFR 1910.95	Hearing Conservation
29 CFR 1903	Inspections, Citations, and Proposed Penalties
29 CFR 1904	Recording and Reporting of Occupational Injuries and Illnesses
29 CFR 1926	Safety and Health Regulations for Construction
29 CFR 1960	Federal Employee Safety and Health Programs
29 CFR 1975	Coverage of Employers Under the Occupational Safety and Health Act
29 CFR 1977	Regulations on Discrimination Against Employees Exercising Rights Under the Occupational Safety and Health Act

Other Federal and State regulations may also address the health and safety of the investigative team and the public. Department of Transportation (DOT) regulations (49 CFR 171-178), for example, specify containers, labeling, and transportation restrictions for hazardous materials. These regulations cover the transport of compressed-air cylinders, certain instruments, solvents, and samples. RCRA regulations (40 CFR 260-265) may apply to the storage, treatment, and disposal of investigation-derived materials, including disposable clothing, used respirator cartridges and canisters, and spent decontamination solutions.

Individual states may have occupational safety and health regulations more stringent than OSHA's. These should be consulted to determine their applicability and to ensure compliance. In addition, several guidance manuals exist that may be helpful in establishing health and safety procedures. These are listed below:

- Ford, P. J. and Turina, P. T. 1985. Characterization of Hazardous Waste Sites--A Methods Manual: Volume I--Site Investigations. EPA- 600/4-84/075. NTIS PB 85-215960. Washington, D.C. 20460.
- U.S. EPA. 1984. Standard Operating Safety Guides. Office of Emergency and Remedial Response. Washington, D.C. 20460.
- U.S. EPA. 1985. Basic Field Activities Safety Training. Office of Emergency and Remedial Response. Washington, D.C. 20460.
- NIOSH/OSHA/USCG/EPA. 1985. Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities. NIOSH 85-115. GPO No. 017-003-00419-6.
- Levine, S.P. and W.F. Martin. 1985. Protecting Personnel at Hazardous Waste Sites. Butterworth Publishers.
- U.S. EPA. 1985. Guidance on Remedial Investigations Under CERCLA. Office of Emergency and Remedial Response. NTIS PB 85-238616. Washington, D.C. 20460.
- U.S. EPA. 1986. Occupational Health and Safety Manual. EPA 1440.
- U.S. EPA. Order 1440.2 - Health and Safety Requirements for Employees Engaged in Field Activities.
- U.S. EPA. Order 1440.3 - Respiratory Protection.

Professional recommendations and standards have also been offered by organizations such as the American Conference of Governmental Industrial

Hygienists, the ASTM, the American National Standards Institute, and the National Fire Protection Association.

### **6.3 Elements of a Health and Safety Plan**

RFI health and safety plans should address the following:

- Names of key personnel and alternates responsible for site safety and health, and the appointment of a site safety officer;
- A safety and health risk analysis for each site task and operation;
- Employee training assignments;
- Personal protective equipment (PPE) to be used by employees for each of the site tasks and operations being conducted;
- Medical surveillance requirements;
- Frequency and types of air monitoring, personnel monitoring, and environmental sampling techniques and instrumentation to be used - also, methods of maintenance and calibration of monitoring and sampling equipment to be used;
- Site control measures;
- Decontamination procedures;
- Site standard operating procedures;
- Confined space entry procedures; and
- A Contingency Plan addressing site emergency action procedures.

## 6.4 Use of Work Zones

Although this section of the RFI Guidance is intended to be only an introduction to the health and safety aspects of hazardous waste site investigations, the establishment of zones of operation or work zones deserves some attention. It should be recognized, however, that the health and safety aspects described below may not apply to all sites.

Hazardous waste sites should be controlled to reduce the possibility of (1) exposure to any contaminants present, and (2) transport of contaminants offsite by personnel and equipment. One recommended method to prevent or reduce the possibility of the transfer of contaminants offsite, and to maintain control at the site, is to establish work zones, or areas on the site where prescribed operations occur. It is also important to control access points (i.e., entrances or exists) for each designated work zone. The use of a three zone system might include:

- Zone 1: Exclusion Zone
- Zone 2: Contamination Reduction Zone
- Zone 3: Support Zone

Zone 1, the Exclusion Zone, would include all areas onsite where contamination is known or suspected to be present. The boundaries can be established based on results of previous investigations, visual observations, facility records, or similar information. Appropriate levels of personal protective equipment (PPE) in this zone are based on the types and concentrations of contaminants known or suspected to be present, and other hazards that may be present. In addition, only specifically authorized personnel should be allowed into this zone. Once the boundaries of Zone 1 have been determined, they should be physically secured and defined by barriers such as fences or barricades.

Zone 2, the Contamination Reduction Zone, would be set up to provide a buffer to separate contaminated areas from non-contaminated areas, and may actually surround Zone 1. Decontamination stations would generally be set up between Zone 1 and Zone 2, or within Zone 2. These stations would serve as areas



for decontamination of both personnel and equipment. Some level of PPE may also be required in this zone, as some level of contamination or other hazard may be present. Access into Zone 2 from the Support Zone (Zone 3), is also controlled; only authorized personnel should be allowed access. Any worker entering Zone 2 should also be wearing the appropriate PPE.

The Support Zone, Zone 3, would be located in a clean or uncontaminated area, and would be directly outside of Zone 2. The support zone may have several functions, including use as a command post and first aid station, and would serve to house equipment sheds or trailers, mobile laboratory facilities, training and briefing areas, etc.

## **SECTION 7**

### **WASTE AND UNIT CHARACTERIZATION**

#### **7.1 Objectives and Purposes of Waste and Unit Characterization**

Because the waste managed or contained in a unit provides the source for a contaminant release, detailed knowledge of the source characteristics is valuable in identifying monitoring constituents and indicator parameters, possible release pathways, a conceptual model of the release, monitoring procedures, and also in linking releases to particular units. Waste and unit characteristics will also provide information for determining release rates and other release characteristics (e.g., continuous as opposed to intermittent). Waste and unit information is also important for determining the nature and scope of any corrective measures which may be applied.

Without adequate waste characterization, it is difficult to ensure that all constituents of concern will be monitored during the release investigation, unless all possible constituents are monitored. The extent of adequate waste characterization, however, will vary depending upon the nature of the facility and types of units studied. For example, waste characterization for a unit dedicated to a single steady-state process will be much less extensive than for a unit at an offsite facility that manages a variety of wastes that vary over time.

As indicated above, waste characterization may also be helpful in identifying constituents to discriminate among releases from different units. In some situations (e.g., more than one unit in a waste management area), it may be important to identify which unit is responsible for the release of concern. Accurate identification of the unit from which the release is occurring may hinge on the ability to link the released contaminants to the waste managed in a particular unit (or, in some cases, to "decouple" the contamination from a particular unit).

Sufficient characterization of the waste for the purpose of the RFI may not be possible due to the diversity of wastes managed in the unit over time or the relative

inaccessibility of the waste in the unit. Waste characterization may be of limited utility where:

- The waste managed in the unit varies over time such that adequate determination of the waste constituents cannot be made. An example of this is an offsite commercial facility receiving different wastes from different generators.
- The unit of concern is no longer active and the waste cannot be sampled through a reasonable effort. This situation may occur at closed landfills where sampling of buried drums may not be practical due to their inaccessibility.

In certain situations, waste characterization may also not be advisable. For example, the waste in question may be extremely toxic (e.g., nerve gas), or highly reactive or explosive (e.g., disposed munitions). In such cases, release characterization may be based on constituents (or parameters) identified in the affected medium (e.g., leachate) at the point where the medium becomes (or is suspected of becoming) contaminated. If it becomes necessary to conduct waste characterizations in these situations, or to remove the waste in question, a high level of health and safety protection (See Section 6) should be instituted.

Waste characterization should also be designed to provide sufficient information to support the implementation of interim measures and/or corrective measures. For example, if buried drums are identified during the RFI, the nature of the waste within these drums (e.g., ignitability, corrosivity, reactivity, constituent concentrations), if accessible, should be ascertained to determine if they should be removed from the site and how they should be subsequently managed as well as to support the investigation of media-specific releases under the RFI.

Design and operational characteristics of the unit are factors that will affect the rate of release and location within the unit from which the contamination is being or has been released. Such factors as unit size, type, operational schedule, and treatment, storage, or disposal practices should be helpful.

Although 40 CFR Section 264.13 of the RCRA regulations (General Waste Analysis) contains waste analysis requirements, the information required may not always be sufficient for purposes of the RFI. Waste characterization to determine specific hazardous constituents, for instance, is not always required. In addition, little or no data on inactive units may be available. The RFI Work Plan should be consistent, as appropriate, with the items identified in the requirements of 40 CFR Section 264.13. Further guidance is given below.

## **7.2 Waste Characterization**

In cases where a waste characterization is to be performed, the following approach is recommended:

- Identify data needs through review of existing information;
- Sample the waste; and
- Characterize the physical and chemical properties of the waste and waste constituents.

If the unit has a leachate collection system, the leachate should also be sampled and analyzed, as it may also provide useful information, particularly with respect to the leachable portions of wastes contained in the unit.

### **7.2.1 Identification of Relevant Information**

In general, a waste characterization should produce the following types of information:

- Identification of specific hazardous constituents and parameters which can be used in release verification or characterization (See Section 3.6);
- Physical and/or chemical characteristics of the waste useful for identifying possible migration pathways through the environmental media of concern; and

- **Physical and/or chemical characteristics of the waste, which may be necessary to evaluate treatment and/or management options.**

**Identifying specific constituents of the waste through a sampling and analysis program may require an extensive level of effort. The owner or operator is advised to use various informational sources on the specific waste in question in order to focus the analytical effort required. Such sources are described below.**

#### **7.2.1.1 EPA Waste Listing Background Document Information**

**The RCRA Hazardous Waste Listing Background Documents developed for the identification and listing of hazardous wastes under 40 CFR Part 261 contain information on waste-specific constituents and their physical and chemical characteristics. These documents contain information on the generation, composition, and management of listed waste streams from generic and industry-specific sources. In addition to identifying hazardous constituents in the wastes, the documents may also provide data on potential decomposition products. In some background documents, migratory potential is discussed and exposure pathways identified.**

**Appendix B of the Listing Documents provides detailed information on the fate and transport of hazardous constituents. Major physical and chemical properties of selected constituents are listed, including molecular weights, vapor pressures and solubilities, octanol-water partition coefficients, hydrolysis rates, biodegradation rates, volatilization rates, and air chemistry (e.g., reaction) rates. Another section of this appendix estimates the migratory potential and environmental persistence of selected constituents based on a conceptual model of disposal in an unconfined landfill or lagoon.**

**The appropriate uses and limitations of the Listing Documents are outlined in Table 7-1. In addition, Case Study No. 1 in Volume IV (Case Study Examples) illustrates the use of the Listing Documents.**

**A list of the available listing background documents may be obtained by reviewing 40 CFR Parts 261.31 and 261.32. These background documents are available in EPA's RCRA docket at the following location:**

**Table 7-1**  
**Uses and Limitations of EPA Listing Background Documents**

Uses	Limitations
<ul style="list-style-type: none"> <li>● Identifies the hazardous constituents for which a waste was listed.</li> <li>● In some cases, provides information on additional hazardous constituents that may be present in a listed waste.</li> <li>● In some cases, identifies decomposition products of hazardous constituents.</li> <li>● Provides overview of industry; gives perspective on range of waste generated (both quantity and general characteristics).</li> <li>● May provide waste-specific characteristic data such as density, pH, and leachability.</li> <li>● May provide useful information on the migratory potential, mobility, and environmental persistence of certain hazardous constituents.</li> <li>● May list physical and chemical properties of selected constituents.</li> </ul>	<ul style="list-style-type: none"> <li>● Applicable only for listed hazardous wastes.</li> <li>● Industry coverage may be limited in scope. For example, the Wood Preserving Industry Listing Document only covers organic preservatives. Inorganics such as inorganic arsenic salts, account for approximately 15 percent of the wood preserving industry.</li> <li>● Data may not be comprehensive. For example, not all potentially hazardous constituents may be identified. Generally, only the most toxic constituents common to the industry as a whole are identified.</li> <li>● Data may not be specific. Constituents and waste characteristics data often represent an industry average which encompasses many different types of production processes and waste treatment operations.</li> <li>● Some Listing Documents were developed from limited data/reports available to EPA at the time of promulgation, resulting in varying levels of detail for different documents.</li> <li>● Listing Documents for certain industries (e.g., the Pesticides Industry) may be subject to CBI (confidential business information) censorship. In such cases, constituent information may be expurgated from the document.</li> </ul>

EPA RCRA Docket  
U.S. Environmental Protection Agency (WH-562)  
Room S-212  
401 M St., S.W.  
Washington, D.C. 20460

#### **7.2.1.2 Facility Information**

Identification of the constituents of a waste stream may be made through examination of records already existing in the facility. Engineering data on process raw materials or analytical data on the process effluents will also provide a good starting point for waste characterization. In some cases, generally where waste characteristics are well-defined, data on process raw materials or effluents will provide sufficient information for performing the RFI. More specifically, these sources may be:

- Hazardous waste characterization data used for a RCRA Permit Application;
- Waste Analysis Plan (as required by 40 CFR Part 264.13);
- State or local permit applications;
- Initial batch treatment results from an offsite hazardous waste disposal facility;
- Hazardous waste compatibility results for bulk shipments;
- Purchase orders and packing lists;
- Analyses conducted to provide data for shipping manifests;
- Facility records of past waste analyses;
- Process operational data;
- Product quality control analyses;

- Data from past releases of hazardous waste into the environment;
- Compatibility results for containment liner studies;
- Past Federal, State, or local compliance and inspection results;
- OSHA industrial hygiene monitoring results;
- Facility health and safety monitoring data;
- Engineering design data from construction of plant processes;
- Performance specifications for process equipment;
- Related emissions data such as NPDES discharge results; and
- Information from past or present employees.

#### 7.2.1.3 Information on Physical/Chemical Characteristics

Information on physical or chemical characteristics of the waste or waste constituents that may be useful in predicting movement of the contamination through the media of concern or in evaluating waste treatment or management options may be found in the following references:

Callahan, et al. 1979. Water-Related Environmental Fate of 129 Priority Pollutants, Volumes I and II. Office of Water Planning and Standards. NTIS PB 297606. Washington, D.C. 20460.

Dawson, et al. 1980. Physical/Chemical Properties of Hazardous Waste Constituents. Prepared by Southeast Environmental Research Laboratory for U.S. EPA. EPA RCRA Docket. Washington, D.C. 20460.

U.S. EPA. 1985. Health Effects Assessment for [Specific Chemical]. [Note: 58 individual documents available for specific chemicals or chemical groups].



Environmental Criteria and Assessment Office. Cincinnati, Ohio 45268. [See Section 8.4 for a list of these documents]

Jaber, et al. 1984. Data Acquisition for Environmental Transport and Fate Screening. Office of Health and Environmental Assessment, U.S. EPA. EPA 600/6-84-009. NTIS PB 84-140102. Washington, D.C. 20460.

Lyman, et al. 1982. Handbook of Chemical Property Estimation Methods. McGraw-Hill, New York.

Mabey, et al. 1982. Aquatic Fate Process Data for Organic Priority Pollutants. Prepared by SRI International, EPA Contract Nos. 68-01-3867 and 68-03-2981. Prepared for Office of Water Regulations and Standards. Washington, D.C. 20460.

U.S. EPA. 1980. Treatability Manual, Volume I. EPA 600/2-82-001a. Office of Research and Development. NTIS PB 80-223050. Washington, D.C. 20460.

U.S. EPA. 1984. Characterization of Constituents from Selected Waste Streams Listed in 40 CFR Section 261. Office of Solid Waste. Washington, D.C. 20460.

U.S. EPA. 1984. Exposure Profiles for RCRA Risk-Cost Analysis Model. Office of Solid Waste. Washington, D.C. 20460.

U.S. EPA. 1986. Ambient Water Quality Criteria. Office of Water Regulations and Standards. Washington, D.C. 20460.

Perry and Chilton. 1973. Chemical Engineers' Handbook. McGraw-Hill. 5th Ed. New York.

Verschueren. 1983. Handbook of Environmental Data for Organic Chemicals. Van Nostrand Reinhold Co. New York. 2nd ed.

Weast et al. 1979. CRC Handbook of Chemistry and Physics. CRC Press.

Windholtz, et al. 1983. The Merck Index. Merck & Co. Rahway, NJ.

U.S. EPA. 1986. Test Methods for Evaluating Solid Wastes. 3rd Edition. Office of Solid Waste. EPA/SW-846. GPO No. 955-001-00000-1. Washington, D.C. 20460.

U.S. EPA. 1984. Characterization of Hazardous Waste Sites--A Methods Manual. Volume III. Available Analytical methods. EPA 600/4-84-038. NTIS PB 84-191048. Washington, D.C. 20460.

Some commercially available computer information systems that contain chemical properties data and/or estimation methods may also be used. An example would be the Chemical Information System (CIS) (7215 York Road, Baltimore, MD 21212). Another example is the Graphical Exposure Modeling System (GEMS) data base discussed in Section 3.5. The owner or operator should consult with the regulatory agency prior to use of such systems.

#### 7.2.1.4 Verification of Existing Information

If existing information is current and sufficient to completely identify the type, amount, and location of waste, then available information may be considered adequate. If existing information is used, constituents present should be verified by recent waste analysis or by dated analysis that is substantiated by recent facility records showing that no changes in process, manufacturing, or other practices that could alter waste composition have occurred. If existing information does not provide adequate waste characterization, or if the waste characteristics have changed, sampling may be required.

#### 7.2.2 Waste Sampling

All sampling should be conducted in a manner that maintains sample integrity and encompasses adequate QA/QC. The characterization of waste in any unit must be representative. As wastes are often generated in bulk quantities from a large variety of processes, adequate determination of the waste profile requires that cyclical or random variations in waste composition be considered. The characterization should account for variation in waste content by collecting samples

that are representative of all potential waste variations. If a wide variation in waste composition is expected, it is preferable to document the range of this variation through the analysis of numerous samples. If little variation is anticipated, a lesser amount of sampling may be appropriate. If composite sampling is proposed, it must not mask unexpected or unanticipated compositional variations, and should always be complemented with an appropriate number of grab (non-composited) samples. Generally, compositing should not be used when evaluating variation in waste composition. Collection of representative samples will involve different procedures for different waste and unit types. This is discussed further in Section 7.4. Case Studies No. 3, 4, and 17 in Volume IV (Case Study Examples) provide illustrations of waste sampling uses, considerations, and techniques.

### **7.2.3 Physical/Chemical Waste Characterization**

Compound-specific waste characterization should consider the constituents listed in 40 CFR Part 261, Appendix VIII, as the universe of overall constituents. Except for especially complex waste, many of the compounds on this list may be eliminated using the guidance presented previously in this section and in Section 3.6. As indicated in Section 3.6

- The owner or operator should provide a sound justification or analytical results of waste analyses as substantiation for the elimination of constituents from further consideration;
- The analysis of waste samples to determine their characteristics should be performed using standard methods, such as those described in the 3rd edition of EPA/SW-846 (Test Methods for Evaluating Solid Waste), or equivalent methods; and
- A detailed QA/QC Plan should clearly define the sample preparation techniques, analytical methodology, required analytical sensitivities and detection limits, and collection of blanks and duplicates.

In addition, for units that contain a mixture of solid, sludge, and/or liquid waste material, each phase should be analyzed and volume proportions measured.

### **7.3 Unit Characterization**

Information on unit characteristics may affect release properties and pathways. The owner or operator should obtain relevant information on the unit for use in developing the RFI strategy. Such information may include

- Unit dimensions (including depth below grade);
- Unit type;
- Unit purpose (e.g., biodegradation);
- Structural description, including materials and methods of construction, and any available drawings;
- Amounts of waste managed;
- Previous uses of area occupied by unit;
- Unit location;
- Description of liner or cap materials;
- Holding/retention time;
- Key operating parameters, such as waste management schedule;
- Waste treatment/application or loading rate;
- Biological activity present;
- Vent numbers and sizes; and
- Drainage areas.

## **7.4 Applicable Waste Sampling Methods**

### **7.4.1 Sampling Approach**

References for waste sampling methods discussed in this section are listed in Section 3.6.3. A summary of available waste sampling methods for various waste matrices is provided in Table 7-2.

Collection of waste samples requires methodology suited to the type of waste and unit sampled. In addition, waste sampling requires specialized equipment and protocols that may be designed especially for waste analysis or adapted from other sampling methods. Several important points to consider when developing a sampling approach are as follows:

- Compatibility of sampling methods and materials with the constituents being sampled.
- Ensuring the safety of personnel. Careful attention should be given to the level of protection and safe practices required for sampling activities. If the sampler is wearing protective gear that limits vision and mobility, or is fatiguing to wear, the collection procedures should be as simple as possible.
- Waste samples are generally not preserved and are considered hazardous for shipping purposes.

### **7.4.2 Sampling Solids**

Sampling of solid materials should utilize readily available techniques. In general, the primary concern for the sampling of solid materials is effectively representing a large amount of possibly heterogeneous material in small samples. In order to address this concern, discrete samples should be collected from sufficient locations to characterize the waste with respect to location and time. Sampling methods vary depending on whether samples are to be collected at the surface, or

TABLE 7-2. SAMPLING METHODS SUMMARY FOR WASTE CHARACTERIZATION

Waste Type/Unit Type	1 Scoops and Shovel	2 Triers	3 Thiefs	4 Augers	5 Core Samplers	6 Glass Tubes	7 Petite Ponar Grab	8 Dippers	9 Coliwasa	10 Pump and Tubing	11 Kemmerer Bottle	12 Bacon Bomb
<b>Solid Wastes</b>												
Waste Piles	X	X	X	X								
Land Treatment Units	X				X*							
Landfills				X	X							
Drum Handling	X		X									
Sacks and Bags	X	X	X									
Trucks	X	X	X		X							
Conveyor Belts	X											
Unloading/Loading/ Transfer Areas	X				X							
<b>Sludge Wastes</b>												
Waste Piles	X	X			X		X					
Drum Handling	X				X	X			X			
Tanks	X							X	X			
Surface Impoundments	X						X	X	X			
Trucks	X	X			X		X	X				
Conveyor Belts	X	X										
Unloading/Loading/ Transfer Areas					X	X		X				
<b>Liquid Wastes</b>												
Drum Handling						X		X	X	X		
Tanks									X	X	X	X
Surface Impoundments								X	X	X	X	X
Trucks								X		X	X	X
Unloading/Loading/ Transfer Areas								X		X		X

\* Core Sampler modified to serve as air-tight container for retention of volatile fraction.

below the surface. For a unit currently in operation, variation in waste stream composition over time should be considered in determining when samples should be taken.

For large amounts of solid materials, sample locations may be determined by applying a three-dimensional grid in combination with random sampling techniques as discussed in Section 3. In certain circumstances, compositing samples may be acceptable to minimize the number of sample analyses, as long as waste composition remains fairly constant over the sampling period. When composition waste is expected to vary (e.g., in complex wastes), grab samples should be taken. Compositing should be employed only when the representativeness of the waste characterization is uncompromised, and should always be accompanied by confirmational grab samples.

Bulk solid materials are generally homogeneous. They are likely to be found in waste piles, drums, bags, trucks or hoppers, or on conveyor belts. Bulk solid materials can be sampled using various methods. Surface soil or soil-like materials found at land treatment units, in landfills, and at waste transfer (e.g., loading and unloading) areas can also be sampled using the same basic methods. Deeper soil sampling will require other methods as described in Section 9 on soil.

Five basic solid sampling methods are discussed below:

- Scoops and shovels are useful for sampling dry or moist granular, powdered, or otherwise unconsolidated solids from piles as well as from other containers of solid material (e.g., bags, drums, hoppers, trucks, or shallow containers). Waste material transported to the unit by conveyor belt can be sampled using a scoop to collect samples from the belt. Scoops are applicable to solid waste materials that are within easy reach of sampling personnel. Scoops made of stainless steel or Teflon are preferable due to the inertness of these materials to most waste types. This sampling method is limited in utility to collection of samples near or on the surface of the waste. For collection of samples at greater depth, other methods are necessary. Shovels are used in the same manner as scoops when larger quantities of sample are needed or when an extended reach is required. Shovels are available in inert materials like

Teflon or stainless steel. Scoops and shovels will enable collection of land treatment unit samples from depths up to about 16 inches. Because most land treatment units manage organic waste streams, extreme care must be taken to retain the volatile organic components of the sample through rapid handling of the exposed sample during the collection process. Containers that have septum caps or air-tight lids should be used in conjunction with the scoop and shovel sampling method. Collection of soil samples from depths lower than the normal depths of tilling are described in Section 9. Contaminated surface soils at waste transfer areas are also easily sampled using scoops and shovels.

- Triers are used to withdraw a core of sample material. The trier is similar to a scoop in that it is inserted by hand into the material to be sampled; however, the design allows for the collection of a core of material. Triers are most useful for sampling waste piles, bags, hoppers, or other sources of loose solid waste material. Cores are most readily obtained with triers when the material being sampled is moist or sticky so that the core, which is cut by rotating the trier, stays together while the sample is removed from the waste material source. These samplers are useful only when they can be inserted horizontally into the material being sampled. Triers are readily available in lengths from 61 to 100 cm and are usually made of stainless steel with wooden handles.
- Thiefs are essentially long hollow tubes with evenly spaced openings along their lengths. An inner tube with similar openings is oriented so that the openings are not aligned and the entire dual-tube thief is inserted into the solid waste material. After insertion, the inner tube is rotated to align the openings, thus allowing the solid material to flow into the inner tube. The inner tube is then rotated back to the closed position, sealing the openings prior to withdrawal of the sampler. Thiefs can be inserted horizontally, vertically, or at various angles into the sample as long as the material will flow (by gravity) into the slots of the sampling tubes. This method is best suited for sampling of dry free-running solids. Thiefs are available in a range of sizes to allow for collection of materials of varying particle size, but are not generally useful for particles in excess of 0.6 cm. Thiefs, like triers, are available in a



variety of materials, usually brass or stainless steel, and are appropriate for sampling waste piles, drums, or hoppers.

- Augers can be used to sample solid material at varying depths. The use of augers is generally exclusive to the collection of soil samples at depth such as at landfills. However, for large waste piles which cannot be sampled in any other manner, it may be necessary to obtain samples from the inside portions of the pile in order to assess the overall characteristics of the material in the pile. Generally, augers are used in conjunction with a thin-wall tube sampler that is inserted into the borehole to collect an undisturbed sample from the depth at which the auger was stopped. The nature of the solid material and the physical size and accessibility of the unit will determine the applicability of augering and the most suitable type of auger. Augers are designed for general types of soil conditions and "disturb" samples to varying degrees. If possible, sampling of waste material should be conducted prior to or during waste placement because sampling by augers and thin-wall tubes can be difficult and time consuming. Backhoes may be required to gain access to the interior portions of the unit (e.g., a waste pile).
- Core samplers such as previously described in conjunction with augers are frequently used for soil sampling. Section 9 addresses soil sampling in greater detail. Core samplers can also be used to collect cores of land treatment unit samples and provide excellent samples for spanning the depth of treated soil. Thin-wall tube core samplers can be used to collect vertical cores at most desired locations. Sampling of top soil layers that contain the applied waste material can usually be accomplished using conventional hand coring techniques. As with the scoop and shovel method, extra consideration should be given to preventing losses of volatile organic components from the sample; the use of air-tight sample containers is recommended. Another technique is to utilize a core sampler which can itself be used as an air-tight sampling container. Recent designs include a coring device with Teflon-gasketed end caps that can be used to both collect and contain land treatment samples for soil and soil-gas analyses.

### 7.4.3 Sampling Sludges

Sludges are "semi-dry" materials ranging from dewatered solids to high-viscosity liquids. Due to their liquid content, sludge materials are not usually stored or handled as solids, and often require containment in drums, tanks, or impoundments, to prevent runoff of the liquid portion of the sludge. Sludges also include sediments with high liquid content under a liquid layer. Sampling must frequently include extended-reach equipment to gain access to the submerged sludge layer. For those cases where sludges are piled and have a sufficiently high solids content, methods previously discussed under "Solids" may be adequate. The equipment used in some of the solid material sampling methods is available with modifications to contain samples with a high liquid content.

Sediments can accumulate at the bottom of drums due to settling of suspended solids in liquid and sludge wastes. These sediments can be readily sampled using the previously discussed methodology. Glass-tube samplers, particularly those of larger bore, can be pressed into bottom sediments of drums to obtain samples. For bottom sediments or sludges that are too thick or resistive for glass tubes, corers with or without core catchers can be inserted into the drum for collection of sediments.

Basic methods for sampling sludges are discussed below:

- Scoops and shovels are useful for collecting sludge samples from the surface of a sludge pile, or at shallow depths in drums, tanks, or surface impoundments. Shovels will allow for the collection of larger volume samples. Extra care may be required to collect "representative" samples if the liquid fraction of the sludge tends to separate from the sample while being collected. The liquid fraction should be considered part of the sludge material and must be retained for adequate characterization. Long-sleeve gloves may be required for personnel protection.
- Triers may be useful for collection of cores of material from sludge piles. The nature of the waste will determine the utility of this method. Triers are not generally used for sludges; however, on a trial-and-error basis, their applicability may be determined.

- Core samplers modified to retain sludge material can be used to collect sludge from waste piles where samples are required from various depths. Core catchers, such as thin-wall tube samplers that prevent washout of the wet sludge during recovery of the sampler from the sludge source, are available for attachment to the tip of coring devices. Because sludges are most often formed through deposition of solids from a liquid mixture, the composition of the sludge may vary significantly with time and location. The use of a core sampler equipped with a core catcher can provide for collection of a sample profile. These types of corers are available with extension sections that allow for collection of samples from depths well below the surface of the waste. Corers are generally equipped with a cutting edge on the tip that greatly facilitates penetration of a thick bottom layer and can also be outfitted with core catchers to assist in retaining looser sediment materials that might be more readily lost from the bottom of a glass tube. The amount of sludge present can be easily estimated by measuring the depth to the apparent bottom and comparing it to the known interior depth.
- Glass tubes or a Composite Liquid Waste Sampler (COLIWASA) can be used to collect bottom sediments from drums or shallow tanks when they are gradually inserted into the solid layer at the bottom. Due to the fragility of glass and the danger of cuts, this technique is applicable only for materials easily penetrated by the tube. High-liquid-content bottom sediments may exhibit washout characteristics similar to liquid samples. In many cases, the only way to determine if sample losses from the bottom of the tube will occur is to carefully test it to see what happens.
- Petite Ponar Grab Samplers are clamshell-type scoops activated by a counter-lever system. The shell is opened and latched in place, then lowered to the bottom. When tension on the sample line is released, the shell halves are unlatched. The lifting action of the cable on the lever system closes the clamshell. These dredges are capable of collecting most types of sludges or sediments from silts to granular materials up to a few centimeters in diameter. As agitation of the liquid above the sludge occurs during sampling, it is advisable to collect sediment samples

after all liquid sampling is complete. This method is particularly useful for tanks and surface impoundments.

#### **7.4.4 Sampling Liquids**

Liquid wastes require distinctly different sampling methods than do solids and sludges, with the exception of some techniques for sampling submerged sediments, and should also account for parameters of interest (e.g., for volatile contaminants, it is important to prevent volatilization). Common liquid waste sources are drum handling units, tanks, and surface impoundments. A general safety concern associated with drums and tanks is the structural integrity. Safe-access procedures for sampling these units should be established prior to sample acquisition.

Liquid wastes handled in drums can be sampled before being loaded into the drum or, if necessary, after placement. For facilities that receive wastes in drums, sampling should be conducted prior to the removal of the waste material from the drum. For waste streams that can be sampled directly prior to drum loading, grab sampling techniques are appropriate. As always, sufficient samples should be collected to account for waste variation over time. Sampling of drums can be done using several different methods, including grab sampling with a dipper from the open drum, routine full-depth drum sampling using a disposable glass tube or COLIWASA, or with a sampling pump with tubing that is lowered into the drum for sampling.

Tanks are containment structures larger than drums that can hold more than a million gallons. Tanks include tanker trucks, above-ground tanks, and partially or fully underground tanks. Tanks usually have limited access due to small hatchway openings, or ladders or walkways that often extend across open-top tanks. Due to the greater depth of tanks versus drums, methods with extended-reach capabilities are necessary. Waste materials in tanks generally include liquids and bottom sludges. When retention time of liquid wastes in tanks is long, layering or stratification including settling out of sediments is likely to occur. Great care should be taken to minimize the disturbance of liquid layers while collecting samples. The surface should be broken gently and samplers lowered gradually. Liquid sampling utilizes either pump and tubing methods or discrete depth samplers, such as

Kemmerer Bottles or Bacon Bomb samplers. Bottom sediments that cannot be drawn up with a pump will require the use of small dredges, such as the Petite Ponar Grab sampler.

Surface impoundments can range from several hundred to several million gallons in capacity. Due to their large size, they are usually open to the atmosphere rather than covered. Sampling of an impoundment may be difficult, except near its edges or from walkways that extend over the impoundment. "Off-shore" sampling, when necessary, should be considered a serious, potentially dangerous operation and should be performed according to strict health and safety procedures. Common means of sampling off-shore locations are boats, floating platforms, cranes with suspended enclosed platforms, and mobile boom vehicles with platforms.

Whenever possible, the waste should be characterized prior to its transfer into the impoundment. For example, waste pipelines can be sampled from valves, and tanker trucks discharging waste into impoundments can be sampled prior to discharging. However, taking samples from the units is desirable, because changes in the concentrations reported for samples taken during transfer may have large impacts on the estimates of the amounts of hazardous waste or constituents in the impoundment.

Liquid sampling techniques for impoundments include Dippers (particularly in the pond sampler configuration with a telescoping handle), pump and tubing, Kemmerer Bottles, and Bacon Bomb samplers. The dipper or pond sampler method is the easiest to use; however, it is not capable of reaching off-shore locations or of collecting samples at varying depths below the surface.

Liquid sampling methods are described below:

- Dippers can be used to collect samples from the surface liquid layer of open drums, tanks, or impoundments. (Other techniques are required to collect samples from drums where the only access is through the bung hole in the lid). This method is appropriate only for wastes that are homogeneous and likely to be represented by a grab sample from the top layer. In most cases, a full-depth composite liquid sample is more

representative. The dipper technique involves the use of an intermediate vessel that is submerged in the waste liquid. The sample is then poured into the designated sample container. Handles are attached to the vessel to make sampling easier and reduce direct contact of the sampling technician with the waste material. In one configuration, the dipper is attached to a telescoping pole for an extended reach; this configuration is called a pond sampler. The dipper sampling device is also useful for sampling from piping system valves.

- Glass tube samplers can collect a full-depth liquid sample from a drum and can be used through the bung hole on the drum lid such that the lid need not be removed. Conventionally, the glass tubes are 122 cm long and 6 to 16 mm in inside diameter. Larger diameter tubes can be used if the liquid to be sampled is more viscous. The major limitation of this method is spillage (i.e., liquid loss from the bottom of the tube is unavoidable). Smaller diameter tubes have fewer problems with sample loss than do large-bore tubes. This method is perhaps the most common drum sampling technique due to its relative ease of use and the minimal equipment decontamination required.
- COLIWASA samplers are a more formalized version of the glass-tube samplers. The COLIWASA (composite liquid waste sampler) utilizes an inner rod attached to a stopper at the bottom of the sampling tube. The sampler is slowly inserted into the drum with the bottom stopper open. When the sampler reaches the bottom, the inner rod is pulled up, sealing the sampling tube for removal of the sample. A COLIWASA can be made of many materials; however, inert materials (e.g., Teflon or glass) are the materials of choice.
- Pump and tubing (e.g., bladder pumps) systems are readily available and are useful for withdrawing liquid samples from up to 28-foot depth. Peristaltic pumps are available in many sizes and flow rates to accommodate many sampling situations. Full-depth composite samples can be collected by gradually lowering the tubing into the material being sampled. One limitation of this system is that the pump applies a vacuum to the sample that can alter the chemical equilibrium in the sample,

resulting in the loss of volatile organic components. A modification to this basic system can be made by placing a sample vessel in-line between the tubing and the pump to prevent sample material from contacting the pump parts. In this configuration, collection of numerous samples is facilitated because pump tubing need not be cleaned or replaced between sampling events.

High flow rates are not advisable because rapid overflowing of sample bottles may occur. A lower flow rate will assist in minimizing the disturbance of liquid layers in the tank and will cause less agitation of the sample as it enters the sample bottle. The peristaltic pump and tubing system can be utilized in two configurations -- one with the tubing connected directly to the pump and a second with an intermediary sample vessel in-line between the pump and tubing. The second configuration also eliminates pump decontamination between samples. When sufficient waste characterization data are available, small submersible pumps can also be used; however, these pumps are not generally made of chemically resistant or relatively inert materials. The utility of these small submersibles depends on their ability to provide samples from greater depths. Peristaltic pumps have an upper limit of approximately 8 meters, whereas submersibles can be used for most depths of concern.

- Kemmerer Bottles are discrete-depth liquid samplers that are usually appropriate for tank or impoundment sampling. The Kemmerer Bottle is a spring-loaded device that is lowered into the liquid in the open position, allowing the liquid sample to flow through it while it is descending. At the desired depth, a messenger is dropped down the sample line, releasing the spring-loaded closing device to obtain the sample. Limitations of Kemmerer Bottles include the poor availability of devices constructed of relatively inert materials, the difficulty in decontamination between sampling, and the inability of this sampler to collect purely depth-discrete samples (because the sampler's surfaces are exposed to materials in the liquid layers as the sampler passes through them to arrive at the designated depth).

- Bacon Bomb samplers are lowered on a sample line. A second line attached to an opening rod, which runs down the center of the bomb, will open the sampler when pulled. The sample can be collected with a minimal amount of agitation since the rod can open the top and bottom of the bomb, allowing the sample to enter the bottom and air to exit through the top. Bacon Bomb samplers are readily available from laboratory supply houses and are frequently constructed of chrome-plated brass. Relatively inert construction materials, such as Teflon or stainless steel, are preferable. Careful maintenance and regular inspection of samplers is advised. Samplers with plating materials flaking off should be removed from use. If waste characteristics are known, sample changes caused by the sampler can be avoided by using materials compatible with the type of waste being sampled. An advantage of the Bacon Bomb sampler is its ability to be lowered to the desired depth in the closed position before collecting a sample. This technique minimizes cross-contamination from liquid layers above.



## **SECTION 8**

### **HEALTH AND ENVIRONMENTAL ASSESSMENT**

#### **8.1 Overview**

This section describes the Health and Environmental Assessment (HEA) that will be conducted by the regulatory agency as part of the RFI. The primary element of this assessment is a set of health and environmental criteria (chemical concentrations) to which measured and in some cases predicted (e.g., for the air medium) concentrations of hazardous constituents developed during the release characterization will be compared. When these criteria ("action levels") are exceeded or there is a reasonable likelihood of this occurring, a Corrective Measures Study (CMS) will generally be required, although the owner or operator may, because of site specific factors, present data and information to support a determination that no further action is necessary. This section describes the HEA process (Section 8.2), the determination of potential exposure routes for each environmental medium of concern (Section 8.3), and the development and use of the health and environmental criteria (Section 8.4), leading to an evaluation of the need for appropriate interim corrective measures and/or a CMS. The evaluation of chemical mixtures is discussed in Section 8.5. Special considerations involved in the evaluation of soil and sediment contamination are discussed in Section 8.6. Section 8.6 also provides a review of statistical procedures that may be used to evaluate ground-water monitoring data. Section 8.7 discusses qualitative and other factors which may be used by the regulatory agency in conducting the health and environmental assessment. Interim corrective measures are discussed in Section 8.8. References used in developing this section are listed in Section 8.9. Finally, Section 8.10 presents the health and environmental criteria and provides several worksheets which may be used to conduct the HEA.

The health and environmental criteria used in determining the need for a CMS are based primarily on EPA-established chronic-exposure limits. These values and their use are described herein. Subchronic exposure limits and qualitative criteria are also discussed. It should be emphasized that the health and environmental criteria provided in this section do not necessarily represent clean-up target levels that must be achieved through the implementation of corrective measures. Rather,

they establish presumptive levels that indicate that a closer examination is necessary. This closer analysis would generally take place as part of a CMS.

The guidance provided in this section presents a general framework for conducting a HEA. It is intended to provide a flexible approach for interpreting release characterization data, as case-specific factors may enter into consideration. For example, State-established criteria and consideration of past environmental problems (e.g., fish-kills) may also be considered.

The regulatory agency may require both interim corrective measures and a CMS as a result of the HEA. One difference between interim corrective measures and definitive corrective measures may be timing. The development and implementation of a comprehensive corrective action program can be a time-consuming process. Between the time of the identification of a contaminant release and the implementation and completion of definitive corrective measures, existing conditions or further contaminant migration could endanger human health and the environment. Under these conditions, interim corrective measures, which may be temporary or short-term measures (e.g., providing bottled water or removing leaking drums) designed to prevent or minimize adverse exposure, can be applied. Case Study No. 11 in Volume IV (Case Study Examples) provides an illustration of the HEA process.

The HEA procedures described in this section apply to releases from all units except releases to ground water from "regulated units" as defined under 40 CFR Part 264.90(a)(2). Releases to ground water from "regulated units" must be addressed according to the requirements of 40 CFR §264.91 through §264.100 for purposes of detection, characterization, and appropriate response.

## **8.2 Health and Environmental Assessment Process**

The HEA is a continuous process that begins with the initiation of the RFI. As investigation data (from monitoring and/or modeling) become available, both within and at the conclusion of discrete phases, they should be reported to the regulatory agency as required. The regulatory agency will compare these data to applicable health and environmental criteria, including evaluation against qualitative criteria, to determine the need for (1) interim corrective measures; and/or (2) a CMS. Notwithstanding this process, the owner or operator has a

continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For these situations, the owner or operator should follow the RCRA Contingency Plan required under 40 CFR Part 264, Subpart D and Part 265, Subpart D.

The results of the media-specific investigations described in Volumes II and III of this Guidance will be used to identify the constituents of concern, constituent concentrations within the release, general release characteristics (e.g., organic, inorganic), the affected environmental media, exposed or potentially exposed human or environmental receptors, the rate of migration of the release, and the extent of the release. The objective of the HEA is to integrate these results to determine whether interim corrective measures and/or a CMS may be necessary. In general, this objective is achieved in a two-step process.

First, potential human and environmental exposure routes are determined. Section 8.3 provides guidance for determining potential exposure routes for the media of concern. For ground water, surface water, soil, and air, methods are described for making exposure route-specific comparisons with the health and environmental criteria. Subsurface gas migration and inter-media transport of contamination from other media to air (e.g., ground-water contamination resulting in seepage of volatile constituents to basements) are addressed as air problems to the extent that they contribute hazardous constituents to ambient air, whether indoors or outdoors. Evaluation of the migration of methane gas in the subsurface is also addressed in this section (Section 8.8) as part of the guidance on interim corrective measures, due to the immediate explosion potential of methane.

Second, the measured (or in some cases, such as releases to air, predicted) constituent concentrations in the release are compared to EPA-established exposure-limit criteria. At any time during the RFI when contaminant concentrations in the release are found to exceed the health and environmental criteria, a CMS will generally be required by the regulatory agency, although the owner or operator may, because of site-specific factors, present data and information to support a determination that no further action is necessary. In addition, when health and environmental criteria are exceeded, the need for appropriate interim corrective measures will also be determined. This process

involves an evaluation of exposed or potentially exposed human and environmental populations. This process is discussed in more detail in Section 8.8.

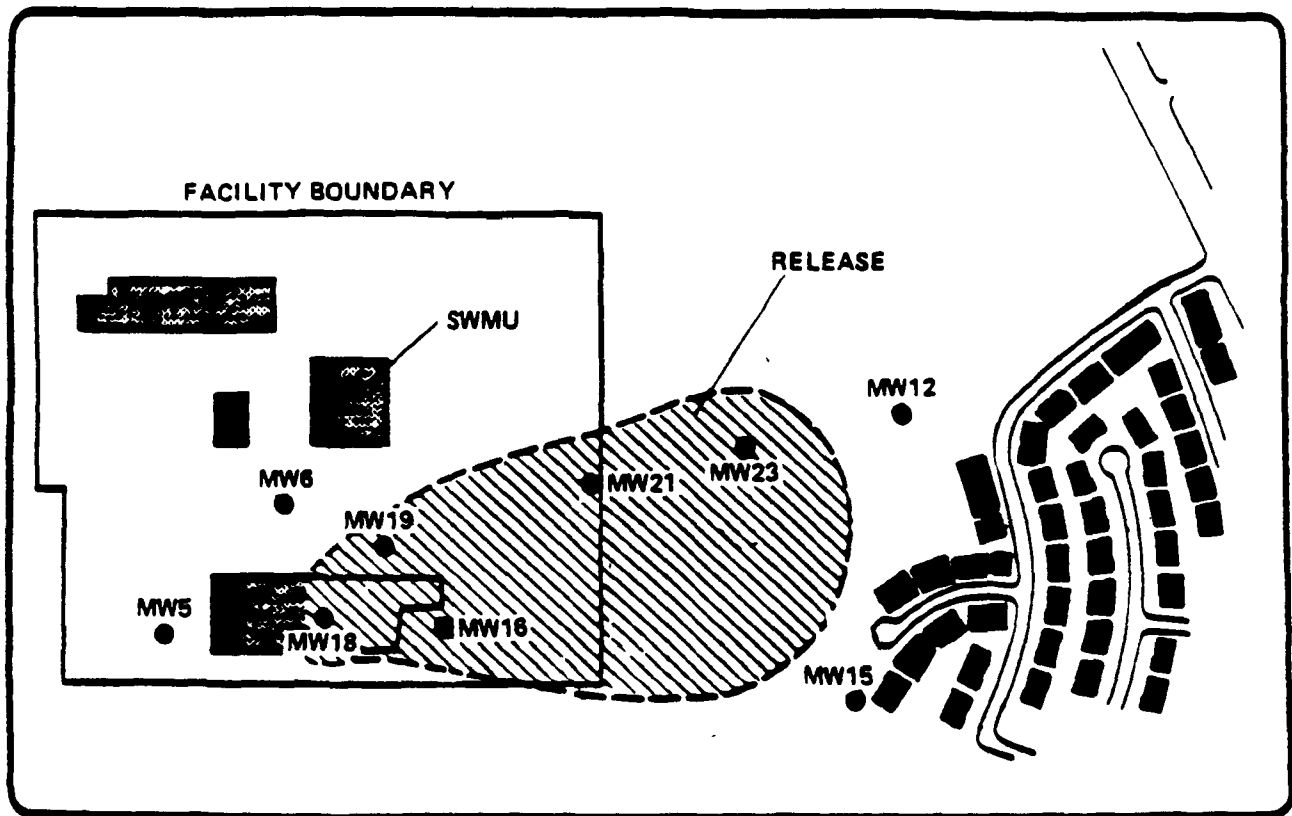
The determination of whether a CMS may be necessary will be made by the regulatory agency, by comparing constituent concentrations determined at locations within the release to the health and environmental criteria discussed in Section 8.4. These criteria serve as "action levels" for determining whether a CMS will be necessary. Figure 8-1 depicts a hypothetical facility with individual solid waste management units and a contaminant release originating from one of the units. For ground water, surface water, soil, and subsurface gas, the comparison of constituent concentrations with the criteria will be made for all measurements within the release at and beyond the limit of the waste management area.

The evaluation procedure for releases to air differs from the other media in that comparison of constituent concentrations with the health and environmental criteria will be made at the facility property boundary. However, onsite air comparisons may be necessary in cases where people reside at the facility or when worker safety regulations are deemed inadequate to protect human health and the environment, although onsite air contamination normally would fall under the jurisdiction of OSHA. As indicated in the Air Section (Section 12), the values compared can be either measured values derived from monitoring or predicted values derived from modeling.

### **8.3 Determination of Exposure Routes**

Some of the more significant potential exposure routes for each environmental medium are presented in Table 8-1. This table should be used to determine the appropriate health and environmental criteria to be used in the comparison with measured or predicted constituent release concentrations. For example, when releases to ground water have been identified, a primary exposure route of concern is drinking water. For each constituent identified in the ground-water release, the measured concentrations are compared with the appropriate criterion values discussed for drinking water in Section 8.4.

Suspected or known inter-media transfers of contamination should have been characterized (i.e., nature, extent and rate) during the RFI process. For example, if



**LEGEND:**

- SAMPLING LOCATIONS

**FIGURE 8-1. HYPOTHETICAL FACILITY WITH INDIVIDUAL SOLID WASTE MANAGEMENT UNITS AND A CONTAMINANT RELEASE ORIGINATING FROM ONE OF THE UNITS.**

**TABLE 8-1**  
**Some Potential Exposure Routes**

Contaminated Medium	Exposure Route
Soil <sup>1</sup>	Soil Ingestion (surficial soil), Dermal Contact
Ground Water	Ingestion of Drinking Water
Subsurface Gas <sup>2</sup>	Inhalation
Air	Inhalation
Surface Water <sup>1</sup>	Ingestion of Drinking Water Consumption of Contaminated Biota (e.g., fish)

- 1 Exposure routes for deep contaminated soils and bottom sediments underlying surface water bodies are addressed separately in Section 8.6.
- 2 Migration of methane gas in the subsurface presents a problem due to the explosive properties of methane. This is treated as an immediate hazard and is discussed under interim corrective measures (Section 8.8).

[Note: Other important exposure pathways can include inhalation of volatile constituents released during domestic use of contaminated ground water or when such ground water seeps into residential basements. Similarly, various exposure pathways can lead to adverse effects on environmental receptors (i.e., animals and plants).]

the initial contaminant release was to the soil medium and eroded soils have been transported to surface water, both soil and surface water contamination should have been adequately characterized during the RFI. In this example, the regulatory agency will consider exposure in both media. In cases where subsurface gas, soil, or ground-water releases have caused contaminant seepage to basements, inter-media transfer to the air may pose an inhalation hazard. In such cases, contamination of basement areas should have been adequately characterized during the RFI process.

## **8.4 Health and Environmental Criteria**

The preliminary set of health and environmental criteria are presented in Tables 8-5 through 8-10 in Section 8.10. The constituents shown in Tables 8-5 through 8-10 are a subset of the hazardous constituents listed in Appendix VIII of 40 CFR Part 261. It should be noted that the definition of constituent may also include components of 40 CFR Part 264, Appendix IX that are not also on Appendix VIII, but are normally monitored for during ground-water investigations. Tables 8-5 through 8-10 identify such constituents, where criteria for these constituents are available.

The concentrations shown for each constituent are derived from EPA-established chronic (and in some cases acute) toxicity criteria for ingestion (soil and drinking water) or inhalation exposure routes, and were calculated using a set of intake assumptions for the various media, as shown in Table 8-2. As indicated in the footnotes accompanying Tables 8-5 through 8-10, the criteria presented are subject to change. Therefore, these numbers should be confirmed by the regulatory agency prior to use.

### **8.4.1 Derivation of Health and Environmental Criteria**

Maximum Contaminant Levels (MCLs) -- Table 8-5 provides the maximum contaminant levels (MCLs) for drinking water promulgated under the Safe Drinking Water Act. In developing these values, total environmental exposure to a particular contaminant from various sources (e.g., air, food, water) and gastrointestinal absorption were considered.

**TABLE 8-2**

**Intake Assumptions for Selected Routes of Exposure**

<b><u>Surficial Soils (Ingestion):</u></b>  0.1 g/day for 70 kg person/70 year exposure period for carcinogens  0.2 g/day for a 16 kg child/5-year exposure period for systemic toxicants*
<b><u>Surface and Ground Water (Ingestion):</u></b>  2 liters/day for 70 kg adult/70-year exposure period
<b><u>Air (Inhalation):</u></b>  20 m <sup>3</sup> air/day for 70 kg adult/70-year exposure period

\* Corresponds to the period of 1 to 6 years of age.



The MCL, when available for a constituent released to ground water or surface water, should be used as the evaluation criterion for human drinking water consumption for that constituent. If an MCL does not yet exist for a particular constituent, criteria in the other tables presented in Section 8.10 should be used, where available. If air, surficial soil, or sediment (See Section 8.6) are the media of concern, or when evaluating aquatic life exposure or human consumption of aquatic organisms, the MCL is not used. In such cases, the criteria in the other tables should be used, as described below. [Note: EPA is in the process of developing a number of new MCLs to be issued over the next several years.]

Carcinogens -- Table 8-6 presents the human health-based criteria for carcinogens. These criteria, calculated from Risk-Specific Doses (RSDs), were developed according to EPA Guidelines for Carcinogen Risk Assessment (U.S. EPA, 1986). The RSD is an upper bound estimate of the average daily dose of a carcinogenic substance that corresponds to a specified excess cancer risk for lifetime exposure. The values presented in Table 8-6 are environmental concentrations that, under the intake assumptions shown in Table 8-2, correspond to excess lifetime cancer risks of  $10^{-6}$  for Class A and B carcinogens, or  $10^{-5}$  for Class C carcinogens. Table 8-6 presents the class (A, B or C) of the carcinogen (See U.S. EPA, 1986, for a description of carcinogen classification).

The criteria presented in Table 8-6 were calculated from RSDs in the following manner:

$$C_i = (R/q_1^*) \times (W/I) \quad \text{(Equation 8-1)}$$

where

- $C_i$  = the criterion concentration for the constituent of interest;
- $R$  = the specified risk level (e.g.,  $10^{-6}$ );
- $q_1^*$  = the carcinogen slope factor (CSF) in  $(\text{mg/kg/day})^{-1}$  developed by the Carcinogen Assessment Group (CAG) of the EPA, Office of Health and Environmental Assessment, or the Agency's Carcinogen Risk Assessment Verification Endeavor (CRAVE) Workgroup;

$(R/q_1^*)$  = the RSD;

$W$  = the assumed weight of the exposed individual; and

$I$  = the intake amount for a given time period.

For example, the health-based criterion ( $C_i$ ) for aldrin, a Class A carcinogen, was calculated for water in the following manner:

$$\begin{aligned} C_i &= (R/q_1^*) \times (W/I) \\ &= (10^{-6}/1.7 \times 10^1 \text{ (mg/kg/day)}^{-1}) \times (70 \text{ kg}/2 \text{ liters/day}) \\ &= 2.1 \times 10^{-6} \text{ mg/liter} \\ &= 2.1 \times 10^{-3} \text{ } \mu\text{g/liter} \end{aligned}$$

Calculation of the criteria for soil ingestion and air inhalation shown in Table 8-6 takes essentially the same form. However, the values for the assumed intake rate ( $I$ ) differ. The assumed intake rate for soil that is used in the calculations for carcinogens is 0.1 g/day for a 70-kg person. The current conservative, linear models that the Agency uses in cancer risk assessments consider the expression of carcinogenic effects to be a function of cumulative dose, and thus assume that, in general, elevated exposures during early childhood alone are not that significant in determining lifetime cancer risk. Therefore, the soil intake value of 0.1 g/day is an upper-range estimate of soil ingestion for adults. The intake rate ( $I$ ) for air inhalation is 20 m<sup>3</sup>/day for a 70-kg person.

Many of the health-based criteria for carcinogens shown in Table 8-6 are below current analytical detection limits (See Section 3.6 for a discussion of detection limits). For example, the concentration for dieldrin in Table 8-6 is  $2.2 \times 10^{-3} \text{ } \mu\text{g/l}$  for the drinking water exposure route, while the corresponding current limit of detection for this constituent is approximately  $5 \times 10^{-2} \text{ } \mu\text{g/l}$ . In those cases where the HEA criterion is less than the limit of detection, the detection limit will be used as a default value when making comparisons to investigation data, unless acceptably determined modeling values can be applied (i.e., values from air dispersion models).

The criteria provided in Table 8-6 address the surficial soil (ingestion), water (ingestion), and air (inhalation) routes of exposure. For human health assessment, the carcinogen criteria for water should be used when ground water or surface water is the medium of concern, unless MCLs exist or there are lower values for the constituents of concern in Table 8-7. The carcinogen criteria for surficial soil (ingestion) and air (inhalation) should be used if surficial soil or air, respectively, is the medium of concern, unless a lower value appears in Table 8-7. If a particular constituent is not identified in Table 8-6, the criteria in Table 8-7 (systemic toxicants) should be used, if available. As alluded to above, constituents that are both known carcinogens and systemic toxicants (e.g., chloroform) will have values in both Tables 8-6 and 8-7. In such cases, the lower of the two values should be used as the action level. Both values are presented in the tables if needed for determining the additive toxicity of mixtures (see Section 8.5).

Systemic Toxicants -- Table 8-7 presents the human health-based criteria for systemic toxicants. These criteria, calculated from Reference Doses (RfDs), are an estimate of the daily exposure an individual (including sensitive individuals) can experience without appreciable risk of health effects during a lifetime. For water ingestion, the systemic criteria are calculated for a 70-kg adult for a chronic lifetime exposure period (i.e., 70 years). For soil ingestion, the assumed intake rate of 0.2 g/day is based on a 5-year exposure period for a 16-kg child. These exposure assumptions for soil are reflective of an average scenario in which children ages 1-6 (who exhibit the greatest tendency to ingest soil) are assumed to ingest an average amount of soil on a daily basis. The concentrations shown in Table 8-7 were calculated using the intake assumptions presented in Table 8-2 for the selected exposure routes, as shown in the following equation:

$$C_i = (RfD) \times (W/I) \quad \text{(Equation 8-2)}$$

For example, the concentration ( $C_i$ ) for surface water and ground water for pentachlorobenzene shown in Table 8-7 was calculated in the following manner:

$C_i$  = Criterion concentration for constituent of interest

RfD = Reference Dose for pentachlorobenzene

$$\begin{aligned}
 &= 8 \times 10^{-4} \text{ mg/kg/day} \\
 I &= \text{ingestion rate (from Table 8-2)} \\
 &= \frac{2 \text{ liters}}{\text{day}} \\
 W &= \text{adult body weight (from Table 8-2)} \\
 &= 70 \text{ kg} \\
 C_i &= (8 \times 10^{-4} \text{ mg/kg/day}) \times (70 \text{ kg}/2 \text{ liters/day}) \\
 &= 2.8 \times 10^{-2} \text{ mg/liter} \\
 C_i &= 2.8 \times 10^1 \text{ } \mu\text{g/liter (which rounds off to } 3 \times 10^1 \text{ } \mu\text{g/liter)}
 \end{aligned}$$

As with the carcinogen criteria, some of the systemic criteria presented in Table 8-7 may be below current analytical detection limits. (See Section 3.6 for a discussion of detection limits.) In cases where the criterion is less than the limit of detection, the detection limit will be used as a default value when making comparisons to investigation data, unless acceptably determined modeling values can be applied (i.e., values from air dispersion models).

EPA is in the process of developing inhalation criteria for 49 systemic toxicants based on inhalation toxicity studies. Inhalation criteria for several of these systemic toxicants are currently available. These criteria are identified in Table 8-7. When additional criteria are developed, they will be incorporated into the Integrated Risk Information System (IRIS) data base (see Section 8.4.2). In addition, EPA is currently conducting research on development of systemic toxicity criteria for dermal exposure through contact with contaminated soil.

The systemic criteria for the water (human ingestion) route of exposure should be used unless MCLs or lower carcinogen criteria exist. For other routes of exposure (e.g., soil ingestion), carcinogen criteria should be used unless lower systemic criteria exist. As indicated previously, some toxicants are both carcinogenic and

systemically toxic (e.g., chloroform) and, thus appear in both Tables 8-6 and 8-7. In such cases, the lower of the two values should be used for human health assessment.

Water Quality Criteria -- A summary of the EPA Water Quality Criteria (WQC) appears in Tables 8-8 and 8-9. These criteria exist to protect both marine and fresh-water aquatic life and address both acute and chronic toxicity. WQC also exist for protection of human health through water and fish consumption (incorporating both routes of exposure), and for fish consumption only. If human consumption of both the surface water and contaminated aquatic organisms is a factor, the set of criterion values based on ingestion of contaminated aquatic organisms and drinking water should be used. The values based on consumption of fish alone should be used only when human consumption of the surface water is not of concern. WQC should be used only when surface water is the medium of concern. If aquatic life exposure and human exposure are both of concern, the more stringent criterion should be used. Aquatic life criteria may be applied even if human exposure is not of concern. [Note: In states which have adopted numerical Water Quality Standards, or where numerical standards can be calculated from non-numeric state standards, such standards may be used in lieu of EPA WQC or other available levels on a constituent-specific basis.]

Acute and Subchronic Criteria -- These criteria address impacts on both children and adults, and are presented in Table 8-10. These criteria are most commonly applied for the determination of the need for interim corrective measures. Their use is described in Section 8.8.

#### **8.4.2 Use of Criterion Values**

As indicated previously, the criteria presented in Tables 8-5 through 8-10 are subject to change. These tables do not present action levels for all of the 40 CFR Part 261, Appendix VIII constituents. In addition, action levels for components of 40 CFR Part 264, Appendix IX that are not also on Appendix VIII, but are normally monitored for during ground-water investigations, may also be applied. As existing health effects data are reviewed and more information becomes available from laboratory and epidemiological studies, these tables may be expanded to include additional hazardous constituents, including those from Appendix IX.

Current information on the health and environmental effects of various toxicants, including information on RSDs and RfDs, and supporting toxicological studies, may be obtained from review of the following document:

U.S. EPA. Integrated Risk Information System (IRIS) Chemical Files. Office of Health and Environmental Assessment, Office of Research and Development. Washington, D.C. 20460.

The Integrated Risk Information System (IRIS), is a computerized library of current information that is up-dated on a continuous basis. It contains health risk assessment information on chemicals which have undergone a detailed review of toxicity data by work groups composed of EPA scientists from several Agency program offices, and represent EPA consensus. IRIS may be accessed by the EPA Regions, and State and local governments through the EPA electronic mail system (Dialcom) or through the Public Health Network of the Public Health Foundation (contact the Network at (202) 898-5600 for details). IRIS is also available to the general public through the EPA electronic mail system (Dialcom-(202) 488-0550). In addition, IRIS is also available on floppy diskettes in ASCII format through the National Technical Information Service (NTIS-(703) 487-4763).

If EPA has not yet developed criteria for constituents which may be pertinent to a particular release, there are various options which may be exercised by the regulatory agency. A literature search may be performed to locate any health effects data which can be used to develop an interim criterion value or, at least, information such as type of health effect (e.g., carcinogenicity) which can be used to make judgments. The regulatory agency, for example, may obtain and review EPA summaries of health and environmental effects produced for a particular constituent. These summaries include Health and Environmental Effects Profiles (HEEPs), Health Effects Assessment (HEA) documents, and other documents produced by EPA to summarize health and environmental effects for particular constituents. These documents are collectively known as Health and Environmental Effects Documents (HEEDs), and are available for many of the 40 CFR Part 261, Appendix VIII constituents through EPA's RCRA Docket and library, located at EPA Headquarters in Washington, D.C. A listing of all the HEEDs currently available is

contained in the following document, which is also available through EPA's RCRA Docket and library:

U.S. EPA, 1987. Background Document, Resource Conservation and Recovery Act, Subtitle C -- Identification and Listing of Hazardous Waste, Appendix A -- Health and Environmental Effects Documents. Office of Solid Waste. Washington, D.C. 20460.

Additionally, the HEA documents can be obtained from the National Technical Information Service (NTIS). Table 8-3 presents a list of all chemicals for which HEAs are currently available, and also identifies the NTIS ordering number.

If little or no useful information regarding a particular constituent can be located, the initiation of a toxicity bioassay may be considered. The Technical Assessment Branch, Health Assessment Section of the Office of Solid Waste, located in Washington, D.C., may be contacted for toxicological information [(202)382-4761]]. This office may also be contacted to determine whether a toxicity bioassay for a particular constituent is planned or is in progress. Comparison of background concentrations (as action levels) to constituent concentrations in the release may be made by the regulatory agency when health and environmental effects information are not available.

Note also that the criteria presented in Tables 8-5 through 8-10 do not address all routes of exposure or forms of toxicity which may be of concern in particular circumstances. For example, dermal toxicity (absorption of toxicants through the skin) may also be of concern in particular cases. Phytotoxicity (toxicity to plants) and other forms of environmental toxicity, such as terrestrial toxicity (toxicity to animals and birds) may also be of concern. Additional information regarding other routes of exposure and forms of toxicity may be obtained from the following reference:

U.S. EPA. October, 1986. Superfund Public Health Evaluation Manual. EPA 540/1-68/060. NTIS PB87-183125. OSWER Directive No. 9285.4-1. Office of Emergency and Remedial Response. Washington, D.C. 20460.

Worksheet 8-1 in Section 8.10 may be used to present release characterization data and to facilitate the comparison of constituent concentrations to health and

TABLE 8-3

CHEMICAL AND CHEMICAL GROUPS HAVING EPA HEALTH  
EFFECTS ASSESSMENT (HEA) DOCUMENTS<sup>1</sup>

CHEMICAL	NTIS <sup>2</sup> PB NUMBER
Acetone	86 134277/AS
Arsenic and Compounds	86 134319/AS
Asbestos	86 134608/AS
Barium and Compounds	86 134327/AS
Benzene	86 134483/AS
Benzo (a) pyrene	86 134335/AS
Cadmium and Compounds	86 134491/AS
Carbon Tetrachloride	86 134509/AS
Chlordane	86 134343/AS
Chlorobenzene	86 134517/AS
Chloroform	86 134210/AS
Chromium III and Compounds	86 134467/AS
Chromium VI and Compounds	86 134301/AS
Coal Tars	86 134350/AS
Copper and Compounds	86 134368/AS
Cresol	86 134616/AS
Cyanides	86 134228/AS
DDT	86 134376/AS
1,1-Dichloroethane	86 134384/AS
1,2-Dichloroethane (DCE)	86 134137/AS
1,1-Dichloroethylene	86 134624/AS
1,2-cis-Dichloroethylene	86 134269/AS
1,2-trans-Dichloroethylene	86 134525/AS
Dichloromethane	86 134392/AS
Ethylbenzene	86 134194/AS
Glycol Ethers	86 134632/AS
Hexachlorobenzene	86 134285/AS
Hexachlorobutadiene	86 134640/AS
Hexachlorocyclopentadiene	86 134129/AS
gamma-Hexachlorocyclohexane (Lindane)	86 134673/AS
Iron and Compounds	86 134657/AS
Lead and Compounds (Inorganic)	86 134665/AS



TABLE 8-3 (Continued)

CHEMICAL AND CHEMICAL GROUPS HAVING EPA HEALTH EFFECTS ASSESSMENT (HEA) DOCUMENTS<sup>1</sup>

CHEMICAL	NTIS <sup>2</sup> PB NUMBER
Manganese and Compounds	86 134681/AS
Mercury	86 134533/AS
Methyl Ethyl Ketone	86 134145/AS
Naphthalene	86 134251/AS
Nickel and Compounds	86 134293/AS
Pentachlorophenol	86 134541/AS
Phenanthrene	86 134400/AS
Phenol	86 134186/AS
Polychlorinated Biphenyls (PCBs)	86 134152/AS
Polynuclear Aromatic Hydrocarbons	86 134244/AS
Pyrene	86 134418/AS
Selenium and Compounds	86 134699/AS
Sodium Cyanide	86 134236/AS
Sulfuric Acid	86 134426/AS
2,3,7,8-TCDD (Dioxin)	86 134558/AS
1,1,2,2-Tetrachloroethane	86 134434/AS
Tetrachloroethylene	86 134202/AS
Toluene	86 134442/AS
1,1,1-Trichloroethane	86 134160/AS
1,1,2-Trichloroethane	86 134566/AS
Trichloroethylene	86 134574/AS
2,4,5-Trichlorophenol	86 134459/AS
2,4,6-Trichlorophenol	86 134582/AS
Vinyl Chloride	86 134475/AS
Xylene	86 134178/AS
Zinc and Compounds	86 134590/AS
Complete Set of 58 HEAs	86 134111/AS

<sup>1</sup> As of the date of publication for this guidance document.

<sup>2</sup> National Technical Information Service.

environmental criteria. Additional worksheets are provided for evaluating hazards posed by mixtures of constituents. Evaluation of chemical mixtures is discussed in the following section.

## 8.5 Evaluation of Chemical Mixtures

There are several situations when the overall potential for adverse effects posed by multiple constituents may be assessed. For example, if no individual constituent exceeds its action level in a given medium, but there are many constituents present in the medium, the overall (additive) health risk may be assessed to determine whether a CMS may be required. In other cases, an evaluation of the health risk posed by a mixture of constituents may be used in assessing the need for interim measures, particularly where exposure is actually occurring. The Guidelines for the Health Risk Assessment of Chemical Mixtures (U.S. EPA, 1986) describe the recommended approach to be used in evaluating the chronic effects of exposure to a chemical mixture. According to the guidelines, a mixture is defined as "any concentration of two or more chemicals regardless of source or of spatial or temporal proximity." Under these guidelines, additivity of effects for carcinogens can be assumed. The guidelines also allow for additivity of systemically toxic constituents which cause similar systemic effects. Carcinogens and systemic toxicants must be evaluated separately. When evaluating mixtures of systemic toxicants, constituents should be grouped by the same mode of toxicological action (i.e., those which induce the same toxicological endpoint, such as liver toxicity).

The overall risk posed by a mixture of constituents is evaluated through the use of a Hazard Index (HI) that is generated for each health endpoint. For systemic toxicants, the hazard index (HI<sub>T</sub>) takes the form:

$$HI_T = \sum_{i=1}^n \frac{E_i}{AL_i} \quad (\text{Equation 8-3})$$

where

$n$  = total number of toxicants;

$E_i$  = exposure level of the  $i$ th toxicant; and

$AL_i$  = maximum acceptable level for the  $i$ th toxicant.

The hazard index for carcinogens ( $HI_c$ ) is similar:

$$HI_c = \sum_{j=1}^n \frac{E_j}{DR_j} \quad (\text{Equation 8-4})$$

where

$n$  = total number of carcinogens;

$E_j$  = exposure level to the  $j$ th carcinogen; and

$DR_j$  = dose at a set level of risk for the  $j$ th carcinogen.

If any calculated hazard index exceeds unity (i.e., one), then the need for interim corrective measures and/or a CMS may be assessed.

The use of the hazard index in the evaluation of chemical mixtures is described below for an example case in which three carcinogens were measured within a contaminant release. Trichloroethylene and carbon tetrachloride levels in the ground water were measured at 2 and 1  $\mu\text{g/l}$ , respectively. A breakdown product of carbon tetrachloride, chloroform, was also measured at a level of 3  $\mu\text{g/l}$ . None of these concentrations exceed the individual criteria presented in Tables 8-5 through 8-10. (The MCL for both trichloroethylene and carbon tetrachloride is 5.0  $\mu\text{g/l}$ , and the carcinogenic criteria for chloroform is 5.7  $\mu\text{g/l}$ .) However, the hazard Index ( $HI_c$ ) for these three chemicals exceeds unity. Rewriting Equation (8-4) in terms of the measured concentration ( $E_j$ ) and the criterion concentrations ( $DR_j$ ) shown in Tables 8-5 through 8-10 gives:

$$HI_c = E_1/DR_1 + E_2/DR_2 + E_3/DR_3$$

$$HI_c = \frac{2 \mu\text{g/l}}{5.0 \mu\text{g/l}} + \frac{1 \mu\text{g/l}}{5.0 \mu\text{g/l}} + \frac{3 \mu\text{g/l}}{5.7 \mu\text{g/l}}$$

$$HI_c = 0.4 + 0.2 + 0.53$$

$$HI_c = 1.13$$

Thus, in this situation, the need for interim corrective measures and/or a CMS may be assessed.

Contaminant additivity is possible both within a medium and across media. When appropriate, the regulatory agency may use the hazard index approach for multiple contaminants within a given medium to help determine the need for interim corrective measures and/or a CMS. Similarly, contaminant additivity may be applied across media, especially when site-specific factors indicate a likelihood of chronic exposure to constituents from multiple media. Information on the toxicological effects of individual systemic toxicants may be found in the HEEDs, and the IRIS data base, referenced earlier.

Worksheet 8-2 (Section 8.10) provides a format that the regulatory agency may use to assess the toxic effects of chemical mixtures based on the hazard index. An example case worksheet is also presented.

## **8.6 Evaluating Deep Soil and Sediment Contamination and Use of Statistical Procedures for Evaluating Ground-Water Contamination**

As indicated previously, determining whether deep soil and sediment contamination warrants consideration of interim corrective measures and/or a CMS may involve the application of specific exposure assumptions and consideration of other factors. Guidance regarding these topics is presented in Subsections 8.6.1 and 8.6.2. This guidance may be revised in future editions of this document as a result of ongoing EPA studies. Subsection 8.6.3 presents a discussion on statistical procedures that may be used for evaluating ground-water contamination.

### **8.6.1 Deep and Surficial Soil Contamination**

As described in the Soil Section of this Guidance (Section 9), releases of hazardous waste or constituents to soil can be described as surficial or deep. Surficial soil is generally described as the top 2 feet of soil; in site-specific conditions, it may extend to 12 feet. Land use that involves housing developments is an example of when the surficial soil depth may extend to 12 feet, because foundation excavation may result in deep contaminated soils being moved to the surface.

Because of the potential for inter-media transport of contamination, the potential routes for exposure to surficial soil contaminants are soil, air, surface

water, and ground water. While air, surface water, and ground-water routes are all important, the most relevant and major route of exposure is through direct contact with and/or ingestion of soil.

Surficial soils may be contaminated with organics, inorganics, organometals, or a combination of these. At high concentrations, some contaminants will cause at least irritation at the point of skin contact. For many contaminants, however, toxicity occurs after they pass through certain barriers (e.g., the wall of the gastrointestinal tract or the skin itself), and enter blood or lymph, and gain access to various organs or systems of the body. Generally, because of the chemical forms in which metals are usually found in soils (e.g., salts, ligand, and chelate complexes), the concern is with their ingestion rather than with dermal contact.

Surficial soil contaminated with lead and/or cadmium presents a unique health risk to children because of the possible ingestion of contaminated soil through their normal exploratory behavior, coupled in some instances with pica, and because of the cumulative nature of lead and cadmium poisoning.

Currently, there is no verified Reference Dose (RfD) or Risk Specific Dose (RSD) for lead. The Carcinogen Assessment Group (CAG) of ORD is evaluating lead as a potential human carcinogen via the oral route of exposure and is currently working on estimating a Carcinogenic Slope Factor (CSF) for lead based on current toxicity studies. The Agency is also attempting to develop a RfD for lead based on new toxicological data on the non-carcinogenic, neuro-behavioral effects of lead exposure. It is not likely, however, that either the RfD or the RSD will be developed and approved soon.

Another metal of concern is cadmium. Although the Agency has not formally approved an RfD for cadmium, a value of 0.0005 mg/kg/day will likely be approved as an RfD. This value would translate to an acceptable soil level of 9 mg/kg.

Toxicological information on lead and cadmium are undergoing extensive Agency review, and decisions on relevant health-based standards are currently being made. The Integrated Risk Information System (IRIS) chemical files should be searched periodically for updated material concerning lead and cadmium.

The criteria discussed in Section 8.4 that apply to soil (and shown in Tables 8-6 and 8-7 in Section 8.10) pertain to ingestion of surficial soils. Because ingestion of deep soils may not be a likely exposure scenario, different evaluation methods may be used for deep soils, as described below.

In making the determination of whether interim corrective measures and/or a CMS should be considered for deep contaminated soils, the regulatory agency may evaluate the potential for the contamination within deep soils to contaminate underlying ground water. If the potential exists for contaminated deep soils to release hazardous constituents to ground water, such that the criteria levels for ground water discussed in Section 8.4 may be exceeded, interim corrective measures and/or a CMS will be considered. This applies not only to situations where ground water has not yet been impacted by deep soil contamination, but also to situations where deep contaminated soils are acting as a continuous source of contamination to already contaminated ground water. In addition, the regulatory agency may apply this evaluation to surficial soils, particularly in cases where the soil ingestion criteria (Section 8.4) are not exceeded and where the surficial soil may pose a future or continuing threat to ground water.

In order to determine whether contaminated soils pose a future or continuing threat to ground water, leaching tests and/or other evaluation procedures may be performed on representative samples of contaminated soils following the guidance presented in Section 9.4.4.3. If the concentration of constituents of concern measured in leachate resulting from leaching tests and/or other procedures exceeds the applicable criteria for ground water discussed in Section 8.4, interim corrective measures and/or a CMS may be necessary, unless the owner or operator demonstrates (following the guidance presented in Section 9.4.4.3) that attenuation and other mechanisms will reduce these concentrations to acceptable levels prior to entry into the ground water.

Case Study No. 16 in Volume IV (Case Study Examples) illustrates the application of leaching tests and the evaluation of other site-specific information to determine whether contaminated soil poses a threat to ground water.

## **8.6.2 Sediment Contamination**

As with deep contaminated soils, direct human exposure to contaminated sediments underlying surface waters is unlikely. However, such sediments may pose risks to both the surface water ecosystem and humans due to toxicity and/or bioaccumulation and biomagnification through the food chain. The regulatory agency may therefore assess the potential for contaminated sediments underlying surface water to act as a continuing or future source of contamination to the water column, to aquatic life that may be present in the surface water, and consequently to humans who may ingest the surface water and/or the aquatic life within the surface water.

Section 13, in addressing releases to surface water, recommends that, whenever metal species or organic constituents having bioaccumulative potential are known to be present in bottom sediments (or in the water column), biomonitoring (e.g., sampling and analysis of aquatic species) be conducted. If potentially bioaccumulative organic or inorganic contaminants (as discussed in Section 13) are measured in the aquatic species of interest, interim corrective measures and/or a CMS may be necessary.

If other hazardous constituents (e.g., those which are not known to be potentially bioaccumulative) are measured in the sediment that can be subsequently released from the sediment into the surface-water column at concentrations above the applicable criteria discussed in Section 8.4, interim corrective measures and/or a CMS may also be required by the regulatory agency.

However, the owner or operator may attempt to show that constituents within the sediment have not bioaccumulated or will not bioaccumulate. The owner or operator may also attempt to show, through use of static or flow-through testing (i.e., analysis of water or aquatic species following a period of contact with the contaminated sediment) or through the use of chemical stability/solubility information, that sediment contaminants will not be released to the water column in concentrations that would exceed the applicable criteria discussed in Section 8.4.

It should also be noted that EPA is working to establish numerical sediment quality criteria that can be applied on a site-specific basis, depending primarily on

the physical/chemical characteristics of the sediment (e.g., sediment organic carbon content). The approach being investigated to assessing sediment contamination examines the correspondence between sediment contaminant concentration, laboratory bioassay, and in situ assessments of biomass and species diversity. Although these criteria are still in the development/validation process, when issued, they may be applied in the case of sediment contamination to determine whether interim corrective measures and/or a CMS may be necessary. Contact the EPA Criteria and Standards Division for additional information at (202) 475-7301.

### **8.6.3 Use of Statistical Procedures For Evaluating Ground-Water Contamination**

On October 11, 1988, EPA promulgated the final rule for Statistical Methods for Evaluating Ground-Water Monitoring Data From Hazardous Waste Facilities (53 FR 39720). This rule, part of 40 CFR Part 264, Subpart F, requires ground-water monitoring at permitted hazardous waste land disposal facilities to detect ground-water contamination. This rule amends the requirement that the Cochran's Approximation to the Behrens Fisher Student's t-test (CABF), be applied to ground-water monitoring data to determine whether there is a statistically significant exceedance of background or other allowable concentration levels of specified chemical parameters. Concerns with the CABF procedure were brought to EPA's attention, and after a review of comments on the procedure, EPA promulgated 5 different statistical methods that are more appropriate for the analysis of ground-water monitoring data. These 5 methods are 1) Parametric analysis-of-variance, 2) Analysis-of-variance based on ranks, 3) Tolerance intervals, 4) Prediction intervals, and 5) Control charts.

Analysis-of-variance models are used to analyze the effects of an independent variable on a dependent variable. For ground-water monitoring data, a well or group of wells is the independent variable, and the aqueous concentration of certain constituents or of a specified contaminant or contaminants is the dependent variable. An analysis-of-variance can determine whether observed variations in aqueous concentrations between different wells or groups of wells are statistically significant. Use of analysis-of-variance models is appropriate in situations where background concentrations for the specific constituent can be determined.



Tolerance intervals define, with a specified probability, a range of values that contain a discrete percentage of the sample population. With ground-water monitoring data, tolerance intervals can be constructed with concentrations from the background well(s); these intervals are then expressed as an interval centered at the mean background well concentration. Possible ground-water contamination is indicated when concentrations of the specified constituent(s) at the compliance well(s) plot outside of the tolerance interval limits.

Prediction intervals are intervals in which the user is confident at a specified percentage that the next observation will lie within the interval, and are based on the number of previous observations, the number of new measurement to be made, and the level of confidence that the user wishes to obtain. This method of statistical analysis can be used in both detection and compliance monitoring programs. It is useful in a detection monitoring program when constituent concentrations from individual compliance wells are compared to one or more background wells. The mean concentration and standard deviation are estimated from the background well sample. In a compliance monitoring program, prediction intervals are constructed from compliance well concentrations beginning when the facility entered the compliance monitoring program. Each compliance well observation is tested to determine if it lies within the prediction interval, and if it is greater than the historical prediction limits, quality has deteriorated to such a point that further action may be warranted.

Control charts are based on repeated random sampling done over various time intervals from the population distribution of a given variable. Different statistical measurements, such as the mean of replicate values at a point in time, are computed and plotted together with upper and/or lower predetermined limits on a chart whose x-axis represents time. When a data point plots outside these boundaries, the process is "out of control", and when it plots within the boundaries the process is "in control". Control charts can be used to analyze the inherent statistical variation of ground-water monitoring data and to note aberrations. Further investigation of out of control points is necessary before taking any direct action. Control charts are also used to evaluate ground-water monitoring data when these data are adjusted and/or transformed as necessary. A control chart can be constructed for each constituent in each well to monitor the concentration of

that constituent over time. New samples can be compared to the historical data from the well to determine if the well is in or out of control.

The October 11, 1988 final rule (53 FR 39720) should be reviewed for further information. In particular, the rule provides a glossary of some of the terminology commonly used in the field of statistics, which may be particularly helpful. The EPA Office of Solid Waste Land Disposal Branch may be contacted for further information at (202) 382-4658.

## **8.7 Qualitative Assessment and Criteria**

Qualitative criteria may also be used to assess the need for interim corrective measures and/or a CMS. Qualitative criteria for interim corrective measures are discussed in Section 8.8. Qualitative criteria for assessing the need for conducting a CMS are discussed below.

The regulatory agency may require that a CMS be performed even though quantitative criteria (See Section 8.4) have not been exceeded. Circumstances under which such actions may be appropriate include the following:

- Presence of sensitive ecosystems or endangered species;
- Data indicating that release concentrations may be increasing over time;
- Information indicating that other contaminant sources may be contributing to overall adverse exposure;
- Information indicating that exposure routes other than those addressed by quantitative criteria (e.g., dermal contact and phytotoxicity) are important; and
- Additional exposure as a result of normal use of a contaminated medium (e.g., use of contaminated ground water or surface water for drinking as well as for washing, cooking, showering, watering the lawn, etc.).

The above list of circumstances is not exhaustive. The regulatory agency may identify other factors on a case-specific basis.

## **8.8 Interim Corrective Measures**

If interim corrective measures are determined to be necessary, population exposure should be prevented or minimized to the extent necessary and further release migration should also be prevented or minimized. The process of determining whether interim corrective measures should be taken, and the selection and implementation of such measures, is similar to removal actions that may be taken under CERCLA (Superfund). In many cases, such action may be relatively simple (e.g., removal of drums from the land surface with proper storage or disposal), while in other cases more extensive action may be necessary.

In evaluating whether interim corrective measures may be necessary, the regulatory agency will review pertinent information about the source and nature of the release or potential threat of release. The regulatory agency will apply scientific judgment in evaluating the potential threat to human health or the environment. The decision to apply interim corrective measures will be made in consideration of the immediacy and magnitude of the potential threat, the nature of appropriate corrective action, and the implications of deferring corrective measures until the RFI/CMS is completed. The following factors will be considered in determining the need for interim corrective measures:

- Actual or potential exposure of nearby human populations or animals to hazardous wastes or constituents;
- Actual or potential contamination of drinking water supplies or sensitive ecosystems;
- Presence of hazardous wastes or constituents in drums, barrels, tanks, or other bulk storage containers that may pose a threat of release;
- Presence of high concentrations of hazardous wastes or constituents in soils largely at or near the surface that may migrate readily to receptors, or to which the public may be inadvertently or unknowingly exposed;

- Weather conditions that may cause hazardous wastes or constituents to migrate or be released;
- Threat of fire or explosion; and
- Other situations or factors that may pose actual or imminent threats to human health or the environment.

Exceedance of any of the criteria discussed in Section 8.4 does not necessarily mean that interim corrective measures will be required. Although the regulatory agency should be notified if health and environmental criteria are exceeded, the overall circumstances will be considered by the regulatory agency in determining whether interim corrective measures should be applied. Notwithstanding this process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For such situations, the owner or operator should follow the RCRA Facility Contingency Plan as required under 40 CFR Part 264, Subpart D and Part 265, Subpart D.

It should also be noted that the regulatory agency may apply health criteria based on acute or subchronic effects, to the determination of the need for interim corrective measures. For example, the EPA Office of Drinking Water has developed drinking water health advisories for a number of compounds, which address acute (1 day) and subchronic (10 day) exposures for both children and adults. A list of the currently available drinking water health advisories is provided in Table 8-10. Health advisory numbers may be periodically revised and can be found in IRIS. For further information on health advisory numbers, call the EPA Office of Drinking Water Hotline at (202) 382-5533 or 1-800-426-4791.

The regulatory agency will base the decision on the need to apply interim corrective measures on a determination of the type and magnitude of the potential hazard and an evaluation of the likelihood and effects of actual or potential human or environmental exposures. For example, in the hypothetical case depicted in Figure 8-1, initial measurements at the indicated sampling locations identified constituent concentrations in excess of health and environmental criteria.

Accordingly, the owner or operator notified the regulatory agency immediately. The circumstances indicated that human population would be exposed to release constituents before definitive corrective measures could be selected and implemented. Therefore, immediate steps to address the hazard were required of the owner or operator. Examples of specific interim corrective measures are provided in Table 8-4. For additional information see RCRA Corrective Action Interim Measures (U.S. EPA, 1987).

To determine whether an actual or potential threat to human health or the environment requires interim corrective measures, the regulatory agency will consider such factors as receptor locations, and rate and extent of release migration. Worksheet No. 3 in Section 8.10.2 presents a list of questions that the regulatory agency may consider in making a determination.

The decision to apply interim corrective measures may involve estimates of the rate of release migration and an assessment of potential human or environmental receptors. Estimates of the rate of release migration will generally be based on simple calculations, analytical models, or well-understood numerical models. For example, the rate of contaminant migration in ground water is likely to be based on time of travel (TOT) calculations or other simple methods for estimating rate. Additional information on determining media-specific migration and the characterization of exposed populations is provided in the Superfund Public Health Evaluation Manual (U.S. EPA, 1986) and the Draft Superfund Exposure Assessment Manual (U.S. EPA, 1987). In addition, information describing data requirements for exposure related measurements is expected to be published by the EPA Office of Research and Development Exposure Assessment Group in the Federal Register in late 1988 or early 1989.

As discussed above, the determination of the type and magnitude of the potential hazard posed by most contaminant releases will be accomplished as part of the assessment, including the comparison of projected or actual exposure concentrations to the health and environmental criteria, as described in Section 8.4. However, the evaluation of subsurface releases of methane gas may pose a direct explosion hazard as a result of a concentration build-up (e.g., in building structures). Explosions of methane gas can occur at the Lower Explosive Limit (LEL) in the presence of a heat source (e.g., a spark). EPA has promulgated criteria for explosive

**TABLE 8-4**

**EXAMPLES OF INTERIM CORRECTIVE MEASURES**

<b>SOILS</b> <ul style="list-style-type: none"> <li>● Sampling/Analysis/Disposal</li> <li>● Run-off/Run-on Control (Diversion or Collection Devices)</li> <li>● Temporary Cap/Cover</li> </ul>	<b>CONTAINERS</b> <ul style="list-style-type: none"> <li>● Overpack/Re-drum</li> <li>● Construct Storage Area/Move to Storage Area</li> <li>● Segregation</li> <li>● Sampling and Analysis</li> <li>● Treatment, Storage and/or Disposal</li> <li>● Temporary Cover</li> </ul>
<b>GROUND WATER</b> <ul style="list-style-type: none"> <li>● Delineation/Verification of Gross Contamination</li> <li>● Sampling and Analysis</li> <li>● Interceptor Trench/Sump/Subsurface Drain</li> <li>● Pump and Treat</li> <li>● In-situ Treatment</li> <li>● Temporary Cap/Cover</li> </ul>	<b>TANKS</b> <ul style="list-style-type: none"> <li>● Overflow/Secondary Containment</li> <li>● Leak Detection/Repair/Partial or Complete Removal</li> </ul>
<b>SURFACE WATER RELEASE (Point and Non-Point)</b> <ul style="list-style-type: none"> <li>● Overflow/Underflow Dams</li> <li>● Filter Fences</li> <li>● Run-off/run-on Control (Diversion or Collection Devices)</li> <li>● Regrading/Revegetation</li> <li>● Sample and Analyze Surface Waters and Sediments or Point Source Discharges</li> </ul>	<b>SURFACE IMPOUNDMENTS</b> <ul style="list-style-type: none"> <li>● Reduce Head</li> <li>● Remove Free Liquids and or Highly Mobile Wastes</li> <li>● Stabilize/Repair Side Walls, Dikes or Liner(s)</li> <li>● Provide Temporary Cover</li> <li>● Run-off/Run-on Control (Diversion of Collection Devices)</li> <li>● Sample and Analysis to Document the Concentration of Constituents Left in Place When a Surface Impoundment Handling Characteristic Wastes is Clean Closed</li> <li>● Interim Ground-water Measures (See Ground-water Section)</li> </ul>
<b>GAS MIGRATION CONTROL</b> <ul style="list-style-type: none"> <li>● Barriers/Collection/Treatment/Monitoring</li> <li>● Evacuation (Buildings)</li> </ul>	<b>LANDFILL</b> <ul style="list-style-type: none"> <li>● Run-off/Run-on Control (Diversion or Collection Devices)</li> <li>● Reduce Head on Liner and/or in Leachate Collection System</li> <li>● Inspect Leachate Collection/Removal System or French Drain</li> <li>● Repair Leachate Collection/Removal System or French Drain</li> <li>● Temporary Cap</li> <li>● Waste Removal (See Soils Section)</li> <li>● Interim Ground-water Measures (See Ground-water Section)</li> </ul>

**TABLE 8-4 (continued)**

**EXAMPLES OF INTERIM CORRECTIVE MEASURES**

<b>PARTICULATE EMISSIONS</b> <ul style="list-style-type: none"> <li>• Truck Wash (Decontamination Unit)</li> <li>• Re-vegetation</li> <li>• Application of Dust Suppressant</li> </ul>	<b>WASTE PILE</b> <ul style="list-style-type: none"> <li>• Run-off/Run-on Control (Diversion to Collection Devices)</li> <li>• Temporary Cover</li> <li>• Waste Removal (See Soils Section)</li> <li>• Interim Ground-Water Measures (See Ground-water Section)</li> </ul>
<b>OTHER TYPES OF ACTIONS</b> <ul style="list-style-type: none"> <li>• Fencing to Prevent Direct Contact</li> <li>• Extend Contamination Studies to Off-site Areas if Permission is Obtained as Required Under Section §3004(v)</li> <li>• Alternate Water Supply to Replace Contaminated Drinking Water</li> <li>• Temporary Relocation of Exposed Population</li> <li>• Temporary or Permanent Injunction</li> <li>• Suspend or Revoke Authorization to Operate Under Interim Status</li> </ul>	

gases under the RCRA, Subtitle D program in 40 CFR Part 257.3. These criteria state that the concentration of explosive gases generated by the facility shall not exceed: (1) 25 percent of the lower explosive limit (LEL) for the gases in facility structures, and (2) the lower explosive limit for the gases at the property boundary. Where these criteria are being approached or exceeded, interim corrective measures for gas migration will generally be necessary.

## **8.9 References**

- U.S. EPA. 1986. Superfund Public Health Evaluation Manual. EPA/540-1-86-060. NTIS PB87-183125. OSWER Directive No. 9285.4-1. Office of Emergency and Remedial Response. Washington, D.C. 20460.
- U.S. EPA. September 24, 1986. Guidelines for Carcinogen Risk Assessment. Federal Register 51(185):33992-34003.
- U.S. EPA. September 24, 1986. Guidelines for the Health Risk Assessment of Chemical Mixtures. Federal Register 51(185):34014-34025.
- U.S. EPA. 1986. Test Methods for Evaluating Solid Wastes. EPA/SW-846. GPO No. 955-001-00000.1. Office of Solid Waste. Washington, D.C. 20460.
- U.S. EPA. 1986. Superfund Exposure Assessment Manual. Draft. Office of Emergency and Remedial Response. Washington, D.C. 20460.
- U.S. EPA. 1987. Data Quality Objectives for Remedial Response Activities: Volume 1 - Development Process, Volume 2: Example Scenario. EPA 540/G-87/003a. OSWER Directive No. 9335.0-7B. Office of Emergency and Remedial Response and Office of Waste Programs Enforcement. Washington, D.C. 20460.
- U.S. EPA. 1987. Integrated Risk Information System (IRIS) Chemical Files. EPA/600/8-86/032b. Office of Health and Environmental Assessment, Office of Research and Development. Washington, D.C. 20460.



U.S. EPA. 1987. Background Document, Resource Conservation and Recovery Act, Subtitle C--Identification and Listing of Hazardous Waste, Appendix A--Health and Environmental Effects Documents. Office of Solid Waste. Washington, D.C. 20460.

U.S. EPA. 1987. RCRA Corrective Action Interim Measures. Office of Solid Waste. Washington, D.C. 20460.

## **8.10 Criteria Tables and Worksheets**

This section presents both the health and environmental assessment criteria tables and worksheets that the regulatory agency may use in conducting the health and environmental assessment.

### **8.10.1 Criteria Tables**

The following are the health and environmental assessment criteria tables discussed in Section 8.4 and 8.8. Table 8-5 presents the Maximum Contaminant Levels (MCLs) promulgated under the Safe Drinking Water Act. Table 8-6 presents human health-based criteria for carcinogens (based on Risk-Specific Doses or RSDs). Table 8-7 presents human health-based criteria for systemic toxicants (based on Reference Doses or RfDs). Table 8-8 presents a summary of the EPA Water Quality Criteria developed under the Clean Water Act. Table 8-8 identifies individual constituents as well as groups of constituents (e.g., chlorinated benzenes). Table 8-9 presents a list of all the individual constituents contained in the chemical groups identified in Table 8-8. Table 8-10 presents drinking water health advisories developed by EPA's Office of Drinking Water.

Table 8-5

**MAXIMUM CONTAMINANT LEVELS (MCLs) PROMULGATED UNDER THE  
SAFE DRINKING WATER ACT\***

Chemical	CAS No.	MCL (mg/l)
Arsenic	7440-38-2	0.05
Barium	7440-39-3	1.0
Benzene	71-343-2	0.005
Cadmium	7440-43-9	0.01
Carbon tetrachloride	56-23-5	0.005
Chromium (hexavalent)	7440-47-3	0.05
2,4-Dichlorophenoxy acetic acid	94-75-7	0.1
1,4-Dichlorobenzene	106-46-7	0.075
1,2-Dichloroethane	107-06-2	0.005
1,1-Dichloroethylene	75-35-4	0.007
Endrin	72-20-8	0.0002
Fluoride	--	4
Lindane	58-89-9	0.004
Lead	7439-92-1	0.05
Mercury	7439-97-6	0.002
Methoxychlor	72-43-5	0.1
Nitrate	--	10
Selenium	7782-49-2	0.01
Silver	7440-22-4	0.05
Toxaphene	8001-35-2	0.005
1,1,1-Trichloroethane	71-55-6	0.2
Trichloroethylene	79-01-6	0.005
2,4,5-Trichlorophenoxy acetic acid	93-76-5	0.01
Vinyl chloride	75-01-4	0.002

\* These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-6. Health-Based Criteria for Carcinogens<sup>1</sup>

Constituent	CAS No.	Class (A, B, C) <sup>2</sup>	Oral Exposure Route RSD <sup>3</sup>			Inhalation Exposure Route RSD <sup>3</sup>	
			CSF (mg/kg/day) <sup>-1</sup>	Soil (mg/kg)	Water (µg/l)	CSF (mg/kg/day) <sup>-1</sup>	Air (µg/m <sup>3</sup> )
Acrylamide <sup>4</sup>	79-06-1	B	3.85E+00	1.82E-01	9.09E-03	3.85E+00	9.09E-04
Acrylonitrile	107-13-1	B	5.4E-01	1.30E+00	6.5E-02	2.4E-01	1.5E-02
Aldrin	309-00-2	B	1.7E+01	4.1E-02	2.1E-03	1.7E+01	2.1E-04
Aniline <sup>4</sup>	62-53-3	C	2.6E-02	2.7E+02	1.3E+01	2.59E-02	1.35E+00
Arsenic <sup>4</sup>	7440-38-2	A	--	--	See MCL	1.51E+01	2.32E-04
Benz(a)anthracene <sup>4</sup>	56-55-3	B	3.12E+00	2.24E-01	1.12E-02	3.12E+00	1.12E-03
Benzene <sup>4</sup>	71-43-2	A	2.9E-02	2.4E+01	See MCL	2.9E-02	1.2E-01
Benzidine	92-87-5	A	2.3E+02	3.0E-03	1.5E-04	2.3E+02	1.5E-05
Benzo(a)pyrene <sup>4</sup>	50-32-8	B	1.15E+01	6.09E-02	3.04E-03	1.15E+01	3.04E-04
Beryllium <sup>4</sup>	7440-41-7	B	4.90+00	1.43E-01	7.14E-03	8.40E+00	4.17E-04
Bis(2-chloroethyl) ether	111-44-4	B	1.1E+00	6.4E-01	3.2E-02	1.1E+00	3.2E-03
Bis(chloromethyl) ether (BCME) <sup>4</sup>	542-88-1	A	9.45E+00	7.41E-02	3.70E-03	9.45E+00	3.70E-04
Bis(2-ethylhexyl) phthalate	117-81-7	B	8.4E-03	8.3E+01	4.2E+00	--	--
Cadmium	7440-43-9	B	--	--	See MCL	7.8E+00	4.5E-04
Carbon tetrachloride	56-23-5	B	1.3E-01	5.4E+00	See MCL	1.3E-01	2.7E-02
Chlordane	57-74-9	B	1.3E+00	5.4E-01	2.7E-02	1.3E+00	2.7E-03
1-Chloro-2,3-epoxypropane (Epichlorohydrin)	106-89-8	B	9.9E-03	7.1E+01	3.5E+00	4.8E-03	7.3E-01
Chloroform	67-66-3	B	6.1E-03	1.1E+02	5.7E+00	8.1E-02	4.3E-02
Chloromethyl methyl ether <sup>4</sup> (CMME)	107-30-2	A	9.45E+00	7.41E-02	3.70E-03	9.45E+00	3.70E-04
Chromium (hexavalent)	7440-47-3	A	--	--	See MCL	4.1E+01	8.5E-05
DDD	72-54-8	B	2.4E-01	2.9E+00	1.5E-01	--	--
DDE	72-55-9	B	3.4E-01	2.1E+00	1.0E-01	--	--
DDT	50-29-3	B	3.4E-01	2.1E+00	1.0E-01	3.4E-01	1.0E-02
Dibenz(a,h)anthracene <sup>4</sup>	53-70-3	B	4.90E+01	1.43E-02	7.14E-04	4.90E+01	7.14E-05
1,2-Dibromo-3-chloropropane <sup>4</sup> (DBCP)	96-12-8	B	2.21E+01	3.17E-02	1.58E-03	2.21E+01	1.58E-04

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-6. (continued)<sup>1</sup>

Constituent	CAS No.	Class (A, B, C) <sup>2</sup>	Oral Exposure Route RSD <sup>3</sup>			Inhalation Exposure Route RSD <sup>3</sup>	
			CSF (mg/kg/day) <sup>-1</sup>	Soil (mg/kg)	Water (µg/l)	CSF (mg/kg/day) <sup>-1</sup>	Air (µg/m <sup>3</sup> )
1,2-Dibromoethane	106-93-4	B	--	--	--	7.6E-01	4.6E-03
Dibutyltin diamine	924-16-3	B	5.40E+00	1.30E-01	6.48E-03	5.40E+00	6.48E-04
1,2-Dichloroethane	107-06-2	B	9.1E-02	7.7E+00	See MCL	9.1E-02	3.8E-02
1,1-Dichloroethylene	75-35-4	C	6.0E-01	1.2E+01	See MCL	1.2E+00	2.9E-02
Dichloromethane (Methylene chloride)	75-09-2	B	7.5E-03	9.3E+01	4.7E+00	1.4E-02	2.5E-01
1,3-Dichloropropene	542-75-6	B	1.8E-01	3.9E+00	1.9E-01	--	--
Dieldrin	60-57-1	B	1.6E+01	4.4E-02	2.2E-03	1.6E+01	2.2E-04
Diethylnitrosamine	55-18-5	B	1.5E+02	4.6E-03	2.3E-04	1.5E+02	2.3E-05
Diethylstilbestrol <sup>4</sup> (DES)	56-53-1	A	4.90E+02	1.43E-03	7.14E-05	4.90E+02	7.14E-06
2,4-Dinitrotoluene	121-14-2	B	3.08E-01	2.27E+00	1.14E-01	--	1E-01
1,4-Dioxane	123-91-1	B	4.90E-03	1.43E+02	7.14E+00	4.90E-03	7.14E-01
1,2-Diphenylhydrazine	122-66-7	B	8.0E-01	8.8E-01	4.4E-02	8.0E-01	4.4E-03
Ethylene oxide <sup>4</sup>	75-21-8	B	3.50E-01	2.00E+00	1.00E-01	3.50E-01	1.00E-02
Heptachlor	76-44-8	B	4.5E+00	1.6E-01	7.8E-03	4.5E+00	7.8E-04
Heptachlor epoxide	1024-57-3	B	9.1E+00	7.7E-02	3.8E-03	9.1E+00	3.8E-04
Hexachlorobenzene <sup>4</sup>	118-74-1	B	1.72E+00	4.07E-01	2.03E-02	1.72E-02	2.03E-01
Hexachlorobutadiene	87-68-3	C	7.8E-02	9.0E+01	4.5E+00	7.8E-02	4.5E-01
Hexachlorodibenzo-p-dioxin	19408-74-3	B	6.2E+03	1.1E-04	5.6E-06	6.2E+03	5.6E-07
Hexachloroethane	67-72-1	C	1.4E-02	5.0E+02	2.5E+01	1.4E-02	2.5E+00
Hydrazine	302-01-2	B	3.0E+00	2.3E-01	1.2E-02	1.02E+01	3.43E-04
Hydrazine sulfate	10034-93-2	B	3.0E+00	2.3E-01	1.2E-02	--	--
Lindane (gamma-Hexachlorocyclohexane) <sup>4</sup>	58-89-9	C	1.3E+00	5.4E+00	See MCL	1.3E+00	2.7E-02
3-Methylcholanthrene <sup>4</sup>	56-49-5	B	9.45E+00	7.41E-02	3.70E-03	9.45E+00	3.70E-04
4,4'-Methylene-bis-(2-chloroaniline) <sup>4</sup>	101-14-4	B	1.65E-01	4.24E+00	2.12E-01	1.65E-01	2.12E-02
Nickel <sup>4</sup>	1440-02-0	A	--	--	--	8.40E-01	4.17E-03
Nickel (refinery dust)	7440-02-0	A	--	--	--	8.4E-01	4.2E-03

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-6. (continued)<sup>1</sup>

Constituent	CAS No.	Class (A, B, C) <sup>2</sup>	Oral Exposure Route RSD <sup>3</sup>			Inhalation Exposure Route RSD <sup>3</sup>	
			CSF (mg/kg/day) <sup>-1</sup>	Soil (mg/kg)	Water (µg/l)	CSF (mg/kg/day) <sup>-1</sup>	Air (µg/m <sup>3</sup> )
Nickel subsulfide	12035-72-2	A	--	--	--	1.7E+00	2.1E-03
2-Nitropropane <sup>4</sup>	79-46-9	B	9.45E+00	7.41E-02	3.70E-03	9.45E+00	3.70E-04
N-Nitrosodiethanolamine	1116-54-7	B	2.8E+00	2.5E-01	1.3E-02	--	--
N-Nitrosodimethylamine (Dimethylnitrosamine)	62-75-9	B	5.1E+01	1.4E-02	6.9E-04	5.1E+01	6.9E-05
N-Nitrosodi-N-propylamine	621-64-7	B	7.0E+00	1.0E-01	5.0E-03	--	--
N-Nitroso-N-methylethylamine	10595-95-6	B	2.2E+01	3.2E-02	1.6E-03	--	--
N-Nitroso-N-methyl urea <sup>4</sup>	684-93-5	B	3.01E+02	2.33E-03	1.16E-04	3.01E+02	1.16E-05
N-Nitroso-pyrrolidine	930-55-2	B	2.1E+00	3.3E-01	1.7E-02	2.1E+00	1.7E-03
PCB's	1336-36-2	B	7.7E+00	9.1E-02	4.5E-03	--	--
Pentachloronitrobenzene <sup>4</sup>	82-68-8	C	2.56E-01	2.73E+01	1.37E+00	2.56E-01	1.37E-01
Perchloroethylene (Tetrachloroethylene)	127-18-4	C	5.1E-02	1.4E+02	6.9E+00	2.5E-01	1.4E-01
Pronamide (Kerb) <sup>4</sup>	23950-58-5	C	--	--	--	--	2E+00
Reserpine <sup>4</sup>	50-55-5	B	1.05E+01	6.67E-02	3.33E-03	1.05E+01	3.33E-04
Styrene	100-42-5	B	3.0E-02	2.3E+01	1.2E+00	2.0E-03	1.8E+00
1,1,2,2-Tetrachloroethane	79-34-5	C	2.00E-01	3.50E+01	1.75E+00	2.00E-01	1.75E-01
Thiourea <sup>4</sup>	62-56-6	B	1.93E+00	3.63E-01	5.18E-02	1.93E+00	5.18E-03
Toxaphene	8001-35-2	B	1.1E+00	6.4E-01	See MCL	1.1E+00	3.2E-03
1,1,2-Trichloroethane	79-00-5	C	5.7E-02	1.2E+02	6.1E+00	5.7E-02	6.1E-01
Trichloroethylene	79-01-6	B	1.1E-02	6.4E+01	See MCL	1.3E-02	2.7E-01
2,4,6-Trichlorophenol	88-06-2	B	2.0E-02	3.5E+01	1.8E+00	2.0E-02	1.8E-01

- 1 These criteria are subject to change and will be confirmed by the regulatory agency prior to use.
- 2 The EPA Carcinogen Classification system is discussed in 51 FR 33992-34003 (Guidelines for Carcinogen Risk Assessment)
- 3 See Table 8-2 for the appropriate intake assumptions used to derive these criteria.
- 4 Indicates criteria undergoing EPA review.

Table 8-7. Health-Based Criteria for Systemic Toxicants<sup>1</sup>

Constituent	CAS No.	RfD <sup>2</sup> (mg/kg/day)	Soil (mg/kg)	Water (µg/l)	Air (µg/m <sup>3</sup> )
Acetone	67-64-1	1E-01	8E + 03	4E + 03	--
Acetonitrile	75-05-8	6E-03	5E + 02	2E + 02	--
Acetophenone	98-86-2	1E-01	8E + 03	4E + 03	--
Aldicarb	116-06-3	1E-03	8E + 01	4E + 01	5E + 00
Aldrin	309-00-2	3E-05	2E + 00	1E + 00	--
Allyl alcohol	107-18-6	5E-03	4E + 02	2E + 02	--
Aluminum phosphide	20859-73-8	4E-04	3E + 01	1E + 01	--
Antimony	7440-36-0	4E-04	3E + 01	1E + 01	--
Barium	7440-39-3	5E-02	4E + 03	See MCL	--
Barium cyanide	542-62-1	7E-02	6E + 03	2E + 03	--
Benzidine	92-87-5	2E-03	2E + 02	7E + 01	--
Beryllium	7440-41-7	5E-03	4E + 02	2E + 02	--
Bis(2-ethylhexyl) phthalate	117-81-7	2E-02	2E + 03	7E + 02	--
Bromodichloromethane	75-27-4	2E-02	2E + 03	7E + 02	7E + 01
Bromoform	75-25-2	2E-02	2E + 03	7E + 02	--
Bromomethane	74-83-9	4E-04	3E + 01	1E + 01	--
Calcium cyanide	592-01-8	4E-02	3E + 03	1E + 03	--
Carbon disulfide	75-15-0	1E-01	8E + 03	4E + 03	--
Carbon tetrachloride	56-23-5	7E-04	6E + 01	See MCL	--
Chlordane	57-74-9	5E-05	4E + 00	2E + 00	--
Chlorine cyanide	506-77-4	5E-02	4E + 03	2E + 03	--
Chlorobenzene	108-90-7	3E-02	2E + 03	1E + 03	--
1-Chloro-2,3 epoxypropane (Epichlorohydrin)	106-89-8	2E-03	2E + 02	7E + 01	--
Chloroform	67-66-3	1E-02	8E + 02	4E + 02	--
Chromium (III)	16065-83-1	1E + 00	8E + 04	4E + 04	--
Chromium (VI)	7440-47-3	5E-03	4E + 02	See MCL	--
Copper cyanide	544-92-3	5E-03	4E + 02	2E + 02	--
Cresols	1319-77-3	5E-02	4E + 03	2E + 03	--
Crotonaldehyde	123-73-9	1E-02	8E + 02	4E + 02	--
Cyanide		2E-02	2E + 03	7E + 02	--
Cyanogen	460-19-5	4E-02	3E + 03	1E + 03	--
2,4-D	94-75-7	1E-02	8E + 02	See MCL	--
DDT	50-29-3	5E-04	4E + 01	2E + 01	--
Di-n-butylphthalate	84-74-2	1E-01	8E + 03	4E + 0	--

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-7. (continued)<sup>1</sup>

Constituent	CAS No.	RfD <sup>2</sup> (mg/kg/day)	Soil (mg/kg)	Water (µg/l)	Air (µg/m <sup>3</sup> )
Dichlorodifluoromethane	75-71-8	2E-01	2E + 04	7E + 03	--
1,1-Dichloroethylene	75-35-4	9E-03	7E + 02	See MCL	--
Dichloromethane (Methylene chloride)	75-09-2	6E-02	5E + 03	2E + 03	--
2,4-Dichlorophenol	120-83-2	3E-03	2E + 02	1E + 02	1E + 01
1,3-Dichloropropene	26952-23-8	3E-04	2E + 01	1E + 01	--
Dieldrin	60-57-1	5E-05	4E + 00	2E + 00	--
Diethyl phthalate	84-66-2	8E-01	6E + 04	3E + 04	--
Dimethoate	60-51-5	2E-02	2E + 03	7E + 02	--
2,4-Dinitrophenol	51-28-5	2E-03	2E + 02	7E + 01	7E + 00
Dinoseb	88-85-7	1E-03	8E + 01	4E + 01	--
Diphenylamine	127-39-4	3E-02	2E + 03	1E + 03	--
Disulfoton	298-04-4	4E-05	3E + 00	1E + 00	--
Endosulfan	115-29-7	5E-05	4E + 00	2E + 00	2E-01
Endothal	145-73-3	2E-02	2E + 03	7E + 02	--
Endrin	72-20-8	3E-04	2E + 01	See MCL	1E + 00
Ethylbenzene	100-41-4	1E-01	8E + 03	4E + 03	--
Heptachlor	76-44-8	5E-04	4E + 01	2E + 01	--
Heptachlor epoxide	1024-57-8	1E-05	8E-01	4E-01	--
Hexachlorobutadiene	87-68-3	2E-03	2E + 02	7E + 01	--
Hexachlorocyclopentadiene	77-47-4	7E-03	6E + 02	2E + 02	--
Hexachloroethane	67-72-1	1E-03	8E + 01	4E + 01	--
Hydrogen cyanide	74-90-8	2E-02	2E + 03	7E + 02	--
Hydrogen sulfide	7783-06-4	3E-03	2E + 02	1E + 02	--
Isobutyl alcohol	78-83-1	3E-01	2E + 04	1E + 04	1E + 03
Isophorone	78-59-1	2E-01	2E + 04	7E + 03	--
Lindane (hexachlorocyclohexane)	58-89-9	3E-04	2E + 01	See MCL	--
Maleic hydrazide	108-31-6	5E-01	4E + 04	2E + 04	--
Methacrylonitrile	126-98-7	1E-04	8E + 00	4E + 00	--
Methomyl	16752-77-5	3E-02	2E + 03	1E + 03	--
Methyl ethyl ketone	78-93-3	5E-02	4E + 03	2E + 03	--
Methylisobutylketone	108-10-01	5E-02	4E + 03	2E + 03	--

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-7. (continued)<sup>1</sup>

Constituent	CAS No.	RfD <sup>2</sup> (mg/kg/day)	Soil (mg/kg)	Water (µg/l)	Air (µg/m <sup>3</sup> )
Methyl mercury	22967-92-6	3E-04	2E + 01	1E + 01	--
Methyl parathion	298-00-0	3E-04	2E + 01	1E + 01	1E + 00
Nickel	7440-02-0	2E-02	2E + 03	7E + 02	--
Nitric oxide	10102-43-9	1E-01	8E + 03	4E + 03	--
Nitrobenzene	98-95-3	5E-04	4E + 01	2E + 01	--
Nitrogen dioxide	10102-44-0	1E + 00	8E + 04	4E + 04	--
Octamethylpyro-phosphoramidate	152-16-9	2E-03	2E + 02	7E + 01	--
Parathion	56-38-2	3E-04	2E + 01	1E + 01	--
Pentachlorobenzene	608-93-5	8E-04	6E + 01	3E + 01	3E + 00
Pentachloronitrobenzene	82-68-8	3E-03	2E + 02	1E + 02	--
Pentachlorophenol	87-86-5	3E-02	2E + 03	1E + 03	1E + 02
Perchloroethylene (Tetrachloroethylene)	127-18-4	1E-02	8E + 02	4E + 02	--
Phenol	108-95-2	4E-02	3E + 03	1E + 03	--
Phenyl mercuric acetate	62-38-4	8E-05	6E + 00	3E + 00	--
Phosphine	7803-51-2	3E-04	2E + 01	1E + 01	--
Potassium cyanide	151-50-8	5E-02	4E + 03	2E + 03	--
Potassium silver cyanide	506-61-6	2E-01	2E + 04	7E + 03	--
Pronamide (Kerb)	23950-58-5	8E-02	6E + 03	3E + 03	--
Pyridine	110-86-1	1E-03	8E + 01	4E + 01	--
Selenious Acid	7782-49-2	3E-03	2E + 02	See MCL	--
Selenourea	630-10-4	5E-03	4E + 02	2E + 02	--
Silver	7440-22-4	3E-03	2E + 02	See MCL	--
Silver cyanide	506-64-9	1E-01	8E + 03	4E + 03	--
Silvex (2,4,5-TP)	93-72-1	8E-03	6E + 02	3E + 02	--
Sodium cyanide	143-33-9	4E-02	3E + 03	1E + 03	--
Strychnine	57-24-9	3E-04	2E + 01	1E + 01	--
Styrene	100-42-5	2E-01	2E + 04	7E + 03	--
1,2,4,5-Tetrachlorobenzene	95-94-3	3E-04	2E + 01	1E + 01	1E + 00

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.



Table 8-7. (continued)<sup>1</sup>

Constituent	CAS No.	RfD <sup>2</sup> (mg/kg/day)	Soil (mg/kg)	Water (µg/l)	Air (µg/m <sup>3</sup> )
2,3,4,6-Tetrachlorophenol	58-90-2	3E-02	2E + 03	1E + 03	1E + 02
Tetraethyl lead	78-00-2	1E-07	8E-03	4E-03	4E-04
Thallic oxide	1314-32-5	4E-04	3E + 01	1E + 01	--
Thallium acetate	563-68-8	5E-04	4E + 01	2E + 01	--
Thallium carbonate	6533-73-9	4E-04	3E + 01	1E + 01	--
Thallium chloride	7791-12-0	4E-04	3E + 01	1E + 01	--
Thallium nitrate	10102-45-1	5E-04	4E + 01	2E + 01	--
Thallium selenite	12039-52-0	5E-04	4E + 01	2E + 01	--
Thallium sulfate	10031-59-1	3E-04	2E + 01	1E + 01	--
Thiram	137-26-8	5E-03	4E + 02	2E + 02	--
Toluene	108-88-3	3E-01	2E + 04	1E + 04	--
1,2,4-Trichlorobenzene	120-82-1	2E-02	2E + 03	7E + 02	--
1,1,1-Trichloroethane	71-55-6	9E-02	7E + 03	See MCL	--
1,1,2-Trichloroethane	79-00-5	2E-01	2E + 04	7E + 03	--
Trichloromono-fluoromethane	75-69-4	3E-01	2E + 04	1E + 04	--
2,4,5-Trichlorophenol	95-95-4	1E-01	8E + 03	4E + 03	4E + 02
2,4,5-Trichlorophenoxy acetic acid (2,4,5-T)	93-76-5	3E-03	2E + 02	See MCL	--
1,1,2-Trichloropropane	598-77-6	5E-03	4E + 02	2E + 02	--
1,2,3-Trichloropropane	96-18-4	1E-03	8E + 01	4E + 01	--
Vanadium pentoxide	1314-62-1	2E-02	2E + 03	7E + 02	--
Warfarin	81-81-2	3E-04	2E + 01	1E + 01	--
Xylene (total)	1330-20-7	2E + 00	2E + 05	7E + 04	--
Zinc cyanide	557-21-1	5E-02	4E + 03	2E + 03	--
Zinc phosphide	1314-84-7	3E-04	2E + 01	1E + 01	--

- 1 These criteria are subject to change and will be confirmed by the regulatory agency prior to use.
- 2 See Table 8-2 for the appropriate intake assumptions used to derive these criteria.

Table 8-8. Water Quality Criteria Summary<sup>1</sup>

Chemical	WATER CONCENTRATIONS IN µg/L FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Acenaphthene <sup>11</sup>	1,700 <sup>8</sup>	520 <sup>8</sup>	970 <sup>8</sup>	710 <sup>8</sup>			1980FR
Acrolein	68 <sup>8</sup>	21 <sup>8</sup>	55 <sup>8</sup>		320 µg	780µg	1980FR
Acrylonitrile	7,550 <sup>8</sup>	2,600 <sup>8</sup>			0.058 µg <sup>9</sup>	0.65µg <sup>9</sup>	1980FR
Aldrin	3.0		1.3		0.074ng <sup>9</sup>	0.079ng <sup>9</sup>	1980FR
Alkalinity <sup>11</sup>		20,000					1976RB
Ammonia <sup>2,11</sup>							1985FR
Antimony	9,000 <sup>8</sup>	1,600 <sup>8</sup>			146µg	45,000 µg	1980FR
Arsenic					2.2ng <sup>9</sup>	17.5ng <sup>9</sup>	1980FR
Arsenic (PENT)	850 <sup>8</sup>	48 <sup>8</sup>	2,319 <sup>8</sup>	13 <sup>8</sup>			1985FR
Arsenic (TRI)	360	190	69	36			1985FR
Asbestos <sup>11</sup>					30k f/L <sup>9</sup>		1960FR
Bacteria <sup>3,11</sup>							1966FR
Barium					1mg		1976RB
Benzene	5,300 <sup>8</sup>		5,100 <sup>8</sup>	700 <sup>8</sup>	0.66µg <sup>9</sup>	40µg <sup>9</sup>	1980FR
Benzidine	2,500 <sup>8</sup>				0.12ng <sup>9</sup>	0.53ng <sup>9</sup>	1980FR
Beryllium	130 <sup>8</sup>	5.3 <sup>8</sup>			6.8ng <sup>9</sup>	117ng <sup>9</sup>	1980FR
BHC	100 <sup>8</sup>		0.34 <sup>8</sup>				1980FR
Cadmium	3.9 <sup>7</sup>	1.1 <sup>7</sup>	43	9.3	10µg		1985FR
Carbon tetrachloride	35,200 <sup>8</sup>		50,000 <sup>8</sup>		0.4µg <sup>9</sup>	6.94µg <sup>9</sup>	1980FR
Chlordane	2.4	0.0043	0.09	0.004	0.46ng <sup>9</sup>	0.48ng <sup>9</sup>	1980FR
Chlorinated Benzenes	250 <sup>8</sup>	50 <sup>8</sup>	160 <sup>8</sup>	129 <sup>8</sup>	488µg		1980FR
Chlorinated Naphthalenes	1,600 <sup>8</sup>		7.5 <sup>8</sup>				1980FR
Chlorine <sup>11</sup>	19	11	13	7.5			1985FR
Chloroalkyl Ethers <sup>11</sup>	238,000 <sup>8</sup>						1980FR

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-8. (continued)<sup>1</sup>

Chemical	WATER CONCENTRATIONS IN µg/L FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Chloroethyl ether (BIS-2),					0.03µg <sup>9</sup>	1.36µg <sup>9</sup>	1980FR
Chloroform	28,900 <sup>8</sup>	1,240 <sup>8</sup>			0.19µg <sup>9</sup>	15.7µg <sup>9</sup>	1980FR
Chloroisopropyl ether (BIS-2) <sup>11</sup>					34.7µg	4.36mg	1980FR
Chloromethyl ether (BIS)					0.00000376 ng <sup>9</sup>	0.00184µg <sup>9</sup>	1980FR
Chlorophenol 2 <sup>11</sup>	4,380 <sup>8</sup>	2,000 <sup>8</sup>					1980FR
Chlorophenol 4			29,700 <sup>8</sup>				1980FR
Chlorophenoxy Herbicides (2,4,5-TP)					10µg		1980FR
Chlorophenoxy Herbicides (2,4,-D)					100µg		1976FR
Chlorpyrifos <sup>11</sup>	0.083	0.041	0.011	0.0056			1986FR
Chloro-4 methyl-3 phenol	30 <sup>8</sup>						1980FR
Chromium (HEX)	16	11	1,100	50	50µg		1985FR
Chromium (TRI)	1,700 <sup>7</sup>	210 <sup>7</sup>	10,300 <sup>8</sup>		170mg	3,433mg	1985FR
Color <sup>4,11</sup>							1976RB
Copper <sup>11</sup>	18 <sup>7</sup>	12 <sup>7</sup>	2.9	2.9			1985FR
Cyanide	22	5.2	1	1	200µg		1985FR
DDT	1.1	0.001	0.13	0.001	0.024ng <sup>9</sup>	0.024ng <sup>9</sup>	1980FR
DDT Metabolite (DDE)	1,050 <sup>8</sup>		14 <sup>8</sup>				1980FR
DDT Metabolite (TDE)	0.06 <sup>8</sup>		3.8 <sup>8</sup>				1980FR
Demeton <sup>11</sup>		0.1		0.1			1976RB
Dibutyl phthalate					35mg	154mg	1980FR
Dichlorobenzenes	1,120 <sup>8</sup>	763 <sup>8</sup>	1,970 <sup>8</sup>		400µg	2.6mg	1980FR
Dichlorobenzidine					0.01µg <sup>9</sup>	0.020µg <sup>9</sup>	1980FR

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-8. (continued)<sup>1</sup>

Chemical	WATER CONCENTRATIONS IN $\mu\text{g/L}$ FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Dichloroethane 1,2	118,000 <sup>a</sup>	20,000 <sup>a</sup>	113,000 <sup>a</sup>		0.94 $\mu\text{g}^b$	243 $\mu\text{g}^b$	1980FR
Dichloroethylenes	11,600 <sup>a</sup>		224,000 <sup>a</sup>		0.033 $\mu\text{g}^b$	1.85 $\mu\text{g}^b$	1980FR
Dichlorophenol 2,4	2,020 <sup>a</sup>	365 <sup>a</sup>			3.09mg		1980FR
Dichloropropane	23,000 <sup>a</sup>	5,700 <sup>a</sup>	10,300 <sup>a</sup>	3,040 <sup>a</sup>			1980FR
Dichloropropene	6,060 <sup>a</sup>	244 <sup>a</sup>	790 <sup>a</sup>		87 $\mu\text{g}$	14.1mg	1980FR
Dieldrin	2.5	0.0019	0.71	0.019	0.071ng <sup>b</sup>	0.076ng <sup>b</sup>	1980FR
Diethyl phthalate					350mg	1.8g	1980FR
Dimethyl phenol 2,4	2,120 <sup>a</sup>						1980FR
Dimethyl phthalate					313mg	2.9g	1980FR
Dinitrotoluene 2,4					0.11 $\mu\text{g}^b$	9.1 $\mu\text{g}^b$	1980FR
Dinitrotoluene					70 $\mu\text{g}$	14.3 $\mu\text{g}$	1980FR
Dinitrotoluene	330 <sup>a</sup>	230 <sup>a</sup>	590 <sup>a</sup>	370 <sup>a</sup>			1980FR
Dinitro-o-Cresol 2,4					13.4 $\mu\text{g}$	765 $\mu\text{g}$	1980FR
Dioxin (2,3,7,8-TCDD)	0.01 <sup>a</sup>	0.00001 <sup>a</sup>			0.000013 ng <sup>b</sup>	0.000014ng <sup>b</sup>	1984FR
Diphenylhydrazine					42ng <sup>b</sup>	0.56 $\mu\text{g}^b$	1980FR
Diphenylhydrazine 1,2	270 <sup>a</sup>						1980FR
Di-2-ethyl hexyl phthalate					15mg	50mg	1980FR
Endosulfan	0.22	0.056	0.034	0.0087	74 $\mu\text{g}$	159 $\mu\text{g}$	1980FR
Endrin	0.18	0.0023	0.037	0.0023	1 $\mu\text{g}$		1980FR
Ethylbenzene <sup>11</sup>	32,000 <sup>a</sup>		430 <sup>a</sup>		1.4mg	3.28mg	1980FR
Fluoranthene	3,980 <sup>a</sup>		40 <sup>a</sup>	16 <sup>a</sup>	42 $\mu\text{g}$	54 $\mu\text{g}$	1980FR
Gases, Total <sup>4,11</sup> Dissolved							1976RB
Guthion <sup>11</sup>		0.01		0.01			1976RB

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-8. (continued)<sup>1</sup>

Chemical	WATER CONCENTRATIONS IN µg/L FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Haloethers	360 <sup>8</sup>	122 <sup>8</sup>					1980FR
Halomethanes	11,000 <sup>8</sup>		12,000 <sup>8</sup>	8,400 <sup>8</sup>	0.19µg <sup>9</sup>	15.7µg <sup>9</sup>	1980FR
Heptachlor	0.52	0.0038	0.053	0.0036	0.28ng <sup>9</sup>	0.29ng <sup>9</sup>	1980FR
Hexachloroethane	960 <sup>8</sup>	540 <sup>8</sup>	940 <sup>8</sup>		1.9µg	8.74µg	1980FR
Hexachlorobenzene					0.72ng <sup>9</sup>	0.74ng <sup>9</sup>	1980FR
Hexachloro-butadiene	90 <sup>8</sup>	9.3 <sup>8</sup>	32 <sup>8</sup>		0.45µg <sup>9</sup>	50µg <sup>9</sup>	1980FR
Hexachlorocyclohexane (Lindane)	2.0	0.08	0.16				1980FR
Hexachlorocyclohexane-Alpha <sup>11</sup>					9.2ng <sup>9</sup>	31ng <sup>9</sup>	1980FR
Hexachlorocyclohexane-Beta <sup>11</sup>					16.3ng <sup>9</sup>	54.7ng <sup>9</sup>	1980FR
Hexachlorocyclohexane-Gamma <sup>11</sup>					18.6ng <sup>9</sup>	62.5ng <sup>9</sup>	1980FR
Hexachlorocyclohexane-Technical <sup>11</sup>					12.3ng <sup>9</sup>	41.4ng <sup>9</sup>	1980FR
Hexachlorocyclopentadine	7 <sup>8</sup>	5.2 <sup>8</sup>	7 <sup>8</sup>		206µg		1980FR
Iron <sup>11</sup>		1,000			0.3mg		1976RB
Isopnorne <sup>11</sup>	117,000 <sup>8</sup>		12,900 <sup>8</sup>		5.2mg	520mg	1980FR
Lead	82 <sup>7</sup>	3.2 <sup>7</sup>	140	5.6	50µg		1985FR
Malathion <sup>11</sup>		0.1		0.1			1976RB
Manganese <sup>11</sup>					50µg	100µg	1976RB
Mercury	2.4	0.012	2.1	0.025	144ng	146ng	1985FR
Methoxychlor		0.03		0.03	100µg		1976RB
Mirex <sup>11</sup>		0.001		0.001			1976RB
Monochlorobenzene					488µg		1980FR
Naphthalene	2,300 <sup>8</sup>	620 <sup>8</sup>	2,350 <sup>8</sup>				1980FR
Nickel	1,400 <sup>7</sup>	160 <sup>7</sup>	75	8.3	13.4µg	100µg	1986FR
Nitrates <sup>11</sup>					10mg		1976RB

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-8. (continued)<sup>1</sup>

Chemical	WATER CONCENTRATIONS IN µg/L FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Nitrobenzene	27,000 <sup>a</sup>		6,680 <sup>a</sup>		19.8mg		1980FR
Nitrophenols	230 <sup>a</sup>	150 <sup>a</sup>	4,850 <sup>a</sup>				1980FR
Nitrosamines	5,650 <sup>a</sup>		3,300,000 <sup>a</sup>		0.8ng <sup>9</sup>	1240ng <sup>9</sup>	1980FR
Nitrosodibutyl- amine N					6.4ng <sup>9</sup>	587ng <sup>9</sup>	1980FR
Nitrosodiethyl- amine N					0.8ng <sup>9</sup>	1,240ng <sup>9</sup>	1980FR
Nitrosodimethyl- amine N					1.4ng <sup>9</sup>	16,000ng <sup>9</sup>	1980FR
Nitrosodiphenyl- amine N					4,900ng <sup>9</sup>	16,100ng <sup>9</sup>	1980FR
Nitrosopyrrolidine N					16ng <sup>9</sup>	91,900ng <sup>9</sup>	1980FR
Oil and Grease <sup>4,11</sup>							1976RB
Oxygen Dissolved <sup>5,11</sup>							1986FR
Parathion	0.065	0.013					1986FR
PCB's	2.0	0.014	10	0.03	0.079ng <sup>9</sup>	0.079ng <sup>9</sup>	1980FR
Pentachlorinated Ethanes	7,240 <sup>a</sup>	1,100 <sup>a</sup>	390 <sup>a</sup>	281 <sup>a</sup>			1980FR
Pentachloro- benzene					74g	85µg	1980FR
Pentachlorophenol	20 <sup>10</sup>	13 <sup>10</sup>	13	7.9 <sup>a</sup>	1.01mg		1966FR
pH <sup>11</sup>		6.5-9		6.5-8.5			1976RB
Phenol	10,200 <sup>a</sup>	2,560 <sup>a</sup>	5,800 <sup>a</sup>		3.5mg		1980FR
Phosphorus Elemental <sup>11</sup>				0.1			1976RB
Phthalate Esters	940 <sup>a</sup>	3 <sup>a</sup>	2,944 <sup>a</sup>	3.4 <sup>a</sup>			1980FR
Polynuclear Aromatic Hydrocarbons			300 <sup>a</sup>		2.8ng <sup>9</sup>	31.1ng <sup>9</sup>	1980FR
Selenium	260	35	410	54	10µg		1980FR
Silver	4.1 <sup>7</sup>	0.12	2.3		50µg		1980FR

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-8. (continued)<sup>1</sup>

Chemical	WATER CONCENTRATIONS IN µg/L FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Solids Dissolved and Salinity <sup>11</sup>					250mg		1976R8
Solids Suspended and Turbidity <sup>4,11</sup>							1976R8
Sulfide-Hydrogen Sulfide		2		2			1976R8
Temperature <sup>6,11</sup>							1976R8
Tetrachlorinated Ethanes	9,320 <sup>8</sup>						1980FR
Tetrachloro- benzene 1,2,4,5					38µg	48µg	1980FR
Tetrachloroethane 1,1,2,2		2,400 <sup>8</sup>	9,020 <sup>8</sup>		0.17µg <sup>9</sup>	10.7µg <sup>9</sup>	1980FR
Tetrachloroethanes	9,320 <sup>8</sup>						1980FR
Tetrachloro- ethylene	5,280 <sup>8</sup>	840 <sup>8</sup>	10,200 <sup>8</sup>	450 <sup>8</sup>	0.8µg <sup>9</sup>	8.85µg <sup>9</sup>	1980FR
Tetrachlorophenol 2,3,5,6				440 <sup>8</sup>			1980FR
Thallium	1,400 <sup>8</sup>	40 <sup>8</sup>	2,130 <sup>8</sup>		13µg	48µg	1980FR
Toluene	17,500 <sup>8</sup>		6,300 <sup>8</sup>	5,000 <sup>8</sup>	14.3mg	424mg	1980FR
Toxaphene	0.73	0.0002	0.21	0.0002	0.71ng <sup>9</sup>	0.73ng <sup>9</sup>	1986FR
Trichlorinated Ethanes	18,000 <sup>8</sup>						1980FR
Trichloroethane 1,1,1			31,200 <sup>8</sup>		18.4mg	1.03g	1980FR
Trichloroethane 1,1,2		9,400 <sup>8</sup>			0.6µg <sup>9</sup>	41.8µg <sup>9</sup>	1980FR
Trichloroethylene	45,000 <sup>8</sup>	21,900 <sup>8</sup>	2,000 <sup>8</sup>		2.7µg <sup>9</sup>	80.7µg <sup>9</sup>	1980FR
Trichlorophenol 2,4,5					2,600µg		1980FR
Trichlorophenol 2,4,6		970 <sup>8</sup>			1.2µg <sup>9</sup>	3.6µg <sup>9</sup>	1980FR
Vinyl Chloride					2µg <sup>9</sup>	525µg <sup>9</sup>	1980FR
Zinc <sup>11</sup>	1207	1107	95	86			1987FR

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

**Footnotes for Table 8-8:**

- 1 This table is for general information purposes only; see criteria documents or detailed summaries in Quality Criteria for Water 1986 for more information. These criteria are subject to change and will be confirmed by the regulatory agency prior to use.**
- 2 Criteria are pH and temperature dependent - See Document (1)**
- 3 For primary recreation and shellfish uses - See Document (1)**
- 4 Narrative statement - See Document (1)**
- 5 Warmwater and coldwater criteria matrix - See Document (1)**
- 6 Species dependent criteria - See Document (1)**
- 7 Hardness Dependent Criteria (100 mg/l used)**
- 8 Insufficient data to develop criteria. Value presented is lowest observed effect level.**
- 9 Human health criteria for carcinogens reported for three risk levels. Value presented in this table is the 10<sup>-6</sup> risk level.**
- 10 pH dependent criteria - 7.8 pH used.**
- 11 Indicates chemical or parameter not on Appendix VIII. The regulatory agency will exercise discretion prior to requiring such chemicals or parameters to be monitored during the RFI.**

**General -    g     =    grams  
              mg    =    milligrams  
              µg    =    micrograms  
  
              ng     =    nanograms  
              f      =    fibers**

**FR    =    Federal Register  
RB    =    Quality Criteria for  
              Water, 1976  
              (Redbook)**



**Table 8-9. Individual Listing of Constituents Contained Within  
Chemical Groups Identified in Table 8-8**

Chemical Group	Individual Constituents
Chlorinated Benzenes	Chlorobenzene 1,2,4-Trichlorobenzene Hexachlorobenzene
Chlorinated Ethanes	1,2-Dichloroethane 1,1,1-Trichloroethane Hexachloroethane 1,1-Dichloroethane 1,1,2-Trichloroethane Chloroethane
Chloroalkyl Ethers	Bis(chloromethyl) ether Bis(2-chloroethyl) ether 2-Chloroethyl vinyl ether (mixed)
Chlorinated Naphthalene	2-Chloronaphthalene
Chlorinated Phenols	2,4,5-Trichlorophenol Parachlorometa cresol
Dichlorobenzenes	1,2-Dichlorobenzene 1,3-Dichlorobenzene 1,4-Dichlorobenzene
Dichlorobenzidine	3,3'-Dichlorobenzidine
Dichloroethylenes	1,1-Dichloroethylene 1,2-Trans-dichloroethylene
Dichloropropane and Dichloropropene	1,2-Dichloropropane 1,2-Dichloropropylene (1,3-dichloropropene)
Dinitrotoluene	2,4-Dinitrotoluene 2,5-Dinitrotoluene
Haloethers	4-Chlorophenyl phenyl ether 4-Bromophenyl phenyl ether Bis (2-chloroisopropyl) ether Bis (2-chloroethoxy) methane
Halomethanes	Methylene chloride (dichloromethane) Methyl chloride (chloromethane) Methyl bromide (bromomethane) Bromoform (tribromomethane) Dichlorobromomethane Trichlorofluoromethane Dichlorodifluoromethane Chlorodibromomethane

Table 8-9. (Continued)

Chemical Group	Individual Constituents
Nitrophenols	2-Nitrophenol 4-Nitrophenol 2,4-Dinitrophenol 4,6-Dinitro-o-cresol
Nitrosamines	N-Nitrosodimethylamine N-Nitrosodiphenylamine N-Nitrosodi-n-propylamine
Phthalate Esters	Bis (2-ethylhexyl) phthalate Butyl benzyl phthalate Di-n-butyl phthalate Di-n-octyl phthalate Diethyl phthalate Dimethyl phthalate
Polynuclear Aromatic Hydrocarbons	Benzo(a) anthracene (1,2-benzanthracene) Benzo(a) pyrene 3,4-Benzofluoranthene Benzo(k) fluoranthene (11,12-benzofluoranthene) Chrysene Acenaphthylene Anthracene Benzo(ghi)Perylene (1,12-benzoperylene) Fluorene Phenanthrene Dibenzo(a,h)anthracene (1,2,5,6-dibenzanthracene) Indeno (1,2,3-cd)pyrene Pyrene
Endosulfan and Metabolites	a-Endosulfan-Alpha p-Endosulfan-Beta Endosulfan sulfate
Endrin and Metabolites	Endrin
Heptachlor and Metabolites	Heptachlor Heptachlor epoxide
Polychlorinated Biphenyls	PCB-1242 (Arochlor 1242) PCB-1254 (Arochlor 1254) PCB-1221 (Arochlor 1221) PCB-1232 (Arochlor 1232) PCB-1248 (Arochlor 1248) PCB-1260 (Arochlor 1260) PCB-1016 (Arochlor 1016)

	Standards				Health Advisories										
Chemicals	Status Reg.*	NPDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)	Status HA *	10-kg Child			70-kg Adult					Cancer Group	
						One-day ug/l	Ten-day ug/l	Longer- term ug/l	Longer- term ug/l	RI/D ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk		
Organics															
Acenaphthylene	-	-	-	-	D	-	-	-	-	-	-	-	-	-	
Acifluorfen	-	-	-	-	F	2000	200	100	400	13	400	-	100	B2	
Acrylamide	P	-	zero	TT	F	150	300	20	70	0.2	7	-	1	B2	
Acrylonitrile	L	-	-	-	-	-	-	-	-	-	-	-	-	-	
Adipates	T	-	zero	-	-	-	-	-	-	-	-	-	-	-	
Alachlor	P	-	zero	2	F	100	100	-	-	10	400	-	40	B2	
Aldicarb	P	-	10	10	F	10	10	10	40	1.3	40	10	-	D	
Aldicarb sulfone	P	-	40	40	F	60	60	60	200	6.0	200	40	-	D	
Aldicarb sulfoxide	P	-	10	10	F	10	10	10	40	1.3	40	10	-	D	
Ametryn	-	-	-	-	F	9000	9000	900	3000	9	300	60	-	D	
Ammonia	L	-	-	-	D	-	-	-	-	-	-	-	-	-	
Ammonium Sulfamate	-	-	-	-	F	20000	20000	20000	80000	250	8000	2000	-	D	
Anthracene	L	-	-	-	-	-	-	-	-	-	-	-	-	D	
Atrazine	P	-	3	3	F	100	100	50	200	5	200	3	-	C	
Baygon	-	-	-	-	F	40	40	40	100	4	100	3	-	C	
Bentazon	-	-	-	-	F	300	300	300	900	2.5	90	20	-	D	
Benz(a)anthracene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2	
Benzene	F	-	zero	5	F	200	200	-	-	-	-	-	100	A	
Benzo(a)pyrene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2	
Benzo(b)fluoranthene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2	
Benzo(g,h,i)perylene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	D	
Benzo(k)fluoranthene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2	
bis-2-Chloroisopropyl ether	-	-	-	-	D	-	-	-	-	-	-	-	-	-	
Bromacil	-	-	-	-	F	5000	5000	3000	9000	130	5000	90	-	C	
Bromobenzene	-	-	-	-	D	-	-	-	-	-	-	-	-	-	
Bromochloroacetonitrile	L	-	-	-	D	-	-	-	-	-	-	-	-	-	
Bromochloromethane	-	-	-	-	D	-	-	-	-	-	-	-	-	-	
Bromodichloromethane (THM)	L	100	-	-	D	-	-	-	-	2	-	-	-	-	
Bromoform (THM)	L	100	-	-	D	-	-	-	-	20	-	-	-	-	
Bromomethane	-	-	-	-	D	-	-	-	-	-	-	-	-	-	
Butyl benzyl phthalate (BBP)	T	zero	-	-	-	-	-	-	-	200	-	-	-	C	
Butylate	-	-	-	-	F	2000	2000	1000	1000	50	2000	350	-	D	
Butylbenzene n-	-	-	-	-	D	-	-	-	-	-	-	-	-	-	
Butylbenzene sec-	-	-	-	-	D	-	-	-	-	-	-	-	-	-	
Butylbenzene tert-	-	-	-	-	D	-	-	-	-	-	-	-	-	-	
Carbaryl	-	-	-	-	F	1000	1000	1000	1000	100	4000	700	-	D	
Carbafuran	P	-	40	40	F	50	50	50	200	5	200	40	-	E	
Carbon Tetrachloride	F	-	zero	5	F	4000	200	70	300	0.7	30	-	30	B2	

Chemicals	Standards				Status HA *	Health Advisories								Cancer Group
	Status Reg.*	MCLDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)		10-kg Child			70-kg Adult					
						One-day ug/l	Ten-day ug/l	Longer- term ug/l	Longer- term ug/l	RfD ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk	
Carboxin	-	-	-	-	F	1000	1000	1000	4000	100	4000	700	-	D
Chloramben	-	-	-	-	F	3000	3000	200	500	15	500	100	-	D
Chloramine	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chlorate	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chlordane	P	-	zero	2	F	60	60	0.5	0.5	0.045	2	-	3	B2
Chlorine	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chlorine dioxide	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chlorite	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chloroacetaldehyde	L	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorodibromomethane (THM)	L	100	-	-	D	-	-	-	-	2	-	-	-	-
Chloroethane	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chloroform (THM)	L	100	-	-	D	-	-	-	-	10	-	-	600	B2
Chloromethane	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chlorophenol (2,4,6-)	L	-	-	-	D	-	-	-	-	-	-	-	300	B2
Chlorophenol (2,4-)	L	-	-	-	D	-	-	-	-	3	100	-	-	-
Chlorophenol (2-)	L	-	-	-	D	-	-	-	-	5	200	-	-	-
Chloropicrin	L	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorothalonil	-	-	-	-	F	200	200	200	500	15	500	-	200	B2
Chlorotoluene o-	L	-	-	-	D	-	-	-	-	20	-	-	-	D
Chlorotoluene p-	L	-	-	-	D	-	-	-	-	0.1	-	-	-	D
Chrysene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2
Cyanazine	L	-	zero	-	F	100	100	20	70	2	70	10	-	D
Cyanogen Chloride	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Cymene p-	-	-	-	-	D	-	-	-	-	-	-	-	-	-
2,4-D	P	100	70	70	F	1000	300	100	400	10	400	70	-	D
Dacthal (DCPA)	-	-	-	-	F	80000	80000	5000	20000	500	20000	4000	-	D
Dalapon	T	-	200	-	F	3000	3000	300	900	26	900	200	-	D
DCE (cis-1,2-)	P	-	70	70	F	4000	1000	1000	1000	10	400	70	-	D
DCE (trans-1,2-)	P	-	100	100	F	20000	2000	2000	6000	20	600	100	-	D
Diazinon	-	-	-	-	F	20	20	5	20	0.09	3	0.6	-	E
Dibenz(a,h)anthracene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2
Dibromoacetonitrile	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dibromochloropropane (DBCP)	P	-	zero	0.2	F	200	50	-	-	-	-	-	3	B2
Dibromomethane	L	-	-	-	D	-	-	-	-	-	-	-	-	D
Dibutyl phthalate (DBP)	T	-	zero	-	-	-	-	-	-	100	-	-	-	D
Dicamba	L	-	-	-	F	300	300	300	1000	30	1000	200	-	D
Dichloroacetaldehyde	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloroacetic acid	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloroacetonitrile	L	-	-	-	D	-	-	-	-	8	-	-	-	C

Chemicals	Standards				Status HA *	Health Advisories								Cancer Group
	Status Reg.*	MPPDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)		10-kg Child			70-kg Adult					
						One-day ug/l	Ten-day ug/l	Longer- term ug/l	Longer- term ug/l	RfD ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk	
Dichlorobenzene p- t	F	-	75	75	F	10000	10000	10000	40000	100	4000	75	-	C
Dichlorobenzene o,m-	P	-	600	600	F	9000	9000	9000	30000	89	3000	600	-	D
Dichlorodifluoromethane	-	-	-	-	D	-	-	-	-	20	-	-	-	-
Dichloroethane (1,1-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloroethane (1,2-)	F	-	zero	5	F	700	700	700	2600	-	-	-	40	B2
Dichloroethylene (1,1-)	F	-	7	7	F	2000	1000	1000	4000	9	400	7	-	C
Dichloromethane	T	-	zero	-	F	10000	2000	-	-	60	2000	-	500	B2
Dichloropropane (1,1-)	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloropropane (1,2-)	P	-	zero	5	F	-	90	-	-	-	-	-	60	B2
Dichloropropane (1,3-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloropropane (2,2-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloropropene (1,1-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloropropene (1,3-)	L	-	-	-	F	30	30	30	100	0.3	10	-	20	B2
Dieldrin	L	-	-	-	F	0.5	0.5	0.5	2	0.05	2	-	0.2	B2
Diethyl phthalate (DEP)	T	-	zero	-	D	-	-	-	-	800	-	-	-	D
Diethylhexyl phthalate (DEHP)	T	-	zero	-	D	-	-	-	-	20	-	-	-	B2
Dimethrin	-	-	-	-	F	10000	10000	10000	40000	300	10000	2000	-	D
Dimethyl phthlate (DMP)	L	-	-	-	-	-	-	-	-	-	-	-	-	D
Dinitrotoluene (2,4-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dinoseb	T	-	7	-	F	300	300	10	40	1	40	7	-	-
Dioxane p-	-	-	-	-	F	4000	400	-	-	-	-	-	700	B2
Diphenamid	-	-	-	-	F	300	300	300	1000	30	1000	200	-	D
Diquat	T	-	20	-	-	-	-	-	-	2.2	-	-	-	-
Disulfoton	-	-	-	-	F	10	10	3	9	0.04	1	0.3	-	E
Diuron	-	-	-	-	F	1000	1000	300	900	2	70	10	-	D
Endosulf	T	-	100	-	F	800	800	200	200	20	700	100	-	D
Endrin	T	0.2	2	-	F	20	20	3	10	3	9	2	-	D
Epichlorohydrin	P	-	zero	TT	F	100	100	70	70	2	70	-	400	B2
Ethylbenzene	P	-	700	700	F	30000	3000	1000	3000	100	3000	700	-	D
Ethylene dibromide (EDB)	P	-	zero	0.05	F	8	8	-	-	-	-	-	0.04	B2
Ethylene glycol	-	-	-	-	F	20000	6000	6000	20000	2000	40000	7000	-	D
ETU	L	-	-	-	F	300	300	100	400	0.03	1	-	20	B2
Fenamiphos	-	-	-	-	F	9	9	5	20	0.25	9	2	-	D
Flumeturon	-	-	-	-	F	2000	2000	2000	5000	13	400	90	-	D
Fluorene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	D
Fluorotrichloromethane	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Fonofos	-	-	-	-	F	20	20	20	70	2	70	10	-	D
Formaldehyde	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Gasoline	-	-	-	-	D	-	-	-	-	-	-	-	-	-

Chemicals	Standards				Status HA *	Health Advisories								Cancer Group
	Status Reg.*	NPDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)		10-kg Child			70-kg Adult					
						One-day ug/l	Ten-day ug/l	Longer- term ug/l	Longer- term ug/l	RfD ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk	
Glyphosate	T	-	700	-	F	20000	20000	1000	1000	100	4000	700	-	D
Heptachlor	P	-	zero	0.4	F	10	10	5	5	0.5	20	-	0.8	B2
Heptachlor epoxide	P	-	zero	0.2	F	10	-	0.1	0.1	0.013	0.4	-	0.4	B2
Hexachlorobenzene	T	-	zero	-	F	50	50	50	200	0.8	30	-	2	B2
Hexachlorobutadiene	-	-	-	-	D	-	-	-	-	2	-	-	50	C
Hexachlorocyclopentadiene	T	-	50	-	-	-	-	-	-	7	200	-	-	-
Hexane (n-)	-	-	-	-	F	10000	4000	4000	10000	-	-	-	-	D
Hexazinone	-	-	-	-	F	3000	3000	3000	9000	30	1000	200	-	D
Hypochlorite	L	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypochlorous acid	L	-	-	-	-	-	-	-	-	-	-	-	-	-
Indeno(1,2,3,-c,d)pyrene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2
Isophorone	L	-	-	-	D	-	-	-	-	150	-	-	-	-
Isopropylbenzene	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Lindane	P	4	0.2	0.2	F	1000	1000	30	100	0.3	10	0.2	3	C
Maleic hydrazide	-	-	-	-	F	10000	10000	5000	20000	500	20000	4000	-	D
MCPA †	-	-	-	-	F	100	100	100	400	0.5	20	4	-	E
Methomyl	-	-	-	-	F	300	300	300	300	25	900	200	-	D
Methoxychlor	P	100	400	400	F	6000	2000	500	2000	50	2000	400	-	D
Methyl ethyl ketone	-	-	-	-	F	80000	8000	3000	9000	50	900	200	-	D
Methyl parathion	-	-	-	-	F	300	300	30	100	0.25	9	2	-	D
Methyl tert butyl ether	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Metolachlor	L	-	-	-	F	2000	2000	2000	5000	150	5000	100	-	C
Metribuzin	L	-	-	-	F	5000	5000	300	900	25	900	200	-	D
Monochloroacetic acid	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Monochlorobenzene	P	-	100	100	F	2000	2000	2000	7000	20	700	100	-	D
Naphthalene	-	-	-	-	D	-	-	-	-	410	-	-	-	-
Oxamyl (Vydate)	T	-	200	-	F	200	200	200	900	25	900	200	-	E
Ozone by-products	L	-	-	-	-	-	-	-	-	-	-	-	-	-
Paraquat	-	-	-	-	F	100	100	50	200	4.5	200	30	-	E
Pentachloroethane	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Pentachlorophenol	P	-	0/200	0/200	F	1000	300	300	1000	30	1000	0/200	-	B2/D
Phenanthrene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	-
Phenol	-	-	-	-	D	-	-	-	-	600	-	-	-	-
Picloram	T	-	500	-	F	20000	20000	700	2000	70	2000	500	-	D
Polychlorinated byphenols (PCBs)	P	-	zero	0.5	P	-	-	1	4	-	-	-	0.5	B2
Prometon	-	-	-	-	F	200	200	200	500	15	500	100	-	D
Pronamide	-	-	-	-	F	800	800	800	3000	75	3000	50	-	C
Propachlor	-	-	-	-	F	500	500	100	500	13	500	90	-	D
Propazine	-	-	-	-	F	1000	1000	500	2000	20	700	10	-	C

	Standards				Health Advisories									Cancer Group
	Status Reg.*	NPDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)	Status HA *	10-kg Child			70-kg Adult					
						One-day ug/l	Ten-day ug/l	Longer-term ug/l	Longer-term ug/l	RfD ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk	
Chemicals														
Propham	-	-	-	-	F	5000	5000	5000	20000	20	600	100	-	D
Propylbenzene n-	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Pyrene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	D
Simazine	T	-	4	-	F	500	500	50	200	5	200	4	-	C
Styrene	P	-	zero/100	5/100	F	20000	2000	2000	7000	200	7000	0/100	1	B2/C
2,4,5-T	L	-	-	-	F	800	800	800	1000	10	350	70	-	D
2,3,7,8-TCDD (Dioxin)	T	-	zero	-	F	0.001	1E-04	1E-05	4E-05	1E-06	4E-05	-	2E-05	B2
Tebuthiuron	-	-	-	-	F	3000	3000	700	2000	70	2000	500	-	D
Terbacil	-	-	-	-	F	300	300	300	900	13	400	90	-	E
Terbulos	-	-	-	-	F	5	5	1	5	0.13	5	0.9	-	D
Tetrachloroethane (1,1,1,2-)	L	-	-	-	D	-	-	-	-	30	-	-	-	-
Tetrachloroethane (1,1,2,2-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Tetrachloroethylene	P	-	zero	5	F	2000	2000	1000	5000	10	500	-	70	B2
Toluene	P	-	2000	2000	F	20000	3000	3000	10000	300	10000	2000	-	-
Toxaphene	P	5	zero	5	F	500	40	-	-	100	-	-	3	B2
2,4,5-TP	P	10	50	50	F	200	200	70	300	7.5	300	50	-	-
Trichloroacetaldehyde	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Trichloroacetic acid	L	-	-	-	D	-	-	-	-	600	-	-	-	-
Trichloroactonitrile	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Trichlorobenzene (1,2,4-)	T	-	9	-	D	-	-	-	-	-	-	-	-	-
Trichlorobenzene (1,3,5-)	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Trichloroethane (1,1,1-) †	F	-	200	200	F	100000	40000	40000	100000	90	1000	200	-	D
Trichloroethane (1,1,2-)	T	-	3	-	D	-	-	-	-	30	-	-	-	C
Trichloroethanol (2,2,2-)	L	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichloroethylene	F	-	zero	5	F	-	-	-	-	7	300	-	300	B2
Trichloropropane (1,1,1-)	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Trichloropropane (1,2,3-)	-	-	-	-	D	-	-	-	-	6	-	-	-	-
Trilluralin	L	-	-	-	F	30	30	30	30	3	100	2	-	C
Trimethylbenzene (1,2,4-)	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Trimethylbenzene (1,3,5-)	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Vinyl chloride	F	-	zero	2	F	3000	3000	10	50	-	-	-	1.5	A
Xylenes	P	-	10000	10000	F	40000	40000	40000	10000	2000	60000	10000	-	D

Chemicals	Standards				Status HA *	Health Advisories									Cancer Group
	Status Reg.*	MCLDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)		10-kg Child			70-kg Adult						
						One-day ug/l	Ten-day ug/l	Longer- term ug/l	Longer- term ug/l	RI/D ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk		
Inorganics															
Aluminum	L	-	-	-	D	-	-	-	-	-	-	-	-	-	
Antimony	T	-	3	-	D	-	-	-	-	0.4	-	-	-	-	
Arsenic	T	50	zero	-	D	-	-	-	-	1	-	-	3	A	
Asbestos (fibers/l > 10um)	P	-	7E+06	7E+06	-	-	-	-	-	-	-	-	-	-	
Barium	P	1000	5000	5000	F	5000	5000	5000	5000	-	-	5000	-	D	
Beryllium	T	-	zero	-	D	-	-	-	-	5	-	-	-	B2	
Boron	L	-	-	-	D	-	-	-	-	-	-	-	-	-	
Cadmium	P	10	5	5	F	40	40	5	20	0.5	20	5	-	D	
Chromium (total)	P	50	100	100	F	1000	1000	200	800	5	200	100	-	D	
Copper	P	-	1300	1300	-	-	-	-	-	-	-	-	-	-	
Cyanide	T	-	200	-	F	200	200	200	800	22	800	200	-	D	
Fluoride	F	-	4000	4000	-	-	-	-	-	60	-	-	-	-	
Lead (at source)	P	-	zero	5	-	-	-	-	-	-	-	-	-	-	
Lead (at tap)	P	50	zero	TT	-	-	-	-	-	-	-	-	-	-	
Manganese	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Mercury	P	2	2	2	F	-	-	-	6	0.3	10	2	-	D	
Molybdenum	L	-	-	-	D	20000	200	6	20	0.6	20	4	-	D	
Nickel	T	-	100	-	F	1000	1000	100	600	20	600	100	-	D	
Nitrate (as N)	P	10000	10000	10000	F	-	1000	-	-	-	-	-	-	D	
Nitrite (as N)	P	-	1000	1000	F	-	1000	-	-	-	-	-	-	D	
Nitrate + Nitrite	P	-	10000	10000	-	-	-	-	-	-	-	-	-	-	
Selenium	P	10	50	50	-	-	-	-	-	-	-	-	-	-	
Silver	L	50	-	-	D	-	-	-	-	3	-	-	-	-	
Sodium	L	-	-	-	D	-	-	-	-	-	20000 ***	-	-	-	
Strontium	L	-	-	-	D	-	-	-	-	-	-	-	-	-	
Sulfate	T	-	300	-	-	-	-	-	-	-	-	-	-	-	
Thallium	T	-	0.4	-	D	-	-	-	-	0.07	-	-	-	-	
Vanadium	L	-	-	-	D	-	-	-	-	20	-	-	-	-	
Zinc	L	-	-	-	D	-	-	-	-	-	-	-	-	-	



[illegible]

Legend for draft version of Drinking Water Standards and Health Advisories table.

Abbreviations column descriptions are:

- NIPDWR** - National Interim Primary Drinking Water Regulation. Interim enforceable drinking water regulations first established under the Safe Drinking Water Act that are protective of public health to the extent feasible.
- MCLG** - Maximum Contaminant Level Goal. A non-enforceable concentration of a drinking water contaminant that is protective of adverse human health effects and allows an adequate margin of safety.
- MCL** - Maximum Contaminant Level. Maximum permissible level of a contaminant in water which is delivered to any user of a public water system.
- RfD** - Reference Dose. An estimate of a daily exposure to the human population that is likely to be without appreciable risk of deleterious effects over a lifetime.
- DWEL** - Drinking Water Equivalent Level. A lifetime exposure concentration protective of adverse, non-cancer health effects, that assumes all of the exposure to a contaminant is from a drinking water source.

(\*) The codes for the Status\_Reg and Status\_HA columns are as follows:

- F** - final
- D** - draft
- L** - listed for regulation
- P** - proposed (Phase II draft proposal)
- T** - tentative (Phase V)

Other codes found in the table include the following:

- NA** - not applicable
- PS** - performance standard 0.5 NTU - 1.0- NTU
- TT** - treatment technique
- \*\*** - No more than 5% of the samples may be positive. For systems collecting fewer than 40 samples/month, no more than 1% may be positive.
- \*\*\*** - guidance
- †** - Large discrepancies between Lifetime and Longer term HA values may occur because of the Agency's conservative policies, especially with regard to carcinogenicity, relative source contribution, and less than lifetime exposures in chronic toxicity testing. These factors can result in a cumulative UF (uncertainty factor) of 10 to 1000 when calculating a Lifetime HA.

### **8.10.2 Worksheets**

Worksheets 8-1 and 8-2 may be used by the regulatory agency in comparing constituent concentrations in the release to health and environmental criteria. Example filled in worksheets are also shown. These worksheets address the following:

- 8-1: Comparison of individual contaminant concentrations with criteria
- 8-2: Use of hazard indices for exposure to chemical mixtures.

A questionnaire that may be used in determining if interim corrective measures are necessary is provided in Worksheet 8-3. Questions are posed to help focus the determination. These questions will be addressed to the extent possible based on available information. The regulatory agency will not necessarily need answers for all questions in order to make a decision as to whether interim corrective measures are necessary. If release concentration information is available, Worksheets 8-1 and 8-2 may also be filled out.

## WORKSHEET 8-1

### COMPARISON OF INDIVIDUAL CONSTITUENT CONCENTRATIONS WITH HEALTH AND ENVIRONMENTAL CRITERIA

Facility Name \_\_\_\_\_  
 Releasing Unit \_\_\_\_\_  
 Contaminated Media \_\_\_\_\_  
 Sample Location \_\_\_\_\_  
 Sample Number(s) \_\_\_\_\_  
 Date \_\_\_\_\_  
 Analyst \_\_\_\_\_

Exposure Medium	Constituent Released	Release Concentration	Table No. and Criterion Type Used	Criterion Value	Release Concentrations Exceed Criterion?
WATER					
SOIL					
AIR					

#### INSTRUCTIONS

1. List chemicals with human-health and environmental criteria for the appropriate exposure medium.
2. List chemical concentration for the appropriate exposure medium.
3. List type of human-health and environmental criteria used and applicable table number.
4. List appropriate criteria values.
5. Compare chemical concentration and criteria values and identify whether release concentration exceeds criteria.

## EXAMPLE WORKSHEET 8-1

### COMPARISON OF INDIVIDUAL CONSTITUENT CONCENTRATIONS WITH HEALTH AND ENVIRONMENTAL CRITERIA

Site Name Site X  
 Releasing Unit Impoundment 2  
 Contaminated Media Ground Water/Air/Soil  
 Sample Location MW 2/X-7 (see Map)  
 Sample Number(s) MW2-1/X-7-1  
 Date 9/4/86  
 Analyst JDP

Exposure Medium	Constituent Released	Release Concentration	Table No. and Criterion Type Used	Criterion Value	Release Concentrations Exceed Criterion?
WATER	Trichloroethylene	2 µg/l	MCL Table 8-7	5 µg/l	No
	Carbon tetrachloride	1 µg/l	MCL Table 8-7	5 µg/l	No
	Chloroform	3 µg/l	Carcinogen Table 8-6	5.7 µg/l	No
SOIL	Chlorobenzene	10 mg/kg	Systemic Tox. Table 8-7	2000 mg/kg	No
	Pentachlorobenzene	7 mg/kg	Systemic Tox. Table 8-7	60 mg/kg	No
AIR	Trichloroethylene	0.1 µg/m <sup>3</sup>	Carcinogen Table 8-6	0.27 µg/m <sup>3</sup>	No

#### INSTRUCTIONS

1. List chemicals with human-health and environmental criteria for the appropriate exposure medium.
2. List chemical concentration for the appropriate exposure medium.
3. List type of human-health and environmental criteria used and applicable table number.
4. List appropriate criteria values.
5. Compare chemical concentration and criteria values and identify whether release concentration exceeds criteria.

# **WORKSHEET 8-2** **USE OF HAZARD INDICES FOR EXPOSURE TO CHEMICAL MIXTURES**

Facility Name \_\_\_\_\_  
 Releasing Unit \_\_\_\_\_  
 Contaminated Media \_\_\_\_\_  
 Sample Location \_\_\_\_\_  
 Sample Number(s) \_\_\_\_\_  
 Date \_\_\_\_\_  
 Analyst \_\_\_\_\_

Exposure Medium	Constituent Released	Ratio of Release Concentration to Criterion Value	HAZARD INDICES	
			Medium Total	Value Exceeds Unity?
WATER				
SOIL				
AIR				

## **INSTRUCTIONS**

1. List chemicals in each environmental medium, as shown in Worksheet 8-1.
2. Compare chemical concentrations and appropriate health criteria values, as shown in Worksheet 8-1. Determine ratio of release concentration to the criteria values.
3. Determine a hazard index for the chemicals in each medium by summing the ratios calculated by comparing chemical concentrations and health criteria.
4. Determine if the hazard index for the chemical mixture found in each individual exposure medium exceeds unity.

## EXAMPLE WORKSHEET 8-2

### USE OF HAZARD INDICES FOR EXPOSURE TO CHEMICAL MIXTURES

Site Name Site X  
 Releasing Unit Impoundment 2  
 Contaminated Media Ground Water/Air/Soil  
 Sample Location MW 2/X-7 (see Map)  
 Sample Number(s) MW2-1/X-7-1  
 Date 9/4/86  
 Analyst JDP

Exposure Medium	Constituent Released	Ratio of Release Concentration to Criterion Value	HAZARD INDICES	
			Medium Total	Value Exceeds Unity?
WATER	Trichloroethylene	0.4		
	Carbon tetrachloride	0.2		
	Chloroform	0.53		
			1.13	Yes
SOIL	Chlorobenzene	0.0005		
	Pentachlorobenzene	0.12		
			0.125	No
AIR	Trichloroethylene	0.37	0.37	No

#### INSTRUCTIONS

1. List chemicals in each environmental medium, as shown in Worksheet 8-1.
2. Compare chemical concentrations and appropriate health criteria values, as shown in Worksheet 8-1. Determine ratio of release concentration to the criteria values.
3. Determine a hazard index for the chemicals in each medium by summing the ratios calculated by comparing chemical concentrations and health criteria.
4. Determine if the hazard index for the chemical mixture found in each individual exposure medium exceeds unity.

## WORKSHEET 8-3

### QUESTIONS TO BE CONSIDERED IN DETERMINING IF INTERIM CORRECTIVE MEASURES MAY BE NECESSARY

In considering the actual or potential threat to human health or the environment posed by a contaminant release, the regulatory agency will consider factors such as type and extent of the release and site demographics. The following questions may be used in evaluating these factors. If sufficient information is available, the worksheets presented on the previous pages may also be used in evaluating the need for interim corrective measures. For further details, see RCRA Corrective Action Interim Measures (U.S. EPA, 1987).

#### A. Release Characterization

1. What is the source(s) (e.g., nature, number of drums, area, depth, amount, location(s))?
2. Regarding hazardous wastes or constituents at the source(s):
  - a. Which hazardous wastes (listed, characteristic) and hazardous constituents are present?
  - b. What are their concentrations?
  - c. What is the background level of each hazardous waste or constituent?
3. What are the known pathways through which the contamination is migrating or may migrate and the extent of contamination?
  - a. Through which media is the release spreading or likely to spread? Direction? Rate?
  - b. How far has the release migrated? At what concentrations?



- c. How mobile is the constituent?
  - d. What are the estimated quantities and/or volumes released?
4. What is the projected fate and transport?

**B. Potential Human Exposure and Effects**

1. What is or will be the exposure pathway(s) (e.g., air, fire/explosion, ground water, surface water, direct contact, ingestion)?
2. What are the location and demographics of populations and environmental resources (potentially) at risk from exposure (e.g., residential areas, schools, drinking water supplies, sole source aquifers near vital ecology or protected natural resources)?
3. What are the potential effects of human exposure (short- and long-term effects)?
4. Has human exposure actually occurred? Or when may human exposure occur?
  - a. What is the exposure route(s) (e.g., inhalation, ingestion, skin contact)?
  - b. Are there any reports of illness, injury, or death?
  - c. How many people will be affected?
  - d. What are the characteristics of the exposed populations(s) (e.g., presence of sensitive populations such as infants or nursing home residents)?
5. If response is delayed, how will the situation change (e.g., what will be the implications to human health)?

### **C. Potential Environmental Exposure and Effects**

- 1. What media have been and may be contaminated (e.g., ground water, air, surface water)?**
- 2. What are the likely short-term and long-term threats and effects on the environment of the released waste or constituents?**
- 3. What natural resource and environmental effects have occurred or are possible (terrestrial, aquatic organisms, aquifers whether or not used for drinking water)?**
- 4. What are the known or projected ecological effects?**
- 5. When is this threat/effect likely to materialize (days, weeks, months)?**
- 6. What are the projected long term effects?**
- 7. If response is delayed, how will the situation change?**

## **APPENDIX A**

### **AERIAL PHOTOGRAPHY, MAPPING, AND SURVEYING**

## **APPENDIX A**

### **AERIAL PHOTOGRAPHY, MAPPING, AND SURVEYING**

Aerial photographs, maps, and surveys can assist in verifying and characterizing contaminant releases and are particularly helpful sources of information that can be used during the development of a monitoring plan. They can also be used, when viewed in historical sense (e.g., over the same location, but at different points in time), to locate old solid waste management units, stream beds, and other facility features. Stereo viewing (using a stereoscope) can further enhance the interpretation of photographs and maps because vertical as well as horizontal spatial relationships can be observed. This Appendix discusses the potential applications of aerial photography, mapping, and surveying in the RFI process.

Case Study Numbers 12, 13 and 14 in Volume IV (Case Study Examples) illustrate the use of several of the techniques presented in this Appendix.

#### **AERIAL PHOTOGRAPHY**

##### **Introduction**

Aerial photography may be used to gather release verification and characterization information during the RFI. Although detailed aerial photographic analysis usually requires a qualified photo-interpreter, the site information that it can readily provide may warrant its use. Aerial photography can provide valuable information on the environmental setting as well as indications of the nature and extent of contaminant releases. However, when using aerial photographic techniques, important release information should be verified through field observations.

##### **Information Obtained From Aerial Photographs**

The basic recognition elements commonly utilized in photographic interpretation are shape, texture, pattern, size, shadow, tone and/or color. Natural

color, false color or color infrared, and black and white film are routinely used in aerial photographic applications. Color imagery may be more readily interpreted than black and white film, by providing enhanced differentiation of subtle evidence of such items as surface leachate (e.g., seeps) and surface water quality. Color infrared film offers an added element of information with its near infrared sensitivity by enabling assessment of vegetation type, damage, or stress, and providing a wide range for detection of moisture conditions in soils.

Subsurface characteristics can be inferred by surface information in the photographs. For example, vegetative stress may indicate leachate and gas migration where the water table is shallow or in discharge areas. Infrared may be able to detect vegetative stress not noticeable during a field inspection. Geologic features (variation in the distribution of geologic units, bedrock fractures, fault zones, etc.) that can affect ground-water flow pathways can also be identified from aerial photographs. Fractures at shallow depths in consolidated rocks can serve as pathways for contaminated ground water and for rapid infiltration of surface runoff. Contamination of surface water bodies can be detected by discoloration or shading in aerial photography. Land surface elevation determinations and contour maps can be compiled, and ground-water flow direction in shallow systems can be estimated using this information. The time of year is also an important consideration when interpreting geologic and hydrologic features. For example, the presence of heavy vegetation during the summer months may obscure certain geologic and hydrologic features. As another example, drainage patterns and seasonal, high water tables are more readily observed after or during winter snowmelt.

Other information available from aerial photographs includes: Natural topography, drainage and erosional features, vegetative cover and damage, indications of leachate, damaged unit containment structures, etc. Observable patterns, colors, and relief can make it possible to distinguish differences in geology, soils, soil moisture, vegetation, and land use. Aerial photography can also indicate important hydrologic features. Springs and marshy areas represent ground-water discharge areas. In cases of releases to ground water, aerial photographs can indicate the existence of likely contaminant migration pathways (e.g., recharge areas, sink holes, karst terrains, subsurface flow patterns, fissures, and joints). For releases to surface water, aerial photographs can indicate the

location of potential contaminant receiving bodies (e.g., ponds and streams) and site runoff channels. Aerial photography can also be used to obtain input information for designing monitoring plans (e.g., defining boundary conditions such as ponds, streams, springs, paved areas, large buildings, irrigation canals).

Major benefits in using aerial photography as a supplement to other investigative methods include:

- Obtaining information on relatively large areas, including surrounding land use and environmental features;
- Indicating effects of contamination; and
- Providing indirect indications of subsurface conditions.

The following limitations should be considered when using aerial photography:

- It does not provide direct information on subsurface characteristics;
- There may be variations in photo quality with age, season of flight, film type, photo scale, cloud cover, etc.; and
- Information obtained from photographs should not be used alone in evaluating surface/subsurface conditions. They should always be verified through field observations.

#### Use of Existing Aerial Photographs (Historical Analysis)

Existing aerial photographs may be available that show the site prior to the existence of some or all hazardous waste management activities. Individual photographs provide an opportunity to identify specific features and activities at a single point in time. By identifying conditions at a site at several points in time (i.e., historical analysis), the sequence of events leading to the current conditions can be better understood. This process may identify changes in surface drainage conditions through time, locations of landfills, waste treatment ponds/lagoons and

their subsequent burial and abandonment, the burial of waste drums, number of drums, estimated depth and horizontal extent of burial pits, sources of spillage, and discharge of liquid wastes, etc. Historical photographic analysis can be used to make maps that reflect conditions that previously existed at a facility if enough control points are provided (e.g., road intersections, power lines, buildings, railroad tracks). This information may be very useful in determining appropriate monitoring locations. Analysis problems that should be considered when using historical photos include variations in placement of the site within a given frame of photography and variations in scale.

### Sources

Town or county offices may have aerial photographs on file. Also, most of the United States has been photographed in recent years for various Federal agencies. A map entitled "Status of Aerial Photography in the United States" has been compiled that lists all areas (by county) that have been photographed by or for the Agricultural Stabilization and Conservation Service, the Soil Conservation Service, Forest Service, U.S. Geological Survey, Army Corps of Engineers, Air Force, and commercial firms. These maps are available from:

Map Information Office  
U.S. Department of the Interior  
Geologic Survey  
507 National Center  
Reston, VA 22092  
(703) 860-6045

The names and addresses of agencies holding negatives for photographs are printed on the back of the map.

The U.S. EPA may also have taken aerial photos of certain facilities. The owner or operator may inquire at specific federal and state regulatory offices for access to any photos that may have been taken. Other sources of aerial photographs are listed below.

Federal government--The following two U.S. Geological Survey locations can provide indices of all published maps and include order blanks, prices, and detailed

ordering instructions. They may also provide a list of addresses of local map reference libraries, local map dealers, and Federal map distribution centers.

Eastern Distribution Branch  
U.S. Geological Survey  
1200 South Eads Street  
Arlington, VA 22202

Western Distribution Branch  
U.S. Geological Survey  
Box 25286 Denver Federal Center  
Denver, CO 80225

**Other Federal Agencies Include:**

Aerial Photography Field Office  
ASCS-U.S. Department of Agriculture (USDA)  
P.O. Box 30010  
Salt Lake City, Utah 84130  
(801) 524-5856

(Has all Agricultural  
Stabilization and  
Conservation Service  
photos, Forest Service  
photos, etc.)

EROS Data Center

U.S. Geological Survey  
Sioux Falls, SD 57198  
(605) 594-6511 (ext. 151)

(Landsat and U-2  
photos,  
black and white at  
1:80,000 scale.  
Computer listings of  
all available photos  
can be accessed)

Soil Conservation Service  
USDA-SCS  
P.O. Box 6567  
Fort Worth, TX 76117  
(817) 334-5292

(Supplies mostly low  
altitude, 1:20,000 scale,  
photos)

National Archives  
841 South Pickett Street  
Alexandria, VA 22304  
(703) 756-6700

(For historical photos)

All of the above agencies will require some information identifying the site location to locate relevant photos. This information may be in the form of a town engineer's map; Department of Transportation map; description of the township, range, section; a hand-drawn map of the site in relation to another town; precise longitude and latitude coordinates of the site area; or a copy of the portion of a U.S. Geological Survey quadrangle that shows the site.



For facilities near the United States-Canada border, the following agency may provide aerial photographs:

The National Air Photo Library  
Surveys and Mapping Branch  
Department of Energy, Mines and Resources  
615 Booth Street  
Ottawa, Ontario K1A 0E9

State government--State agencies may also have aerial photographs on file. These include:

- Pollution control agencies;
- Health departments;
- Water resources departments;
- Forestry or Agricultural departments;
- Highway departments; and
- Geological survey departments.

Private companies--Photographs required for the site of concern may be held by private aerial survey companies and can often be ordered directly from these sources. Local telephone listings and Photogrammetric Engineering, the Journal of the American Society of Photogrammetry, can provide sources of information.

Aerial photographic surveys--If existing photographs are not available or do not provide enough information, the owner or operator may arrange for an aerial photographic survey to be conducted. When deciding whether an aerial survey is appropriate, the owner or operator should consider whether the information needs can be filled with data obtained from an aerial survey (or from another source or investigative technique) and the size of the site (for a small site, a ground survey may be more economical). This survey should be conducted by professionals who

will plan, schedule, and perform the flight, collect data with appropriate scale and/or film requirements, analyze results, and compile maps, if necessary.

Conducting New Aerial Photographic Surveys--A local telephone listing, the Journal of the American Society of Photogrammetry, or the government agencies listed in this section may provide names of companies or organizations that conduct aerial photographic surveys. When requesting that an aerial photographic survey be conducted, the owner or operator should supply the site location (e.g., marked on a topographic map). Property boundaries and waste management areas should be outlined. If photographic interpretation is also requested, a brief site description, type and number of solid waste management units, and types of wastes handled would also be helpful.

## **MAPPING**

To assist in adequately characterizing a release, various types of maps may be useful. Maps can be used to show geology, hydrology, topography, climate, land use, and vegetative characteristics. Maps can be generated through compilation of existing maps, aerial photographs, or through ground surveys. This section discusses the usefulness of mapping in verifying and characterizing the nature and extent of a release. In general, displaying information from all types of maps can be presented on the facility's existing topographic map as discussed below.

### Topographic Maps

The owner or operator should use, to the extent possible, the topographic map and associated information that meets the requirements of 40 CFR Part 270 14(b)(19) of EPA's Hazardous Waste Permit Program which states:

"A topographic map showing a distance of 1000 feet around the facility at a scale of 2.5 centimeters (1 inch) equal to not more than 61.0 meters (200 feet). Contours must be shown on the map. The contour interval must be sufficient to clearly show the pattern of surface water flow in the vicinity of and from each operational unit of the facility. For example, contours with an interval of 1.5 meters (5 feet), if relief is greater than 6.1 meters (20 feet), or an interval of 0.6 meters ( 2 feet), if relief is less than 6.1 meters (20 feet). Owners and operators of HWM facilities located in mountainous areas should use large contour intervals to adequately show topographic profiles of facilities. The map shall clearly show the following:

- (i) Map scale and date.
- (ii) 100-year floodplain area.
- (iii) Surface waters including intermittent streams.
- (iv) Surrounding land uses (residential, commercial, agricultural, recreational).
- (v) A wind rose (i.e., prevailing wind-speed and direction).
- (vi) Orientation of the map (north arrow).
- (vii) Legal boundaries of the HWM facility site.
- (viii) Access control (fences, gates).
- (ix) Injection and withdrawal wells both onsite and offsite.
- (x) Buildings; treatment; storage, or disposal operations; or other structures (recreation areas, runoff control systems, access and internal roads, storm, sanitary, and process sewerage systems, loading and unloading areas, fire control facilities, etc.).
- (xi) Barriers for drainage or flood control.
- (xii) Location of operational units within the HWM facility site, where hazardous waste is (or will be) treated, stored, or disposed (include equipment cleanup areas)."

Additional information that should be noted on the topographic map is specified in the requirements of 40 CFR Part 270.14(c)(3), which states:

"On the topographic map required under paragraph (b)(19) of this section, a delineation of the waste management area, the property boundary, the proposed "point of compliance" as defined under §264.95, the proposed location of ground water monitoring wells as required under §264.97, and, to the extent possible, the information required in paragraph (c)(2) of this section.", that being . . . "(2) Identification of the uppermost aquifer and aquifers hydraulically interconnected beneath the facility property, including ground water flow direction and rate, and the basis for such identification (i.e., the information obtained from hydrogeologic investigations of the facility area)."

The use of topographic maps will enable the owner or operator to identify and display many features useful in characterizing a release, such as potential surface water receiving bodies, runoff pathways, and engineered structures.

### Sources

**Topographic maps of the facility area may be available or obtained from:**

- U.S.G.S. (generally with 10-foot contour intervals);
- Local town offices (e.g., Building Department, Board of Assessors);

- Onsite surveying to obtain site specific elevation information; and
- Use of an aerial photographic consultant to fly the site and surrounding area and develop a map.

A site-specific topographic map may be constructed by measuring and plotting land elevations by a stadia survey. This method of surveying determines distances and elevations by means of a telescopic instrument having two horizontal lines through which the marks on a graduated rod are observed. A local telephone directory will usually list companies providing this service.

Existing topographic maps may also be obtained from:

Eastern Distribution Branch U.S. Geological Survey 1200 South Eads Street Arlington, VA 22202	(East of the Mississippi River)
--	---------------------------------

Western Distribution Branch U.S. Geological Survey Box 25286 Denver Federal Center Denver, CO 80225	(West of the Mississippi River)
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Before requesting a map, the proper quadrangle must be determined. Maps are indexed by geographic location--longitude and latitude. The quadrangle size is given in minutes or degrees. 7.5 minute quadrangles provide the best resolution.

Other sources of topographic information include:

- Local colleges or universities that may have index map sets;
- Local town officials (town engineers, planners, etc.) who know which quadrangles cover their area;
- Nearby institutions or firms that deal with land holdings are likely to have USGS quadrangles for that area; and
- Local USGS offices, map distributors and other suppliers.

Although for the most part the above identified sources will not supply topographic maps which satisfy the requirements of 40 CFR Part 270, they may still be useful for pointing out old solid waste management units and other facility features which may be useful in planning the RFI.

### Land Use Maps

Land uses, including residential, commercial, industrial, agricultural, and recreational, should also be shown on the site topographic map. This information is useful for assessing the need for interim corrective measures, and in evaluating potential exposure points and the need for a Corrective Measures Study when air is the medium of contamination.

### Sources

Information may be obtained by contacting local officials, conducting first-hand observations, and using a USGS quadrangle. USGS maps indicate structures, including dwellings, places of employment, schools, churches, cemeteries, barns, warehouses, golf courses, and railroad tracks. Various types of boundary lines delineate city limits, national and state reservations, small parks, land grants, etc. Other land use information may be obtained by contacting local planning boards, regional planning commissions, and State agencies. Also, the USGS has special land use maps available for some areas. Inquiries regarding the availability of such maps may be directed to:

Geography Program  
Land Information and Analysis Office  
USGS-MS 710  
Reston, VA 22092  
(703) 860-6045

### Climatological Maps

Relevant climatological data should be identified. For example, a wind rose graphically displays wind speed and direction. Such information may be critical in the characterization of an air release. Other climatological and meteorological information (e.g., precipitation and temperature) are often important in

characterizing releases to the various environmental media. Because many of these types of meteorological and climatological information may not be effectively displayed on the 40 CFR Part 270 topographic map, they should be identified in a separate map or other document.

#### Sources

National Climatic Center  
Department of Commerce  
Federal Building  
Ashville, NC 28801  
(704) 258-2850

The National Climatic Center may also refer the owner or operator to a data collection office in the vicinity of the area of concern. In addition, local libraries and other sources may provide local climatological data for various period storms (e.g., the 100-year storm), and other information.

#### Floodplain Maps

The 100-year floodplain area, if applicable, should also be included on the facility's topographic map. Special flooding factors (e.g., wave action) or special flood control features included in the design, construction, operation or maintenance of a facility should also be noted. The topographic map submitted should include the boundaries of the site property in relation to floodplain areas.

#### Sources

The National Flood Insurance Program (NFIP) has prepared Flood Hazard Boundary Maps for flood-prone areas. These maps delineate the boundaries of the 100-year floodplain. Such maps are often included as part of the Flood Insurance Study for a particular political jurisdiction along a waterway. The U.S. Federal Emergency Management Administration (FEMA) located in Washington, D.C. ((202) 246-2500) publishes such studies. Hydraulic analyses used to determine flood level, community description, and principal flood problems and flood protective measures (provided in the flood insurance studies) should also be included. The USGS, U.S. Army Corps of Engineers, U.S. Soil Conservation Service and the Office of Coastal Zone Management may be contacted for further floodplain information.

## **Additional Information**

Other information that should be shown on the topographic map includes:

- Access control (fences, gates, etc.);
- Buildings, treatment, storage, disposal operation areas and other structures nearby or onsite;
- Buried pipeline, sewers and electrical conduits;
- Barriers for drainage or flood control;
- Areas of past spills;
- Location of all existing (active and inactive) solid waste management units;
- Location and nature of industrial and product process and storage units; and
- Facility design features such as run-on/runoff control systems and wind dispersal control systems.

## **Sources**

This information can be obtained from aerial photographs, field observations, operating records, construction and inspection records, etc. The owner or operator may need to locate additional site-specific information. This information may be available on existing maps, such as:

Geomorphology	-	surficial geology maps historical aerial photographs topographic maps
Eolian Erosion and Deposition	-	county soil maps (historical) aerial photographic

		interpretation topographic maps
Fluvial Erosion and Deposition	-	floodplain maps county soil maps (historical) aerial photographic interpretation topographic maps
Drainage Patterns	-	topographic maps county soil maps hydrologic maps aerial photgraphic interpretation
Geologic Features	-	bedrock geology maps county soil maps topographic maps
Land Use	-	zoning maps current aerial photos local conservation commission maps county soil recent topographic maps
Hydrologic Features	-	hydrologic maps topographic maps wetlands maps well data aerial photographic interpretation local conservation commission maps

Some examples of how the above information may be useful to the owner or operator in characterizing a release are given below:

- Knowledge of floodplain areas, surface water bodies, drainage patterns and flood control systems identifies potential migration pathways for surface and ground water contamination;
- Wind speed and direction may help identify air contaminant dispersion areas;
- Injection and withdrawal wells may provide locations and information (e.g., influences in ground-water flow patterns) for ground-water monitoring;
- Structures on or offsite can provide ideal locations for subsurface gas monitoring; and



- Potential sources of contamination in close proximity to the facility may be revealed by investigating surrounding land use practices.

## **SURVEYING**

Ground surveying is a direct process for obtaining topographic and other terrain features in the field. A local telephone directory should be consulted for companies providing surveying services.

Information that can be obtained from a ground survey includes:

- Facility boundary;
- Location of engineered structures (e.g., buildings, pipelines);
- Natural formations at the site (e.g., bedrock outcrops);
- Topographic features;
- Drainage patterns and ponding areas;
- Elevation benchmarks ("permanent" elevation reference points that can be used in the future);
- Location of ground-water monitoring wells (e.g., surface location and elevation); and
- Profiles of surface water bodies (e.g., depths of lakes/ponds) that are not possible by aerial means.

The above information, obtained during a survey of the facility, may be useful in characterizing a contaminant release through:

- Identification of engineered structures that may inhibit or promote contaminant migration (e.g., accumulation areas for subsurface gas);

- Identification of natural features at the site (e.g., barriers or pathways) affecting contaminant migration;
- Topographic influences (e.g., drainage patterns and ponding areas);
- Location of ground water or subsurface gas monitoring wells;
- Ground-water depth (knowledge of location and elevation of wells, enables measurement of ground-water depth); and
- Depths of surface water bodies that may be useful in predicting surface water contamination and in determining ground-water breakout.

## REFERENCES

- Ritchie. 1977. Mapping for Field Scientists. A. S. Barnes & Co., NY.
- Todd, David. 1980. Ground Water Hydrology, second ed. Wiley & Sons, NY.
- U.S. EPA. 1982. Environmental Science and Technology, "Airborne Remote Sensing", Vol. 16, No. 6. 1982.
- U.S. EPA. 1983. Permit Applicants' Guidance Manual for the General Facility Standards of 40 CFR 264. EPA SW-968. NTIS PB 87-151064. Washington, D.C. 20460.

## **APPENDIX B**

### **MONITORING CONSTITUENTS AND INDICATOR PARAMETERS**

- LIST 1: Indicator Parameters Generally Applicable to Specific Media**
- List 2: 40 CFR 264 Appendix IX Constituents Commonly Found in Contaminated Ground Water and Amenable to Analysis by EPA Method 6010-Inductively Coupled Plasma (ICP) Spectroscopy (Metals) and by Method 8240 (Volatile Organics)**
- LIST 3: Monitoring Constituents Potentially Applicable to Specific Media**
- LIST 4: Industry Specific Monitoring Constituents**

## LIST 1

### INDICATOR PARAMETERS GENERALLY APPLICABLE TO SPECIFIC MEDIA

#### SOIL

##### INDICATOR PARAMETERS

Aluminum	Potassium
Boron	Silica
Calcium	Sodium
Carbonate/bicarbonate	Soil Eh
Chloride	Soil pH (Hydrogen Ion)
Cobalt	Strontium
Copper	Sulfate
Fluoride	Total Kjeldahl Nitrogen (TKN)
Iron	Total Organic Carbon (TOC)*
Magnesium	Total Organic Halogen (TOX)*
Manganese	Total Phenols
Nitrate (as N)	Vanadium
Phosphorus	Zinc

- 
- \* Although TOC and TOX have historically been used as indicator parameters for site investigations, the latest data suggests that the use of these parameters may not provide an adequate indication of contamination. Both methods suffer precision and accuracy problems. The normal procedure for TOC can strip samples of the volatile fraction, and the presence of chlorine/chloride has been shown to interfere with the TOX determination. In addition, the sensitivity of these methods (generally in the parts per million level) are often too high for constituents of concern.

## LIST 1 (Continued)

### GROUND WATER (See also 40 CFR 264, Appendix IX)

#### INDICATOR PARAMETER

Aluminum	pH (Hydrogen Ion)
Boron	Potassium
Calcium	Silica
Carbonate/bicarbonate	Sodium
Chloride	Strontium
Cobalt	Sulfate
Copper	Specific Conductance
Fluoride	Total Organic Carbon (TOC)*
Iron	Total Organic Halogen (TOX)*
Magnesium	Total Phenols
Manganese	Vanadium
Nitrate (as N)	Zinc

- 
- \* Although TOC and TOX have historically been used as indicator parameters for site investigations, the latest data suggests that the use of these parameters may not provide an adequate indication of contamination. Both methods suffer precision and accuracy problems. The normal procedure for TOC can strip samples of the volatile fraction, and the presence of chlorine/chloride has been shown to interfere with the TOX determination. In addition, the sensitivity of these methods (generally in the parts per million level) are often too high for constituents of concern.

## LIST 1 (Continued)

### SUBSURFACE GAS

#### INDICATOR PARAMETERS

Methane

Carbon dioxide

Total Hydrocarbons (THC)

Colorimetric Indicators (e.g., Draeger Tubes)

Explosivity

### AIR

#### INDICATOR PARAMETERS

Total Hydrocarbons (THC)

Colorimetric Indicators (e.g., Draeger tubes)

## LIST 1 (Continued)

### SURFACE WATER

#### INDICATOR PARAMETERS

Alkalinity (mg/l as  $\text{CaCO}_3$ )  
Biochemical Oxygen Demand (BOD)  
Calcium  
Chemical Oxygen Demand (COD)  
Chloride  
Dissolved Oxygen (DO)  
Dissolved solids  
Magnesium  
Nitrates  
Nitrites  
pH  
Salinity  
Sodium  
Specific Conductance  
Sulfate  
Suspended solids  
Temperature  
Total solids  
Total Organic Carbon (TOC)\*  
Total Organic Halogen (TOX)\*  
Total Phenols  
Turbidity

- 
- \* Although TOC and TOX have historically been used as indicator parameters for site investigations, the latest data suggests that the use of these parameters may not provide an adequate indication of contamination. Both methods suffer precision and accuracy problems. The normal procedure for TOC can strip samples of the volatile fraction, and the presence of chlorine/chloride has been shown to interfere with the TOX determination. In addition, the sensitivity of these methods (generally in the parts per million level) are often too high for constituents of concern.



**LIST 2**

**40 CFR 264 APPENDIX IX CONSTITUENTS COMMONLY FOUND IN CONTAMINATED  
GROUND WATER AND AMENABLE TO ANALYSIS BY EPA METHOD 6010 -  
INDUCTIVELY COUPLED PLASMA (ICP) SPECTROSCOPY (METALS) AND BY METHOD  
8240 (VOLATILE ORGANICS)**

Common Name	Chemical Abstracts Number	Method <sup>1</sup> 8240	Method 6010
Acetone	67-64-1	x	
Acrolein	107-02-8	xa	
Acrylonitrile	107-13-1	xa	
Allyl chloride	107-05-1	xb	
Antimony	(total)		x
Arsenic	(total)		x
Barium	(total)		x
Benzene	71-43-2	xc	
Beryllium	(total)		x
Bromodichloromethane	75-27-4	xb	
Bromoform, Tribromomethane	75-25-2	xb	
Cadmium	(total)		x
Carbon disulfide	75-15-0	x	
Carbon tetrachloride	56-23-5	xb	
Chlorobenzene	108-90-7	xb	
Chloroethane, Ethyl chloride	75-00-3	xb	
Chloroform	67-66-3	xb	
Chloroprene	126-99-8	xb	
Chromium	(total)		x
Cobalt	(total)		x
Copper	(total)		x
Dibromochloromethane, Chlorodibromomethane	124-48-1	xb	
1,2-Dibromo-3-chloropropane, DBCP	96-12-8	xb	
1,2-Dibromoethane, Ethylene dibromide	106-93-4	xb	

**LIST 2 (Continued)**

Common Name	Chemical Abstracts Number	Method <sup>1</sup> 8240	Method 6010
trans-1,4-Dichloro-2-butene	110-57-6	x	
Dichlorodifluoromethane	75-71-8	xb	
1,1-Dichloroethane	75-34-3	xb	
1,2-Dichloroethane, Ethylene dichloride	107-06-2	xb	
1,1-Dichloroethylene, Vinylidene chloride	75-35-4	xb	
trans-1,2-Dichloroethylene	156-60-5	xb	
1,2-Dichloropropane	78-87-5	xb	
cis-1,3-Dichloropropene	10061-01-5	xb	
trans-1,3-Dichloropropene	10061-02-6	xb	
Ethylbenzene	100-41-4	xc	
Ethyl methacrylate	96-63-2	xd	
2-Hexanone	591-78-6	x	
Lead	(total)		x
Methacrylonitrile	126-98-7	xd	
Methyl bromide, Bromomethane	74-83-9	xb	
Methyl chloride, Chloromethane	74-87-3	xb	
Methylene bromide, Dibromomethane	74-95-3	xb	
Methylene chloride, Dichloromethane	76-09-2	xb	
Methyl ethyl ketone, MEK	78-93-3	xd	
Methyl iodide, Iodomethane	74-88-4	xb	
Methyl methacrylate	80-62-6	xd	
4-Methyl-2-pentanone, Methyl isobutyl ketone	108-10-1	xd	
Nickel	(total)		x
Pentachloroethane	76-01-7	x	

**LIST 2 (Continued)**

Common Name	Chemical Abstracts Number	Method <sup>1</sup> 8240	Method 6010
2-Picoline	109-06-8	x	
Propionitrile, Ethyl cyanide	107-12-0	xd	
Pyridine	110-86-1	xe	
Selenium	(total)		x
Silver	(total)		x
Styrene	100-42-5	xc	
1,1,1,2-Tetrachloroethane	630-20-6	xb	
1,1,2,2-Tetrachloroethane	79-34-5	xb	
Tetrachloroethylene, Perchloroethylene, Tetrachloroethene	127-18-4	xb	
Thallium	(total)		x
Toluene	108-88-3	xc	
1,1,1-Trichloroethane, Methyl chloroform	71-55-6	x	
1,1,2-Trichloroethane	79-00-5	xb	
Trichloroethylene, Trichloroethene	79-01-6	xb	
Trichlorofluoromethane	96-18-4	xb	
1,2,3-Trichloropropane	96-18-4	xb	
Vanadium	(total)		x
Vinyl Acetate	108-05-4	x	
Vinyl Chloride	75-01-4	xb	
Xylene (total)	1330-20-7	xc	
Zinc	(total)		x

**NOTE:** Method 6010 is not recommended for Mercury and Tin.

**1** Caution, these are representative methods and may not always be the most suitable for a given application.

- a Method 8030 is also suggested.
- b Method 8010 is also suggested.
- c Method 8020 is also suggested.
- d Method 8015 is also suggested.
- e Method 8070 is also suggested.

### LIST 3

#### MONITORING CONSTITUENTS POTENTIALLY APPLICABLE TO SPECIFIC MEDIA

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
Acetonitrile	75-05-8	X	X	X		X
Acetophenone	98-86-2	X	X	X		X
2-Acetylaminofluorene	53-96-3	X	X	X		
Acetyl chloride	75-36-5					
1-Acetyl-2-thiourea	591-08-2					
Acrolein	107-02-8	X	X	X		X
Acrylamide	79-06-1					X
Acrylonitrile	107-13-1	X	X	X		X
Aflatoxins	1402-68-2					
Aldicarb	116-06-3					X
Aldrin	309-00-2	X	X	X		
Allyl alcohol	107-18-6					
Allyl chloride	107-05-1	X	X	X		
Aluminum phosphide	20859-73-8					
4-Aminobiphenyl	92-67-1	X	X	X		
5-(Aminomethyl)-3-isoxazolol	2763-96-4					
4-Aminopyridine	504-24-5					
Amitrole	61-82-5					
Ammonium vanadate	7803-55-6					
Aniline	62-53-3	X	X	X		X
Antimony and compounds, N.O.S. <sup>1</sup>	7440-36-0	X	X	X		
Aramite	140-57-8	X	X	X		
Arsenic and compounds, N.O.S. <sup>1</sup>	7440-38-2	X	X	X		X
Arsenic acid	7778-39-4			X		
Arsenic pentoxide	1303-28-2			X		
Arsenic trioxide	1327-53-3			X		
Auramine	492-80-8					
Azaserine	115-02-6					
Barium and compounds, N.O.S. <sup>1</sup>	7440-39-3	X	X	X		
Barium cyanide	542-62-1			X		
Benz(c)acridine	225-51-4					

## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
Benz(a)anthracene	56-55-3	X	X	X		
Benzal chloride	98-87-3			X		
Benzene	71-43-2	X	X	X	X	X
Benzenearsonic acid	98-05-5					
Benzidine	92-87-5			X		
Benzo(b)fluoranthene	205-99-2	X	X	X		
Benzo(j)fluoranthene	205-82-3					
Benzo(a)pyrene	50-32-8	X	X	X		
p-Benzoquinone	106-51-4			X		
Benzotrichloride	98-07-7			X		X
Benzyl chloride	100-44-7			X		X
Beryllium and compounds, N.O.S. <sup>1</sup>	7440-41-7	X	X	X		
Bis(2-chloromethoxy)ethane	111-91-1	X	X	X		
Bis(2-chloroethyl) ether	111-44-4	X	X	X		
Bis(2-chloroisopropyl) ether	39638-32-9	X	X	X	X	
Bis(chloromethyl) ether	542-88-1			X		X
Bis(2-ethylhexyl)phthalate	117-81-7	X	X	X		X
Bromoacetone	589-31-2					
Bromoform	75-25-2	X	X	X		X
4-Bromophenyl phenyl ether	101-55-3	X	X	X		
Brucine	357-57-3					
Butyl benzyl phthalate	85-68-7	X	X	X		
Cacodylic acid	75-60-5					
Cadmium and compounds, N.O.S. <sup>1</sup>	7440-43-9	X	X	X		X
Calcium chromate	13765-19-0			X		
Calcium cyanide	592-01-8			X		
Carbon disulfide	75-15-0	X	X	X	X	X
Carbon oxyfluoride	353-50-4					X
Carbon tetrachloride	56-23-5	X	X	X	X	X
Chloral	75-87-6					

## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
Chlorambucil	305-03-3					
Chlordane, alpha and gamma isomers	57-74-9	X	X	X		X
Chlorinated benzenes, N.O.S. <sup>1</sup>		X	X	X	X	X
Chlorinated ethanes, N.O.S. <sup>1</sup>		X	X	X	X	X
Chlorinated fluorocarbons, N.O.S. <sup>1</sup>						X
Chlorinated naphthalene, N.O.S. <sup>1</sup>		X	X	X		
Chlorinated phenol, N.O.S. <sup>1</sup>				X		X
Chlornaphazine	494-03-1					
Chloroacetaldehyde	107-20-0					
Chloroalkyl ethers, N.O.S. <sup>1</sup>						
p-Chloroaniline	106-47-8	X	X	X		X
Chlorobenzene	108-90-7	X	X	X	X	X
Chlorobenzilate	510-15-6	X	X	X		
p-Chloro-m-cresol	59-50-7	X	X	X		
1-Chloro-2,3-epoxypropane	106-89-8					X
2-Chloroethyl vinyl ether	110-75-8			X		
Chloroform	67-66-3	X	X	X	X	X
Chloromethyl methyl ether	107-30-2					
beta-Chloronaphthalene	91-58-7	X	X	X		
o-Chlorophenol	95-57-8	X	X	X		X
1-(o-Chlorophenyl) thiourea	5344-82-1					
Chloroprene	126-99-8	X	X	X		X
3-Chloropropionitrile	542-76-7			X		
Chromium and compounds, N.O.S. <sup>1</sup>	7440-47-3	X	X	X		X
Chrysene	218-01-9	X	X	X		
Citrus red No. 2	6358-53-8					
Coal tars	8005-45-2			X		
Copper cyanide	544-92-3			X		X
Creosote	8001-58-9			X		
Cresols (Cresylic acid)	1319-77-3	X	X	X		X
Crotonaldehyde	4170-30-3					X

## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
Cyanides (soluble salts and complexes) N.O.S. <sup>1</sup>		X	X	X		X
Cyanogen	460-19-5					X
Cyanogen bromide	506-68-3					
Cyanogen chloride	506-77-4					
Cycasin	14901-08-7					
2-Cyclohexyl-4,6-dinitrophenol	131-89-5					
Cyclophosphamide	50-18-0					
2,4-D, salts and esters	94-75-7	X	X	X		X
Daunomycin	20830-81-3					
DDD	72-54-8	X	X	X		
DDE	72-55-9	X	X	X		
DDT	50-29-3	X	X	X		
Diallate	2303-16-4	X	X	X		
Dibenz(a,h)acridine	226-36-8					
Dibenz(a,j)acridine	224-42-0					
Dibenz(a,h)anthracene	53-70-3	X	X	X		
7H-Dibenzo(c,g)carbazole	194-59-2					
Dibenzo(a,e)pyrene	192-65-4			X		
Dibenzo(a,h)pyrene	189-64-0			X		
Dibenzo(a,i)pyrene	189-55-9			X		
1,2-Dibromo-3-chloropropane	96-12-8	X	X	X		
Dibutylphthalate	84-74-2	X	X	X		
o-Dichlorobenzene	95-50-1	X	X	X		X
m-Dichlorobenzene	541-73-1	X	X	X		X
p-Dichlorobenzene	106-46-7	X	X	X		X
Dichlorobenzene, N.O.S. <sup>1</sup>	25821-22-6	X	X	X		X
3,3'-Dichlorobenzidine	91-94-1	X	X	X		
1,4-Dichloro-2-butene	764-41-0	X	X	X		X
Dichlorodifluoromethane	75-71-8	X	X	X	X	X
1,2-Dichloroethylene	156-60-5	X	X	X	X	

## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
Dichloroethylene, N.O.S. <sup>1</sup>	25323-30-2	X	X	X		X
1,1-Dichloroethylene	75-35-4	X	X	X		X
2,4-Dichlorophenol	120-83-2	X	X	X		
2,6-Dichlorophenol	87-65-0	X	X	X		
Dichlorophenylarsine	696-28-6					
Dichloropropane, N.O.S. <sup>1</sup>	26638-19-7	X	X	X		X
Dichloropropanol, N.O.S. <sup>1</sup>	26545-73-3					
Dichloropropene, N.O.S. <sup>1</sup>	26952-23-8	X	X	X		X
1,3-Dichloropropene	542-75-6	X	X	X		X
Dieldrin	60-57-1	X	X	X		
1,2,3,4-Diepoxybutane	1464-53-5					
Diethylarsine	692-42-2					
1,4-Diethyleneoxide	123-91-1	X	X	X		X
N,N'-Diethylhydrazine	1615-80-1					
O,O-Diethyl S-methyldithiophosphate	3288-58-2					
Diethyl-p-nitro phenyl phosphate	311-45-5			X		
Diethylphthalate	84-66-2	X	X	X		X
O,O-Diethyl O-pyrazinyl phosphorothioate	297-97-2	X	X	X		
Diethylstilbesterol	56-53-1					
Dihydrosafrole	94-58-6					
3,4-Dihydroxy-alpha-(methylamino)methyl benzyl alcohol	329-65-7					
Diisopropylfluorophosphate (DFP)	55-91-4					
Dimethoate	60-51-5	X	X	X		
3,3'-Dimethoxybenzidine	119-90-4	X	X	X		
p-Dimethoxyminoazobenzene	60-11-7	X	X	X		
7,12-Dimethylbenz(a)anthracene	57-97-6	X	X	X		
3,3'-Dimethylbenzidine	119-93-7	X	X	X		
Dimethylcarbamoyl chloride	79-44-7					
1,1-Dimethylhydrazine	57-14-7					X
1,2-Dimethylhydrazine	540-73-8					



## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
alpha, alpha-Dimethylphenethylamine	122-09-8	X	X	X		
2,4-Dimethylphenol	105-67-9	X	X	X		X
Dimethylphthalate	131-11-3	X	X	X		
Dimethyl sulfate	77-78-1					
Dinitrobenzene, N.O.S. <sup>1</sup>	25154-54-5	X	X	X		
4,6-Dinitro-o-cresol and salts	534-52-1	X	X	X		
2,4-Dinitrophenol	51-28-5	X	X	X		
2,4-Dinitrotoluene	121-14-2	X	X	X		X
2,6-Dinitrotoluene	606-20-2	X	X	X		
Dinoseb	88-85-7	X	X	X		
Di-n-octylphthalate	117-84-0	X	X	X		
Diphenylamine	122-39-4	X	X	X		
1,2-Diphenylhydrazine	122-66-7			X		X
Di-n-propylnitrosamine	621-64-7	X	X	X		
Disulfoton	298-04-4	X	X	X		
Dithioburet	541-53-7					
Endosulfan	115-29-7	X	X	X		
Endothal	145-73-3					
Endrin	72-20-8	X	X	X		
Ethyl carbamate (urethane)	51-79-6					
Ethyl cyanide	107-12-0			X		
Ethylenebisdithiocarbamic acid, salts, and esters	111-54-6					
Ethylene dibromide	106-93-4					X
Ethylene dichloride	107-06-2				X	X
Ethylene glycol monoethyl ether	110-80-5					
Ethyleneimine	151-56-4					X
Ethylene oxide	75-21-8					X
Ethylenethiourea	96-45-7					
Ethylidene dichloride	75-34-3				X	X
Ethyl methacrylate	97-63-2	X	X	X		

## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
Ethylmethane sulfonate	62-50-0	X	X	X		
Famphur	52-85-7	X	X	X		
Fluoranthene	206-44-0	X	X	X		
Flourine	7782-41-4			X		
Fluoroacetamide	640-19-7					
Fluoroacetic acid, sodium salt	62-74-8					
Formaldehyde	50-00-0					X
Glycidylaldehyde	765-34-4					
Halomethane, N.O.S. <sup>1</sup>		X	X	X	X	X
Heptachlor	76-44-8	X	X	X		X
Heptachlor epoxide	1024-57-8	X	X	X		
Hexachlorobenzene	118-74-1	X	X	X		
Hexachlorobutadiene	87-68-3	X	X	X		X
Hexachlorocyclopentadiene	77-47-4	X	X	X		
Hexachlorodibenzo-p-dioxins		X	X	X		
Hexachlorodibenzofurans		X	X	X		
Hexachloroethane	67-72-1	X	X	X		X
Hexachlorophene	70-30-4	X	X	X		
Hexachloropropene	1888-71-7	X	X	X		
Hexaethyltetraphosphate	757-58-4					
Hydrazine	302-01-2					X
Hydrogen cyanide	74-90-8					X
Hydrogen fluoride	7664-39-3					
Hydrogen sulfide	7783-06-4			X	X	X
Indeno(1,2,3cd)pyrene	193-39-5	X	X	X		
Iron dextran	9004-66-4					
Isobutyl alcohol	78-83-1	X	X	X		X
Isodrin	465-73-6	X	X	X		
Isosafrole	120-58-1	X	X	X		
Kepone	143-50-0	X	X	X		
Lasiocarpine	303-34-4					
Lead and compounds, N.O.S. <sup>1</sup>	7439-92-1	X	X	X		X
Lead acetate	301-04-2			X		

## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
Lead phosphate	7446-27-7			X		
Lead subacetate	1335-32-6					
Lindane	58-89-9	X	X	X		
Maleic anhydride	108-31-6					X
Maleic hydrazide	123-33-1					
Malonitrile	109-77-3			X		
Melphalan	148-82-3					
Mercury fulminate	628-86-4					
Mercury and compounds N.O.S. <sup>1</sup>	7439-97-6	X	X	X		X
Methacrylonitrile	126-98-7	X	X	X		X
Methapyrilene	91-80-5	X	X	X		
Methomyl	16752-77-5					
Methoxychlor	72-43-5	X	X	X		
Methyl bromide	74-83-9	X	X	X		X
Methyl chloride	74-87-3	X	X	X		X
Methylchlorocarbonate	79-22-1					
Methyl chloroform	71-55-6	X	X	X	X	X
3-Methylcholanthrene	56-49-5	X	X	X		
4,4',Methylenebis(2-chloroaniline)	101-14-4	X	X	X		
Methylene bromide	74-95-3	X	X	X		
Methylene chloride	75-09-2	X	X	X	X	X
Methyl ethyl ketone (MEK)	78-93-3	X	X	X		X
Methyl ethyl ketone peroxide	1338-23-4			X		X
Methyl hydrazine	60-34-4					
Methyl iodide	74-88-4	X	X	X		X
Methyl isocyanate	624-83-9					X
2-Methylactonitrile	75-86-5					X
Methyl methacrylate	80-62-6	X	X	X		X
Methyl methanesulfonate	66-27-3	X	X	X		
Methyl parathion	298-00-0	X	X	X		

## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
Methylthiouracil	56-04-2					
Mitomycin C	50-07-7					
MNNG	70-25-7					
Mustard gas	505-60-2					
Naphthalene	91-20-3	X	X	X		X
1,4-Naphthoquinone	130-15-4	X	X	X		
alpha-Naphthylamine	134-32-7	X	X	X		
Beta-Naphthylamine	91-59-8	X	X	X		
alpha-Naphthylthiourea	86-88-4					
Nickel and compounds, N.O.S. <sup>1</sup>	7440-02-0	X	X	X		
Nickel carbonyl	13463-39-3					
Nickel cyanide	557-19-7			X		
Nicotine and salts	54-11-5					
Nitric oxide	10102-43-9			X		X
p-Nitroaniline	100-01-6	X	X	X		
Nitrobenzene	98-95-3	X	X	X		X
Nitrogen dioxide	10102-44-0			X		
Nitrogen mustard and hydrochloride salt	51-75-2			X		
Nitrogen mustard N-oxide and hydrochloride salt	126-85-2					
Nitroglycerin	55-63-0					X
p-Nitrophenol	100-02-7	X	X	X		X
2-Nitropropane	79-46-9					
4-Nitroquinoline-1-oxide	56-57-5	X	X	X		
Nitrosamine, N.O.S. <sup>1</sup>	35576-91-1	X	X	X		
N-Nitrosodi-n-butylamine	924-16-3	X	X	X		
N-Nitrosodiethanolamine	1116-54-7					
N-Nitrosodiethylamine	55-18-5	X	X	X		
N-Nitrosodimethylamine	62-75-9	X	X	X		
N-Nitroso-N-ethyl urea	759-73-9					
N-Nitrosomethylethylamine	10595-95-6	X	X	X		
N-Nitroso-N-methylurea	684-93-5					

## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
N-Nitroso-N-methylurethane	615-53-2					
N-Nitrosomethylvinylamine	4549-40-0					
N-Nitrosomorpholine	59-89-2	X	X	X		
N-Nitrosornicotine	16543-55-8					
N-Nitrosopiperidine	100-75-4	X	X	X		
Nitrosopyrrolidine	930-55-2	X	X	X		
N-Nitrososarcosine	13256-22-9					
5-Nitro-o-toluidine	99-55-8	X	X	X		
Octamethylpyrophosphoramidate	152-16-9					
Osmium tetroxide	20816-12-0					X
Paraldehyde	123-63-7					
Parathion	56-38-2	X	X	X		X
Pentachlorobenzene	608-93-5	X	X	X		X
Pentachlorodibenzo p dioxins		X	X	X		
Pentachlorodibenzofurans		X	X	X		
Pentachloroethane	76-01-7	X	X	X		X
Pentachloronitrobenzene (PCNB)	82-68-8	X	X	X		
Pentachlorophenol	87-86-5	X	X	X		X
Phenacetin	62-44-2	X	X	X		
Phenol	108-95-2	X	X	X		X
Phenylenediamine	25265-76-3					
Phenylmercury acetate	62-38-4					
Phenylthiourea	103-85-5					
Phosgene	75-44-5					X
Phosphine	7803-51-2					X
Phorate	298-02-2	X	X	X		X
Phthalic acid esters, N.O.S. <sup>1</sup>						
Phthalic anhydride	85-44-9					X
2-Picoline	109-06-8	X	X	X		
Polychlorinated biphenyls N.O.S. <sup>1</sup>		X	X	X		X
Potassium cyanide	151-50-8			X		
Potassium silver cyanide	506-61-6			X		
Pronamide	23950-58-5	X	X	X		

## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
1,3-Propane sultone	1120-71-4					
n-Propylamine	107-10-8					
Propargyl alcohol	107-19-7					
Propylene dichloride	78-87-5					X
1,2-Propylenimine	75-55-8					
Propylthiouracil	51-52-5					
Pyridine	110-86-1	X	X	X		X
Reserpine	50-55-5					X
Resorcinol	108-46-3			X		X
Saccharin and salts	81-07-2					
Safrole	94-59-7	X	X	X		
Selenium dioxide	7783-00-8					
Selenium and compounds, N.O.S.	7782-49-2	X	X	X		
Selenium sulfide	7446-34-6			X		
Selenourea	630-10-4					
Silver and compounds, N.O.S. <sup>1</sup>	7440-22-4	X	X	X		
Silver cyanide	506-64-9			X		
Silvex (2,4,5-TP)	93-72-1	X	X	X		
Sodium cyanide	143-33-9					
Streptozotocin	18883-66-4					
Strontium sulfide	1314-96-1			X		
Strychnine and salts	57-24-9					
TCDD	1746-01-6	X	X	X		X
1,2,4,5-Tetrachlorobenzene	95-94-3	X	X	X		
Tetrachlorodibenzo-p-dioxins		X	X	X		
Tetrachlorodibenzofurans		X	X	X		
Tetrachloroethane, N.O.S. <sup>1</sup>	25322-20-7	X	X	X	X	
1,1,1,2-Tetrachloroethane	630-20-6	X	X	X		
1,1,2,2-Tetrachloroethane	79-34-5	X	X	X	X	
Tetrachloroethylene	127-18-4	X	X	X	X	X

## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
2,3,4,6-Tetrachlorophenol	58-90-2	X	X	X		
Tetraethyldithiopyrophosphate	3689-24-5	X	X	X		
Tetraethyl lead	78-00-2					X
Tetraethylpyrophosphate	107-49-3			X		
Tetranitromethane	509-14-8			X		
Thallium and compounds, N.O.S. <sup>1</sup>	7440-28-0	X	X	X		
Thallic oxide	1314-32-5			X		
Thallium (1) acetate	563-68-8			X		
Thallium (1) carbonate	6533-73-9			X		
Thallium (1) chloride	7791-12-0			X		
Thallium (1) nitrate	10102-45-1			X		
Thallium selenite	12039-52-0			X		
Thallium (1) sulfate	10031-59-1			X		
Thioacetamide	62-55-5					X
Thiofanox	39196-18-4					
Thiomethanol	74-93-1					X
Thiophenol	108-98-5			X		
Thiosemicarbazide	79-19-6					
Thiourea	62-56-6					
Thiram	137-26-8					
Toluene	108-88-3	X	X	X	X	X
Toluenediamine	25376-45-8					
2,4-Toluenediamine	95-80-7					X
2,6-Toluenediamine	823-40-5					
3,4-Toluenediamine	496-72-0					
Toluene diisocyanate	584-84-9			X		X
p-Toluidine	106-49-0					
o-Toluidine hydrochloride	636-21-5					
Toxaphene	8001-35-2	X	X	X		X
1,2,4-Trichlorobenzene	120-82-1	X	X	X		X
1,1,2-Trichloroethane	79-00-5	X	X	X	X	

## LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water <sup>2</sup>	Soil <sup>3</sup>	Subsurface Gas <sup>4</sup>	Air
Trichloroethylene	79-01-6	X	X	X	X	X
Trichloromethanethiol	75-70-7			X		
Trichloromonofluoromethane	75-69-4	X	X	X		
2,4,5-Trichlorophenol	95-95-4	X	X	X		
2,4,6-Trichlorophenol	88-06-2	X	X	X		
2,4,5-T	93-76-5	X	X	X		
Trichloropropane, N.O.S. <sup>1</sup>		X	X	X		X
1,2,3-Trichloropropane	96-18-4	X	X	X		X
0,0,0-Triethylphosphorothioate	126-68-1	X	X	X		
sym-Trinitrobenzene	99-35-4	X	X	X		
Tris(1-aziridinyl)phosphine sulfide	52-24-4					
Tris(2,3-dibromopropyl)phosphate	126-72-7					
Trypan blue	72-57-1					
Uracil mustard	66-75-1					
Vanadium pentoxide	1314-62-1			X		X
Vinyl chloride	75-01-4	X	X	X	X	X
Warfarin	81-81-2					
Zinc cyanide	557-21-1			X		
Zinc phosphide	1314-84-7			X		

\* See also 40 CFR 264, Appendix IX.

<sup>1</sup> The abbreviation N.O.S. (not otherwise specified) signifies those members of the general class not specifically listed by name.

<sup>2</sup> Applies to the water column only. Additional constituents may be of concern if sediment and/or biota are to be sampled and subjected to analysis (See Section 13).

<sup>3</sup> Includes both saturated and unsaturated soils. Some of these are gases at ambient temperature and pressure which may be present in wet or saturated soils. Degradation as a result of chemical, biological or physical processes, may result in decreasing concentrations of constituents over time, and is dependent on moisture content as well as other factors.

<sup>4</sup> Compounds indicated are those which may be present within a carrier gas (e.g., methane).



## **LIST 4**

### **INDUSTRY SPECIFIC MONITORING CONSTITUENTS**

#### **REFERENCES FOR INDUSTRY SPECIFIC MONITORING CONSTITUENTS**

1. 40 CFR 122, National Pollutant Discharge Elimination System
2. U.S. EPA, Development Document for Effluent Limitation Guidelines and Standards for the ... Point Source Category.  
(Total of 30 Industries)
3. U.S. EPA, 1980, Treatability Manual. Volume I. Treatability Data
4. U.S. EPA Regional Offices for Industry Specific Data.

## LIST 4\*

## SW-846 Chemical Classifications - See Supplemental Tables

Industrial Category	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	2-11	2-12	2-13	2-14	2-15
Auto and Other Laundries	•	•	•	•		•		•		•		•		•	•
Coal Mining	•	•	•	•		•		•		•		•		•	•
Coal Coating	•	•		•		•		•		•		•		•	•
Copper Forming	•		•	•		•				•		•		•	•
Electroplating	•					•				•				•	•
Electrical and Electronic Components	•	•	•	•		•		•		•		•		•	•
Explosives Manufacturing	•	•	•			•				•		•		•	•
Foundries	•	•	•	•		•		•		•		•		•	•
Gum and Wood Chemicals	•					•		•		•		•		•	•
Inorganic Chemicals Manufacturing	•	•	•	•		•				•		•	•	•	•
Iron and Steel Manufacturing	•	•	•	•	•	•		•		•		•	•	•	•
Leather Tanning and Finishing	•	•		•		•				•		•		•	•
Metal Finishing	•	•	•	•	•	•		•		•		•	•	•	•
Nonferrous Metals Manufacturing	•	•	•	•		•		•		•		•		•	•
Ore Mining	•	•				•		•		•		•		•	•
Organic Chemicals Manufacturing	•	•	•	•		•		•		•		•		•	•
Paint and Ink Formulation	•	•	•			•		•		•		•		•	•
Pesticides and Herbicides	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

LIST 4 (Continued)\*

SW-846 Chemical Classifications - See Supplemental Tables

Industrial Category	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	2-11	2-12	2-13	2-14	2-15
Petroleum Refining	•	•		•		•		•		•		•		•	•
Pharmaceutical Preparations	•	•	•	•		•		•		•		•	•	•	•
Photographic Equipment and Supplies	•	•	•	•		•				•		•		•	•
Plastics Molding and Forming	•	•		•		•		•		•		•		•	•
Porcelain Enameling	•	•				•				•		•		•	•
Pulp and Paper Mills	•	•	•	•		•		•		•		•	•	•	•
Rubber Processing	•	•	•			•				•		•	•	•	•
Soap and Detergent Manufacturing	•	•		•		•		•		•		•		•	•
Steam Electric Power Plants	•	•	•	•		•		•		•		•	•	•	•
Textile Mills	•	•	•	•	•	•		•		•		•	•	•	•
Timber Products	•			•		•		•		•		•		•	•
Wood Preserving	•	•	•	•		•		•		•		•	•	•	•

- \* - A "•" indicates that one or more constituents within a category are likely candidates for monitoring.
- This list does not contain all industries that may be subject to an RFI.
- The constituents within the categories indicated may not be mutually exclusive. If a chemical category is checked for a particular industry, the owner or operator may be responsible for all constituents within the category, regardless of whether the constituent is contained in other categories.

**SUPPLEMENT TO LIST 4**

**REPRINTED TABLES FROM TEST METHODS FOR EVALUATING SOLID WASTES:  
3RD ED. U.S. EPA SW-846. GPO No. 955-001-0000-1. 1986.**

**Table 2-1: Phenols and Organic Acids**

Benzoic acid  
Benzyl alcohol  
2-sec-Butyl-4,6-dinitrophenol (DNBP)  
4-Chloro-3-methylphenol  
2-Chlorophenol  
Cresol (methyl phenols)  
2-Cyclohexyl-4,6-dinitrophenol  
2,4-Dichlorophenol  
2,6-Dichlorophenol  
2,4-Dimethylphenol  
4,6-Dinitro-o-cresol  
2,4-Dinitrophenol  
2-Methyl-4,6-dinitrophenol  
2-Nitrophenol  
4-Nitrophenol  
Pentachlorophenol  
Phenol  
Tetrachlorophenols  
Trichlorophenols

**Table 2-2: Phthalate Esters**

Benzyl butyl phthalate  
Bis(2-ethylhexyl)phthalate  
Diethyl phthalate  
Di-n-butyl phthalate  
Dimethyl phthalate  
Di-n-octyl phthalate

**Table 2-3: Nitroaromatics and Cyclic Ketones**

Dinitrobenzene  
2,4-Dinitrotoluene  
2,6-Dinitrotoluene  
Isophorone  
Naphthoquinone  
Nitrobenzene

**Table 2-4: Polyaromatic Hydrocarbons**

Acenaphthene  
Acenaphthylene  
Anthracene  
Benzo(a)anthracene  
Benzo(a)pyrene  
Benzo(b)fluoranthene  
Benzo(j)fluoranthene  
Benzo(k)fluoranthene  
Benzo(g,h,i)perylene  
Chrysene  
Dibenz(a,h)acridine  
Dibenz(a,j)acridine  
Dibenz(a,h)anthracene (Dibenzo(a,h)anthracene)  
7H-Dibenzo(c,g)carbazole  
Dibenzo(a,e)pyrene  
Dibenzo(a,h)pyrene  
Dibenzo(a,i)pyrene  
Fluoranthene  
Fluorene  
Indeno(1,2,3-cd)pyrene  
3-Methylcholanthrene  
Naphthalene  
Phenanthrene  
Pyrene



**Table 2-5: Chlorinated Hydrocarbons**

Benzotrichloride  
Benzyl chloride  
2-Chloronaphthalene  
Dichlorobenzenes  
Dichloromethylbenzenes (Dichlorotoluenes)  
Hexachlorobenzene  
Hexachlorobutadiene  
Hexachlorocyclohexane  
Hexachlorocyclopentadiene  
Hexachloroethane  
Pentachlorohexane  
Tetrachlorobenzenes  
Trichlorobenzenes

**Table 2-6: Base/Neutral**

Acenaphthene	$\alpha,\alpha$ -Dimethylphethylamine
Acenaphthylene	Dimethyl phthalate
Acetophenone	2,4-Dinitrotoluene
Aldrin	2,6-Dinitrotoluene
Aniline	Diphenylamine
Anthracene	1,2-Diphenylhydrazine
4-Aminobiphenyl	Di-n-octyl phthalate
Aroclor-1016	Endosulfan I
Aroclor-1221	Endosulfan II
Aroclor-1232	Endosulfan sulfate
Aroclor-1242	Endrin
Aroclor-1248	Endrin aldehyde
Aroclor-1254	Endrin ketone
Aroclor-1260	Ethyl methanesulfonate
Benzidine	Fluoranthene
Benzo(a)anthracene	Fluorene
Benzo(b)fluoranthene	2-Fluorobiphenyl
Benzo(k)fluoranthene	Heptachlor
Benzo(g,h,i)perylene	Heptachlor epoxide
Benzo(a)pyrene	Hexachlorobenzene
$\alpha$ -BHC	Hexachlorobutadiene
$\beta$ -BHC	Hexachlorocyclopentadiene
$\delta$ -BHC	Hexachloroethane
$\gamma$ -BHC	Indeno(1,2,3-cd)pyrene
Bis(2-chloroethoxy)methane	Isophorone
Bis(2-chloroethyl)ether	Met. oxychlor
Bis(2-chloroisopropyl)ether	3-Methylcholanthrene
Bis(2-ethylhexyl)phthalate	Methyl methanesulfonate
4-Bromophenyl phenyl ether	2-Methylnaphthalene
Butyl benzyl phthalate	Naphthalene
Chlordane	1-Naphthylamine
4-Chloroaniline	2-Naphthylamine
1-Chloronaphthalene	2-Nitroaniline
2-Chloronaphthalene	3-Nitroaniline
4-Chlorophenyl phenyl ether	4-Nitroaniline
Chrysene	Nitrobenzene
4,4'-DDD	N-Nitroso-di-n-butylamine
4,4'-DDE	N-Nitrosodimethylamine
4,4'-DDT	N-Nitrosodiphenylamine
Dibenz(a,j)acridine	N-Nitrosodipropylamine
Dibenz(a,h)anthracene	N-Nitrosopiperidine
Dibenzofuran	Pentachlorobenzene
Di-n-butyl phthalate	Pentachloronitrobenzene
1,3-Dichlorobenzene	Phenacetin
1,4-Dichlorobenzene	Phenanthrene
1,2-Dichlorobenzene	2-Picoline
3,3'-Dichlorobenzidine	Pronamide
Dieldrin	Pyrene
Diethyl phthalate	1,2,4,5-Tetrachlorobenzene
p-Dimethylaminoazobenzene	1,2,4-Trichlorobenzene
7,12-Dimethylbenz(a)anthracene	Toxaphene

**Table 2-7: Organophosphorous Pesticides**

Azinphos methyl  
Bolstar (Sulprofos)  
Chlorpyrifos  
Coumaphos  
Demeton  
Diazinon  
Dichlorvos  
Dimethoate  
Disulfoton  
EPN  
Ethoprop  
Fensulfothion  
Fenthion  
Malathion  
Merphos  
Mevinphos  
Monochrotophos  
Naled  
Parathion  
Parathion methyl  
Phorate  
Ronnel  
Stiropfos (Tetrachlorvinphos)  
Sulfotepp  
TEPP  
Tokuthion (Prothiofos)  
Trichloronate

**Table 2-8: Organochlorine Pesticides and PCB's**

Aldrin  
 $\alpha$ -BHC  
 $\beta$ -BHC  
 $\delta$ -BHC  
 $\gamma$ -BHC (Lindane)  
Chlordane  
4,4'-DDD  
4,4'-DDE  
4,4'-DDT  
Dieldrin  
Endosulfan I  
Endosulfan II  
Endosulfan sulfate  
Endrin  
Endrin aldehyde  
Heptachlor  
Heptachlor epoxide  
Kepone  
Methoxychlor  
Toxaphene  
PCB-1016 (Aroclor-1016)  
PCB-1221 (Aroclor-1221)  
PCB-1232 (Aroclor-1232)  
PCB-1242 (Aroclor-1242)  
PCB-1248 (Aroclor-1248)  
PCB-1254 (Aroclor-1254)  
PCB-1260 (Aroclor-1260)

**Table 2-9: Chlorinated Herbicides**

2,4-D  
2,4-DB  
2,4,5-T  
2,4,5-TP (Silvex)  
Dalapon  
Dicamba  
Dichloroprop  
Dinoseb  
MCPA  
MCP

**Table 2-10: Halogenated Volatiles**

Benzyl chloride  
Bis(2-chloroethoxy)methane  
Bis(2-chloroisopropyl)ether  
Bromobenzene  
Bromodichloromethane  
Bromoform  
Bromomethane  
Carbon tetrachloride  
Chloracetaldehyde  
Chloral  
Chlorobenzene  
Chloroethane  
Chloroform  
1-Chlorohexane  
2-Chloroethyl vinyl ether  
Chloromethane  
Chloromethyl methyl ether  
Chlorotoluene  
Dibromochloromethane  
Dibromomethane  
1,2-Dichlorobenzene  
1,3-Dichlorobenzene  
1,4-Dichlorobenzene  
Dichlorodifluoromethane  
1,1-Dichloroethane  
1,2-Dichloroethane  
1,1-Dichloroethylene (Vinylidene chloride)  
trans-1,2-Dichloroethylene  
Dichloromethane  
1,2-Dichloropropane  
1,3-Dichloropropylene  
1,1,2,2-Tetrachloroethane  
1,1,1,2-Tetrachloroethane  
Tetrachloroethylene  
1,1,1-Trichloroethane  
1,1,2-Trichloroethane  
Trichloroethylene  
Trichlorofluoromethane  
Trichloropropane  
Vinyl chloride

**Table 2-11: Non-halogenated Volatiles**

Acrylamide  
Diethyl ether  
Ethanol  
Methyl ethyl ketone (MEK)  
Methyl isobutyl ketone (MIBK)  
Paraldehyde (trimer of acetaldehyde)

**Table 2-12: Aromatic Volatiles**

Benzene  
Chlorobenzene  
1,2-Dichlorobenzene  
1,3-Dichlorobenzene  
1,4-Dichlorobenzene  
Ethyl benzene  
Toluene  
Xylenes (Dimethyl benzenes)



**Table 2-13: Acetonitrile, Acrolein, Acrylonitrile**

- Acetonitrile
- Acrolein (Propenal)
- Acrylonitrile

**Table 2-14: Volatiles**

Acetone	cis-1,3-Dichloropropene
Acrolein	trans-1,3-Dichloropropene
Acrylonitrile	1,4-Difluorobenzene
Benzene	Ethanol
Bromochloromethane	Ethylbenzene
Bromodichloromethane	Ethyl methacrylate
4-Bromofluorobenzene	2-Hexanone
Bromoform	Iodomethane
Bromomethane	Methylene chloride
2-Butanone (Methyl ethyl ketone)	4-Methyl-2-pentanone
Carbon disulfide	Styrene
Carbon tetrachloride	1,1,2,2-Tetrachloroethane
Chlorobenzene	Toluene
Chlorodibromomethane	1,1,1-Trichloroethane
Chloroethane	1,1,2-Trichloroethane
2-Chloroethyl vinyl ether	Trichloroethene
Chloroform	Trichlorofluoromethane
Chloromethane	1,2,3-Trichloropropane
Dibromomethane	Vinyl acetate
1,4-Dichloro-2-butane	Vinyl chloride
Dichlorodifluoromethane	Xylene
1,1-Dichloroethane	
1,2-Dichloroethane	
1,1-Dichloroethene	
trans-1,2-Dichloroethene	

**Table 2-15: (Partial): Metals**

Aluminum  
Antimony  
Arsenic  
Barium  
Beryllium  
Cadmium  
Chromium  
Cobalt  
Copper  
Iron  
Lead  
Magnesium  
Manganese  
Mercury  
Nickel  
Potassium  
Selenium  
Silver  
Sodium  
Thallium  
Vanadium  
Zinc

## RFI GUIDANCE FEEDBACK QUESTIONNAIRE

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1. Does the format of the guidance lend itself to easily finding specific topics of concern when needed? (Please provide any suggestions you may have to improve the format).

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2. Does the guidance provide adequate information on how to develop an RFI Work Plan? (Provide suggestions if applicable).

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3. Are the technical methods in the guidance up-to-date? Are there other technical methods that should be added?

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4. Does the guidance provide sufficient examples to perform investigatory tasks?

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5. Other comments or suggestions?

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**INTERIM FINAL**

**RCRA FACILITY INVESTIGATION (RFI) GUIDANCE**

**VOLUME II OF IV**

**SOIL, GROUND WATER AND  
SUBSURFACE GAS RELEASES.**

**EPA 530/SW-89-031**

**MAY 1989**

**WASTE MANAGEMENT DIVISION  
OFFICE OF SOLID WASTE  
U.S. ENVIRONMENTAL PROTECTION AGENCY**

## **ABSTRACT**

On November 8, 1984, Congress enacted the Hazardous and Solid Waste Amendments (HSWA) to RCRA. Among the most significant provisions of HSWA are §3004(u), which requires corrective action for releases of hazardous waste or constituents from solid waste management units at hazardous waste treatment, storage and disposal facilities seeking final RCRA permits; and §3004(v), which compels corrective action for releases that have migrated beyond the facility property boundary. EPA will be promulgating rules to implement the corrective action provisions of HSWA, including requirements for release investigations and corrective measures.

This document, which is presented in four volumes, provides guidance to regulatory agency personnel on overseeing owners or operators of hazardous waste management facilities in the conduct of the second phase of the RCRA Corrective Action Program, the RCRA Facility Investigation (RFI). Guidance is provided for the development and performance of an investigation by the facility owner or operator based on determinations made by the regulatory agency as expressed in the schedule of a permit or in an enforcement order issued under §3008(h), §7003, and/or §3013. The purpose of the RFI is to obtain information to fully characterize the nature, extent and rate of migration of releases of hazardous waste or constituents and to interpret this information to determine whether interim corrective measures and/or a Corrective Measures Study may be necessary.

## **DISCLAIMER**

**This document is intended to assist Regional and State personnel in exercising the discretion conferred by regulation in developing requirements for the conduct of RCRA Facility Investigations (RFIs) pursuant to 40 CFR 264. Conformance with this guidance is expected to result in the development of RFIs that meet the regulatory standard of adequately detecting and characterizing the nature and extent of releases. However, EPA will not necessarily limit acceptable RFIs to those that comport with the guidance set forth herein. This document is not a regulation (i.e., it does not establish a standard of conduct which has the force of law) and should not be used as such. Regional and State personnel must exercise their discretion in using this guidance document as well as other relevant information in determining whether an RFI meets the regulatory standard.**

**Mention of company or product names in this document should not be considered as an endorsement by the U.S. Environmental Protection Agency.**

**RCRA FACILITY INVESTIGATION (RFI) GUIDANCE**  
**VOLUME II**  
**SOIL, GROUND WATER AND SUBSURFACE GAS RELEASES**  
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## LIST OF ACRONYMS

AA	- Atomic Absorption
AI	- Soil Adsorption Isotherm Test
ASCS	- Agricultural Stabilization and Conservation Service
ASTM	- American Society for Testing and Materials
BCF	- Bioconcentration Factor
BOD	- Biological Oxygen Demand
CAG	- EPA Carcinogen Assessment Group
CPF	- Carcinogen Potency Factor
CBI	- Confidential Business Information
CEC	- Cation Exchange Capacity
CERCLA	- Comprehensive Environmental Response, Compensation, and Liability Act
CFR	- Code of Federal Regulations
CIR	- Color Infrared
CM	- Corrective Measures
CMI	- Corrective Measures Implementation
CMS	- Corrective Measures Study
COD	- Chemical Oxygen Demand
COLIWASA	- Composite Liquid Waste Sampler
DNPH	- Dinitrophenyl Hydrazine
DO	- Dissolved Oxygen
DOT	- Department of Transportation
ECD	- Electron Capture Detector
EM	- Electromagnetic
EP	- Extraction Procedure
EPA	- Environmental Protection Agency
FEMA	- Federal Emergency Management Agency
FID	- Flame Ionization Detector
foc	- Fraction organic carbon in soil
FWS	- U.S. Fish and Wildlife Service
GC	- Gas Chromatography
GC/MS	- Gas chromatography/Mass Spectroscopy
GPR	- Ground Penetrating Radar
HEA	- Health and Environmental Assessment
HEEP	- Health and Environmental Effects Profile
HPLC	- High Pressure Liquid Chromatography
HSWA	- Hazardous and Solid Waste Amendments (to RCRA)
HWM	- Hazardous Waste Management
ICP	- Inductively Coupled (Argon) Plasma
ID	- Infrared Detector
Kd	- Soil/Water Partition Coefficient
Koc	- Organic Carbon Adsorption Coefficient
Kow	- Octanol/Water Partition Coefficient
LEL	- Lower Explosive Limit
MCL	- Maximum Contaminant Level
MM5	- Modified Method 5
MS/MS	- Mass Spectroscopy/Mass Spectroscopy
NFIP	- National Flood Insurance Program
NIOSH	- National Institute for Occupational Safety and Health
NPDES	- National Pollutant Discharge Elimination System
OSHA	- Occupational Safety and Health Administration

## **LIST OF ACRONYMS (Continued)**

<b>OVA</b>	- <b>Organic Vapor Analyzer</b>
<b>PID</b>	- <b>Photo Ionization Detector</b>
<b>pKa</b>	- <b>Acid Dissociation Constant</b>
<b>ppb</b>	- <b>parts per billion</b>
<b>ppm</b>	- <b>parts per million</b>
<b>PUF</b>	- <b>Polyurethane Foam</b>
<b>PVC</b>	- <b>Polyvinyl Chloride</b>
<b>QA/QC</b>	- <b>Quality Assurance/Quality Control</b>
<b>RCRA</b>	- <b>Resource Conservation and Recovery Act</b>
<b>RFA</b>	- <b>RCRA Facility Assessment</b>
<b>RfD</b>	- <b>Reference Dose</b>
<b>RFI</b>	- <b>RCRA Facility Investigation</b>
<b>RMCL</b>	- <b>Recommended Maximum Contaminant Level</b>
<b>RSD</b>	- <b>Risk Specific Dose</b>
<b>SASS</b>	- <b>Source Assessment Sampling System</b>
<b>SCBA</b>	- <b>Self Contained Breathing Apparatus</b>
<b>SCS</b>	- <b>Soil Conservation Service</b>
<b>SOP</b>	- <b>Standard Operating Procedure</b>
<b>SWMU</b>	- <b>Solid Waste Management Unit</b>
<b>TCLP</b>	- <b>Toxicity Characteristic Leaching Procedure</b>
<b>TEGD</b>	- <b>Technical Enforcement Guidance Document (EPA, 1986)</b>
<b>TOC</b>	- <b>Total Organic Carbon</b>
<b>TOT</b>	- <b>Time of travel</b>
<b>TOX</b>	- <b>Total Organic Halogen</b>
<b>USGS</b>	- <b>United States Geologic Survey</b>
<b>USLE</b>	- <b>Universal Soil Loss Equation</b>
<b>UV</b>	- <b>Ultraviolet</b>
<b>VOST</b>	- <b>Volatile Organic Sampling Train</b>
<b>VSP</b>	- <b>Verticle Seismic Profiling</b>
<b>WQC</b>	- <b>Water Quality Criteria</b>

## **SECTION 9**

### **SOIL**

#### **9.1 Overview**

The objective of an investigation of a release to soil is to characterize the nature, extent, and rate of migration of a release of hazardous waste or constituents to that medium. This section provides:

- An example strategy for characterizing releases to soils, which includes characterization of the source and the environmental setting of the release, and conducting a monitoring program that will characterize the release.
- Formats for data organization and presentation;
- Field methods that may be used in the investigation; and
- A checklist of information that may be needed for release characterization.

The exact type and amount of information required for sufficient release characterization will be site-specific and should be determined through interactions between the regulatory agency and the facility owner or operator during the RFI process. This guidance does not define the specific data needed in all instances; however, it identifies possible information that might be necessary to perform release characterizations and methods for obtaining this information. The RFI Checklist, presented at the end of this section, provides a tool for planning and tracking information for release characterization. This list is not meant to be a list of requirements for all releases to soil. Some release investigations will involve the collection of only a subset of the items listed, while others may involve the collection of additional data.

## **9.2 Approach for Characterizing Releases to Soil**

### **9.2.1 General Approach**

A preliminary task in any soil investigation should be to review existing site information that might help to define the nature and magnitude of the release. Information supplied by the regulatory agency in permit conditions or an enforcement order will indicate known or suspected releases to soil from specific units at the facility needing investigation; and may also indicate situations where inter-media contaminant transfer should be investigated.

A conceptual model of the release should be formulated using all available information on the waste, unit characteristics, environmental setting, and any existing monitoring data. This model (not a computer or numerical simulation model) should provide a working hypothesis of the release mechanism, transport pathway/mechanism, and exposure route (if any). The model should be testable/verifiable and flexible enough to be modified as new data become available. For soil investigations, this model should account for the ability of the waste to be dissolved by infiltrating precipitation, its affinity for soil particles (i.e., sorption), its degradability (biological and chemical), and its decomposition products. Unit-specific factors affecting the magnitude and configuration of the release should also be incorporated (e.g., large area releases from land treatment versus more localized releases from small drum storage areas). The conceptual model should also address the potential for transfer of contaminants in soil to other environmental media (e.g., overland runoff to surface water, leaching to ground water, and volatilization to the atmosphere).

Characterizing contaminant releases to soils may employ a phased approach. Data collected during an initial phase can be evaluated to determine the need for or scope of subsequent efforts. For example, if a suspected release was identified by the regulatory agency, the initial monitoring effort may be geared to release verification. Table 9-1 presents an example of a release characterization strategy. The intensity and duration of the investigation will depend on the complexity of the environmental setting and the nature and magnitude (e.g., spatial extent and concentrations) of the release.

**TABLE 9-1**

**EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO SOIL \***

---

**INITIAL PHASE**

1. Collect and review existing information on:
  - Waste
  - Unit
  - Environmental setting
  - Releases, including inter-media transport
2. Identify additional information necessary to fully characterize release:
  - Waste
  - Unit
  - Environmental setting
  - Releases, including inter-media transport
3. Develop monitoring procedures:
  - Formulate conceptual model of release
  - Determine monitoring program objectives
  - Select constituents and indicators to be monitored
  - Plan initial sampling based on unit/waste/environmental setting characteristics and conceptual model. May include field screening methods, if appropriate.
  - Define study and background areas
  - Determine sampling methods, locations, depths and numbers
  - Sampling frequency
  - Analytical methods
  - QA/QC procedures



**TABLE 9-1 (Continued)**

**EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO SOIL\***

---

**4 Conduct initial monitoring phase:**

- Employ field screening methods, if appropriate
- Conduct initial soil sampling and other appropriate field measurements
- Collect geologic data
- Analyze samples for selected constituents and indicators

**5. Collect, evaluate, and report results:**

- Compare monitoring results to health and environmental criteria and identify and respond to emergency situations and identify priority situations that may warrant interim corrective measures - Notify regulatory agency
- Evaluate potential for inter-media contaminant transfer
- Summarize and present data in an appropriate format
- Determine if monitoring program objectives were met (e.g., monitoring locations, constituents and frequency were adequate to characterize release (nature, rate and extent))
- Report results to regulatory agency

**SUBSEQUENT PHASES (if necessary)**

**1. Identify additional information necessary to characterize release:**

- Determine need to expand or include further soil stratigraphic and hydrologic sampling
- Information needed to evaluate potential for inter-media contaminant transfer (e.g., leaching studies to evaluate potential for ground-water contamination)

**2. Expand monitoring network as necessary:**

- Expand area of field screening, if appropriate
- Expand sampling area and/or increase density
- Add or delete constituents and parameters of concern
- Increase or decrease monitoring frequency

**TABLE 9-1 (Continued)**

**EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO SOIL \***

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3. Conduct subsequent monitoring phases:
    - Perform expanded monitoring and field analyses
    - Analyze samples for selected constituents and parameters
  
  4. Collect, evaluate, and report results/identify additional information necessary to characterize release:
    - Compare results to health and environmental criteria and identify and respond to emergency situations and identify priority situations that warrant interim corrective measures - Notify regulatory agency
    - Summarize and present data in appropriate format
    - Determine if monitoring program objectives were met
    - Determine if monitoring locations, constituents, and frequency were adequate to characterize release (nature, extent, and rate)
    - Determine need to expand monitoring system
    - Evaluate potential for inter-media contaminant transfer
    - Report results to regulatory agency, including results of inter-media transfer evaluation, if applicable.
- 

- \* The possibility for inter-media transfer of contamination should be anticipated throughout the investigation.

The owner or operator should plan the initial characterization effort with all available information on the site, including wastes and soil characteristics. During the initial phase, constituents of concern as well as indicator parameters should be identified that can be used to characterize the release and determine the approximate extent and rate of migration of the release. Table 9-2 lists tasks that can be performed to characterize a release to soils and displays the associated techniques and outputs from each of these tasks. Soil characteristics and other environmental factors include 1) surface features such as topography, erosion potential, land-use capability, and vegetation; 2) stratigraphic/hydrologic features such as soil profile, particle size distribution, hydraulic conductivity, pH, porosity, and cation exchange capacity; and 3) meteorological factors such as temperature, precipitation, runoff, and evapotranspiration. Relevant soil physical and chemical properties should be measured and related to waste properties to determine the potential mobility of the contaminants in the soil.

As monitoring data become available, both within and at the conclusion of discrete investigation phases, it should be reported to the regulatory agency as directed. The regulatory agency will compare the monitoring data to applicable health and environmental criteria to determine the need for (1) interim corrective measures; and/or (2) a Corrective Measures Study. In addition, the regulatory agency will evaluate the monitoring data with respect to adequacy and completeness to determine the need for any additional monitoring efforts. The health and environmental criteria and a general discussion of how the regulatory agency will apply them are supplied in Section 8. A flow diagram illustrating RFI decision points is provided in Section 3 (see Figure 3-2).

Notwithstanding the above process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For such situations, the owner or operator is directed to obtain and follow the RCRA Contingency Plan requirements under 40 CFR Part 264, Subpart D, and Part 265, Subpart D.

As indicated above, depending on the results of the initial phase, the need for further characterization will be determined by the regulatory agency. Subsequent phases, if necessary, may involve expansion of the sampling network, changes in the study area, investigation of contaminant transfer to other media, or other

**TABLE 9-2**  
**RELEASE CHARACTERIZATION TASKS FOR SOILS**

Investigatory Tasks	Investigatory Techniques	Data Presentation Formats/Outputs
1. Waste/Unit Characterization	Refer to Sections 3 and 7	<ul style="list-style-type: none"> <li>- Table of monitoring constituents and their chemical/physical properties</li> <li>- Table of unit features contributing to soil releases</li> </ul>
2. Environmental Setting Characterization <ul style="list-style-type: none"> <li>- Determine surface features and topography</li> <li>- Characterize soil stratigraphy and hydrology</li> <li>- Meteorological Conditions</li> </ul>	<ul style="list-style-type: none"> <li>- Aerial photography or mapping (See Appendix A)</li> <li>- Soil core examination</li> <li>- Measurement of soil properties</li> <li>- On-site meteorological monitoring</li> </ul>	<ul style="list-style-type: none"> <li>- Soil survey map</li> <li>- Topographic map</li> <li>- Photographs</li> <li>- Soil boring logs</li> <li>- Soil profile, transect, or fence diagram</li> <li>- Particle size distribution</li> <li>- Table of unsaturated hydraulic conductivities for each soil layer</li> <li>- Table of soil chemistry and structure (e.g., pH, porosity) for each soil type</li> <li>- Temperature charts</li> <li>- Tables of monthly and annual precipitation, runoff, and evapo-transpiration</li> </ul>
3. Release Characterization	<ul style="list-style-type: none"> <li>- Field Screening</li> <li>- Sampling and Analysis</li> <li>- Soil Transport Modeling</li> </ul>	<ul style="list-style-type: none"> <li>- Maps and tables showing results of soil gas surveys</li> <li>- Tables and graphs showing results of chemical analyses performed in the field</li> <li>- Map of sampling points</li> <li>- Table of constituent concentrations measured at each sampling point</li> <li>- Area and profile maps of site, showing distribution of contaminants</li> <li>- Table of input values, boundary conditions, output values, and modeling assumptions</li> <li>- Maps of present or future extent of contamination</li> </ul>

objectives dictated by the initial findings. The owner or operator may propose to use mathematical models (e.g., chemical, physical) to aid in the choice of additional sampling locations or to estimate contaminant mobility in soil. The results of all characterization efforts should be organized and presented to the regulatory agency in a format appropriate to the data.

Case Study Numbers 2, 3, 15, 16 and 17 in Volume IV (Case Study Examples) illustrate various aspects of soil investigations.

### **9.2.2 Inter-media Transport**

As mentioned above, the potential for inter-media transfer of releases from the soil medium to other media is significant. Contaminated soil can be a major source of contamination to ground water, air, subsurface gas and surface water. Hazardous wastes or constituents, particularly those having a moderate to high degree of mobility, can leach from the soil to the ground water. Volatile wastes or constituents can contribute to subsurface gas and releases to air. Contaminated soils can also contribute to surface water releases, especially through run-off during heavy rains. Application of the universal soil loss equation (See Section 13.6) can indicate whether inter-media transport from soil to surface water as a result of erosion can act as a source of contamination. The owner or operator should recognize the potential for inter-media transport of releases to soil and should communicate as appropriate with the regulatory agency when such transport is suspected or identified during the investigation.

Similarly, the potential for inter-media transport of constituents from other media to the soil also exists. For example, hazardous waste or constituents may be transported to the soil via atmospheric deposition (especially during rain or snowfall events) through the air medium, and also through releases of subsurface gas. The guidance provided in this section addresses characterization of releases to soil from units and also can be used to characterize releases to soil as a result of inter-media transport through other media. A key to such characterization is determining the nature of the contaminant source, which is described in Section 9.3.

It is also important to recognize that where multiple media appear to be contaminated, the investigation can be coordinated to provide results that can

apply to more than one of the affected media. For example, soil-gas analysis (e.g., using a portable gas chromatograph during the subsurface investigation) can be used to investigate releases to soil and subsurface gas releases, and may also provide information concerning the spatial extent of contaminated ground water

### **9.3 Characterization of the Contaminant Source and the Environmental Setting**

#### **9.3.1 Waste Characterization**

The physical and chemical properties of the waste or its constituents affect their fate and transport in soil; and, therefore affect the selection of sampling and analytical methods. Identification of monitoring constituents and the use of indicator parameters is discussed in Section 3 and Appendix B. Sources of information and sampling techniques for determining waste characteristics are discussed in detail in Section 7.

Chemicals released to soil may undergo transformation or degradation by chemical or biological mechanisms, may be adsorbed onto soil particles, or may volatilize into soil pore spaces or into the air. Table 9-3 summarizes various physical, chemical, and biological transformation/transport processes that may affect waste and waste constituents in soil.

The chemical properties of the contaminants of concern also influence the choice of sampling method. Important considerations include the water solubility and volatility of the contaminants, and the potential hazards to equipment and operators during sampling. For example, water soluble compounds that are mobile in soil water may be detected by pore-water sampling and whole soil sampling. Volatile organic contaminants require specialized sampling and sample storage measures to prevent losses prior to analysis. Viscous substances require different sampling techniques due to their physical properties.

Reactive, corrosive, or explosive wastes may pose a potential hazard to personnel during soil sampling. High levels of organic contamination may also cause health problems due to toxicity. For example, landfills can produce methane gas that can explode if ignited by sparks or heat from the drilling operation.

**TABLE 9-3**  
**TRANSFORMATION/TRANSPORT PROCESSES IN SOIL**

Process	Key Factor
Biodegradation	Waste degradability Waste toxicity Acclimation of microbial community Aerobic/anaerobic conditions pH Temperature Nutrient concentrations
Photodegradation	Solar irradiation Exposed surface area
Hydrolysis	Functional group of chemical Soil pH and buffering capacity Temperature
Oxidation/reduction	Chemical class of contaminant Presence of oxidizing agents
Volatilization	Partial pressure Henry's Law Constant Soil porosity Temperature
Adsorption	Effective surface area of soil Cation exchange capacity (CEC) Fraction organic content ( $F_{oc}$ ) of soil Octanol/water partition coefficient ( $K_{ow}$ )
Dissolution	Solubility Soil pH and buffering capacity Complex formation

Corrosive, reactive, or explosive wastes can also damage soil sampling equipment or cause fires and explosions. Appropriate precautions to prevent such incidents include having an adequate health and safety plan in place, using explosimeters or organic vapor detectors as early-warning devices, and employing geophysical techniques to help identify buried objects (e.g., to locate buried drums). All contaminated soil samples should be handled as if they contain dangerous levels of hazardous wastes or constituents.

Identity and composition of contaminants--The owner or operator should identify and provide approximate concentrations for any constituents of concern found in the original waste and, if available, in leachate from any releasing unit. Identification of other (non-hazardous) waste components that may affect the behavior of hazardous constituents or may be used as indicator parameters is also recommended. Such components may form a primary leachate causing transport behavior different from water and may also mobilize hazardous constituents bound to the soil. Estimations of transport behavior can help to focus the determination of sampling locations.

Physical state of contaminants--The physical state (solid, liquid, or gas) of the contaminants in the waste and soil should be determined by inspection or from site operating records. Sampling can then be performed at locations most likely to contain the contaminant.

Viscosity--The viscosity of any bulk liquid wastes should be determined to estimate potential mobility in soils. A liquid with a lower viscosity will generally travel faster than one of a higher viscosity.

pH--Bulk liquid pH may affect contaminant transport in at least two ways: (1) it may alter the chemical form of acids and bases, metal salts, and other metal complexes, thereby altering their water solubility and soil sorption properties, and (2) it may alter the soil chemical or physical makeup, leading to changes in sorptive capacity or permeability. For example, release of acidic (low pH) wastes in a karst (e.g., limestone) environment can lead to the formation of solution channels. See Section 10.3 for more information on karst formations.



Dissociation constant (pKa)--For compounds that are appreciably ionized within the expected range of field pH values, the pKa of the compound should be determined. Ionized compounds have either a positive or negative charge and are often highly soluble in water; therefore, they are generally more mobile than in their neutral forms when dissolved. Compounds that may ionize include organic and inorganic acids and bases, phenols, metal salts, and other inorganic complexes. Estimated contaminant concentration isopleths can be plotted with this information and can be used in determining sampling locations.

Density--The density of major waste components should be determined, especially for liquid wastes. Components with a density greater than water, such as carbon tetrachloride, may migrate through soil layers more quickly than components less dense than water, such as toluene, assuming viscosity to be negligible. Density differences become more significant when contaminants reach the saturated zone. Here they may sink, float, or be dissolved in the ground water. Some fraction of a "sinker" or "floater" may also be dissolved in the ground water.

Water solubility--This chemical property influences constituent mobility and sorption of chemicals to soil particle surfaces. Highly water-soluble compounds are generally very mobile in soil and ground water. Liquid wastes that have low solubility in water may form a distinct phase in the soil with flow behavior different from that of water. Additional sampling locations may be needed to characterize releases of insoluble species.

Henry's Law constant--This parameter indicates the partitioning ratio of a chemical between air and water phases at equilibrium. The larger the value of a constituent's Henry's Law Constant, the greater is the tendency of the constituent to volatilize from water surrounding soil particles into soil pore spaces or into above-ground air. The Henry's Law Constant should be considered in assessing the potential for inter-media transport of constituents in soil gas to the air. Therefore, this topic is also discussed in the Subsurface Gas and Air sections (Sections 11 and 12, respectively). Information on this parameter can help in determining which phases to sample in the soil investigation.

Octanol/Water partition coefficient ( $K_{ow}$ )--The characteristic distribution of a chemical between an aqueous phase and an organic phase (octanol) can be used to

predict the sorption of organic chemicals onto soils. It is frequently expressed as a logarithm ( $\log K_{ow}$ ). In transport models,  $K_{ow}$  is frequently converted to  $K_{oc}$ , a parameter that takes into account the organic content of the soil. The empirical expression used to calculate  $K_{oc}$  is:  $K_{oc} = 0.63 K_{ow} f_{oc}$ , where  $f_{oc}$  is the fraction by weight of organic carbon in the soil. The higher the value of  $K_{ow}$  (or  $K_{oc}$ ) the greater the tendency of a constituent to adsorb to soils containing appreciable organic carbon. Consideration of this parameter will also help in determining which phases to sample in the soil investigation.

**Biodegradability**--There is a wide variety of microorganisms that may be present in the soil. Generally, soils that have significant amounts of organic matter will contain a higher microbial population, both in density and in diversity. Microorganisms are responsible for the decay and/or transformation of organic materials and thrive mostly in the "A" (uppermost) soil horizon where carbon content is generally highest and where aerobic digestion occurs. Because some contaminants can serve as organic nutrient sources that soil microorganisms will digest as food, these contaminants will be profoundly affected within organic soils. Digestion may lead to complete decomposition, yielding carbon dioxide and water, but more often results in partial decomposition and transformation into other substances. Transformation products will likely have different physical, chemical or toxicological characteristics than the original contaminants. These products may also be hazardous constituents (some with higher toxicities) and should therefore be considered in developing monitoring programs. The decomposition or degradation rate depends on various factors, including:

- The molecular structure of the contaminants. Certain manmade compounds (e.g., PCBs and chlorinated pesticides) are relatively nondegradable (or persistent), whereas others (e.g., methyl alcohol) are rapidly consumed by bacteria. The owner or operator should consult published lists of compound degradability, such as Table 9-4, to estimate the persistence of waste constituents in soil. This table provides relative degradabilities for some organic compounds and can be an aid to identifying appropriate monitoring constituents and indicator parameters. It may be especially useful for older releases where degradation may be a significant factor. For example, some of the parent compounds that are relatively degradable (see Table 9-4) may

**TABLE 9-4. BOD<sub>5</sub>/COD RATIOS FOR VARIOUS ORGANIC COMPOUNDS\***

Compound	Ratio	Compound	Ratio
<b>RELATIVELY UNDEGRADABLE</b>		<b>MODERATELY DEGRADABLE (CONT'D)</b>	
Butane	~0	Mineral spirits	~0.02
Butylene	~0	Cyclohexanol	0.03
Carbon tetrachloride	~0	Acrylonitrile	0.031
Chloroform	~0	Nonanol	>0.033
1,4-Dioxane	~0	Undecanol	<0.04
Ethane	~0	Methylethylpyridine	0.04-0.75
Heptane	~0	1-Hexene	<0.044
Hexane	~0	Methyl isobutyl ketone	<0.044
Isobutane	~0	Diethanolamine	<0.049
Isobutylene	~0	Formic acid	0.05
Liquefied natural gas	~0	Styrene	>0.06
Liquefied petroleum gas	~0	Heptanol	<0.07
Methane	~0	sec-Butyl acetate	0.07-0.23
Methyl bromide	~0	n-Butyl acetate	0.07-0.24
Methyl chloride	~0	Methyl alcohol	0.07-0.73
Monochlorodifluoromethane	~0	Acetonitrile	0.079
Nitrobenzene	~0	Ethylene glycol	0.081
Propane	~0	Ethylene glycol monoethyl ether	<0.09
Propylene	~0	Sodium cyanide	<0.09
Propylene oxide	~0	Linear alcohols (12-15 carbons)	>0.09
Tetrachloroethylene	~0	Allyl alcohol	0.091
Tetrahydronaphthalene	~0	Dodecanol	0.097
1 Pentrene	<0.002	<b>RELATIVELY DEGRADABLE</b>	
Ethylene dichloride	0.002	Valeraldehyde	<0.10
1 Octene	>0.003	n-Decyl alcohol	>0.10
Morpholine	<0.004	p-Xylene	<0.11
Ethylenediaminetetracetic acid	0.005	Urea	0.11
Triethanolamine	<0.006	Toluene	<0.12
o-Xylene	<0.008	Potassium cyanide	0.12
m-Xylene	<0.008	Isopropyl acetate	<0.13
Ethylbenzene	<0.009	Amyl acetate	0.13-0.34
<b>MODERATELY DEGRADABLE</b>		Chlorobenzene	0.15
Ethyl ether	0.012	Jet fuels (various)	~0.15
Sodium alkylbenzenesulfonates	~0.017	Kerosene	~0.15
Monoisopropanolamine	<0.02	Range oil	~0.15
Gas oil (cracked)	~0.02	Glycerine	<0.16
Gasolines (various)	~0.02	Adiponitrile	0.17

TABLE 9-4. (Continued)

Compound	Ratio	Compound	Ratio
<b>RELATIVELY DEGRADABLE (CONT'D.)</b>		<b>RELATIVELY DEGRADABLE (CONT'D.)</b>	
Furfural	0.17-0.46	Ethyleneimine	0.46
2-Ethyl-3-propylacrolein	<0.19	Monoethanolamine	0.46
Methylethylpyridine	<0.20	Pyridine	0.46-0.58
Vinyl acetate	<0.20	Dimethylformamide	0.48
Diethylene glycol monomethyl ether	<0.20	Dextrose solution	0.50
Napthalene (molten)	<0.20	Corn syrup	~0.50
Dibutyl phthalate	0.20	Maleic anhydride	>0.51
Hexanol	~0.20	Propionic acid	0.52
Soybean oil	~0.20	Acetone	0.55
Paraformaldehyde	0.20	Aniline	0.56
n-Propyl alcohol	0.20- 0.63 < 0.24	Isopropyl alcohol	0.56
Methyl methacrylate	<0.24	n-Amyl alcohol	0.57
Acrylic acid	0.26	Isoamyl alcohol	0.57
Sodium alkyl sulfates	0.30	Cresols	0.57-0.68
Triethylene glycol	0.31	Crotonaldehyde	<0.58
Acetic acid	0.31-0.37	Phthalic anhydride	0.58
Acetic anhydride	>0.32	Benzaldehyde	0.62
Ethylenediamine	<0.35	Isobutyl alcohol	0.63
Formaldehyde solution	0.35	2,4-Dichlorophenol	0.78
Ethyl acetate	<0.36	Tallow	~0.80
Octanol	0.37	Phenol	0.81
Sorbitol	<0.38	Benzoic acid	0.84
Benzene	<0.39	Carbolic acid	0.84
n-Butyl alcohol	0.42-0.74	Methyl ethyl ketone	0.88
Propionaldehyde	<0.43	Benzoyl chloride	0.94
n-Butyraldehyde	<0.43	Hydrazine	1.0
		Oxalic acid	1.1

\*Source: U.S. EPA 1985. Handbook: Remedial Action at Waste Disposal Sites (Revised). EPA/625/6-85/006. NTIS PB82-239054. Office of Emergency and Remedial Response. Washington, D.C. 20460.

have been reduced to carbon dioxide and water or other decomposition products prior to sampling. Additional information on degradability can be found in Elliott and Stevenson, 1977; Sims et al, 1984; and U.S. EPA, 1985. See Section 9.8 for complete citations for these references.

- **Moisture content.** Active biodegradation does not generally occur in relatively dry soils or in some types of saturated soils, such as those that are saturated for long periods of time, as in a bog.
- **The presence or absence of oxygen in the soil.** Most degradable chemicals decompose more rapidly in aerobic (oxygenated) soil. Although unsaturated surficial soils are generally aerobic, anaerobic conditions may exist under landfills or other units. Soils that are generally saturated year round are relatively anaerobic (e.g., as in a bog); however, most saturated soils contain enough oxygen to support active biodegradation. Anaerobic biodegradation, however, can also be significant in some cases. For example, DDT degrades more rapidly under anaerobic conditions than under aerobic conditions.
- **Microbial adaptation or acclimation.** Biodegradation depends on the presence in the soil of organisms capable of metabolizing the waste constituents. The large and varied population of microorganisms in soil is likely to have some potential for favorable growth using organic wastes and constituents as nutrients. However, active metabolism usually requires a period of adaptation or acclimation that can range from several hours to several weeks or months, depending on the constituent or waste properties and the microorganisms involved.
- **The availability of contaminants to micro-organisms.** Releases that occur below the upper 6 to 8 inches of soil are less likely to be affected because fewer micro-organisms exist there. In addition, compounds with greater aqueous solubilities are generally more available for degradation. However, high solubility also correlates directly to the degree of mobility. If relatively permeable soil conditions prevail and constituents migrate rapidly, they are less likely to be retained long enough in the soil for biodegradation to occur.

- Other factors. Activity of organisms is also dependent on favorable temperature and pH conditions as well as the availability of other organic and inorganic nutrients for metabolism.

Rates of Hydrolysis, Photolysis, and Oxidation--Chemical and physical transformation of the waste can also affect the identity, amounts, and transport behavior of the waste constituents. Photolysis is important primarily for chemicals on the land surface, whereas hydrolysis and oxidation can occur at various depths. Published literature sources should be consulted to determine whether individual constituents are likely to be degraded by these processes, but it should be recognized that most literature values refer to aqueous systems. Relevant references include Elliott and Stevenson, 1977; Sims et al, 1984; and U.S. EPA, 1985. Chemical and physical degradation will also be affected by soil characteristics such as pH, water content, and soil type.

### **9.3.2 Unit Characterization**

Unit-related factors that may be important in characterizing a release include:

- Unit design and operating characteristics;
- Release type (point-source or nonpoint-source);
- Depth of the release;
- Magnitude of the release; and
- Timing of the release.

#### **9.3.2.1 Unit Design and Operating Characteristics**

Information on design and operating characteristics of a unit can be helpful in characterizing a release. Table 9-5 presents important mechanisms of contaminant release to soils for various unit types. This information can be used to identify areas for initial soil monitoring.

**TABLE 9-5  
POTENTIAL RELEASE MECHANISMS FOR VARIOUS UNIT TYPES**

Unit Type	Release Mechanisms
Surface Impoundment	Loading/unloading areas Releases from overtopping  Seepage
Landfill	Migration of releases outside the unit's runoff collection and containment system  Migration of releases outside the containment area from loading and unloading operations  Leakage through dikes or unlined portions to surrounding soils
Waste Pile	Migration of runoff outside the unit's runoff collection and containment system  Migration of releases outside the containment area from loading and unloading operations.  Seepage through underlying soils
Land Treatment Unit	Migration of runoff outside the containment area  Passage of leachate into the soil horizon
Container Storage Area	Migration of runoff outside the containment area Loading/unloading areas Leaking drums
Above-ground or In-ground Tank	Releases from overflow  Leaks through tank shell  Leakage from coupling/uncoupling operations  Leakage from cracked or corroded tanks
Incinerator	Routine releases from waste handling/preparation activities  Leakage due to mechanical failure
Class I and IV Injection Wells	Leakage from waste handling operations at the well head

\* Waste transfer stations and waste recycling operations generally have mechanisms of release similar to tanks.

### 9.3.2.2 Release Type (Point or Non-Point Source)

The owner or operator should establish whether the release involved a localized (point) source or a non-point source. Units that are likely sources of localized releases to soil include container handling and storage areas, tanks, waste piles, and bulk chemical transfer areas (e.g., loading docks, pipelines, and staging areas). Non-point sources may include airborne particulate contamination originating from a land treatment unit and widespread leachate seeps from a landfill. Land treatment can also result in widespread releases beyond the treatment zone if such units are not properly designed and operated; refer to EPA's Permit Guidance Manual on Hazardous Waste Land Treatment Demonstration, July, 1986 (NTIS PB86-229192) for additional information on determining contamination from land treatment units. This manual also discusses use of the RITZ model (Regulatory and Investigation Treatment Zone Model), which may be particularly useful for evaluating mobility and degradation within the treatment zone. This model is discussed in more detail in Section 9.4.4.2.

The primary characteristic of a localized release is generally a limited area of relatively high contaminant concentration surrounded by larger areas of relatively clean soil. Therefore, the release characterization should focus on determining the boundaries of the contaminated area to minimize the analysis of numerous uncontaminated samples. Where appropriate, a survey of the area with an organic vapor analyzer, portable gas chromatograph, surface geophysical instruments (see Appendix C), or other rapid screening techniques may aid in narrowing the area under investigation. Stained soil and stressed vegetation may provide additional indications of contamination. However, even if the extent of contamination appears to be obvious, it is the responsibility of the owner or operator to verify boundaries of the contamination by analysis of samples both inside and outside of the contaminated area.

Non-point type releases to soil may also result from deposition of particulates carried in the air, such as from incinerator "fallout". Such releases generally have a characteristic distribution with concentrations often decreasing logarithmically away from the source and generally having low variability within a small area. The highest contaminant concentrations tend to follow the prevailing wind directions (See also Section 12 on Air). Non-point releases occurring via other mechanisms



(e.g., land treatment) may be distributed more evenly over the affected area. In these situations, a large area may need to be investigated in order to determine the extent of contamination. However, the relative lack of "hot spots" may allow the number of samples per unit area to be smaller than for a point source type release.

#### **9.3.2.3 Depth of the Release**

The owner or operator should consider the original depth of the release to soil and the depth to which contamination may have migrated since the release. Often, releases occur at the soil surface as a result of spillage or leakage. Releases directly to the subsurface can occur from leaking underground tanks, buried pipelines, waste piles, impoundments, landfills, etc.

Differentiating between deep and shallow soil or surficial soil can be important in sampling and in determining potential impacts of contaminated soil. Different methods to characterize releases within deep and surficial soils may be used. For example, sampling of surficial soil may involve the use of shovels or hand-driven coring equipment, whereas deep-soil contamination usually requires the use of power-driven equipment (see Section 9.6 for more information). In addition, deep-soil and surficial-soil contamination may be evaluated differently in the health and environmental assessment process discussed in Section 8. Assessment of surficial-soil contamination will involve assessing risk from potential ingestion of the contaminated soil as well as assessing potential impacts to ground water. The assessment of deep-soil contamination may be limited to determining the potential for the soil to act as a continuing source of potential contamination to ground water.

For purposes of the RFI, surficial or shallow-zone soils may be defined as those comprising the upper 2 feet of earth, although specific sites may exhibit surficial soil extending to depths of up to 12 feet or more. Considerations for determining the depth of the shallow-soil zone may include:

- Meteorological conditions (e.g., precipitation, erosion due to high winds, evaporation of soil-pore gases);

- Potential for excessive surface runoff, especially if runoff would result in gully formation;
- Transpiration, particularly from the root zone, and effects on vegetation and animals, including livestock, that may feed on the vegetation; and
- Land use, including potential for excavation/construction, use of the soil for fill material, installation of utilities (e.g., sewer lines or electrical cables), and farming activities.

Land use that involves housing developments is an example of when the surficial soil depth may extend to 12 feet because foundation excavation may result in deep contaminated soils being moved to the surface. Deep-soil zones, for purposes of the RFI, may be defined as those extending from 2 feet below the land surface to the ground-water surface. If deep-soil contamination is already affecting ground water (through inter-media transport) at a specific site, consideration should be given to evaluating the potential for such contamination to act as a continuing source of ground-water contamination.

The depth to which a release may migrate depends on many factors, including volume of waste released, amount of water infiltrating the soil, age of the release, and chemical and physical properties of the waste and soil (as addressed in the previous section). In a porous, homogeneous soil, contaminants tend to move primarily downward within the unsaturated zone. Lateral movement generally occurs only through dispersion and diffusion. However, changes in soil structure or composition with depth (e.g., stratification), and the presence of zones of seasonally saturated soil, fractures, and other features may cause contaminants to spread horizontally for some distance before migrating downward. Careful examination of soil cores and accurate measurement of physical properties and moisture content of soil are therefore essential in estimating the potential for contaminant transport.

Transport of chemicals in the soil is largely caused by diffusion and mass flow. Diffusion results from random thermal motion of molecules. Mass flow, also known as convective flow, is transport by a flowing liquid or by a gaseous phase. Mass flow is typically downward (due to gravity); however, mass flow could also be upward

due to capillary action (e.g., if significant evaporation occurs at the surface). Mass flow is a much faster transport mechanism than is diffusion (Morrill et al., 1985).

Other factors that can promote downward contaminant migration include turnover of soil by burrowing animals, freeze/thaw cycles, and plowing or other human activities. All factors that may affect the depth of contamination should be considered. The owner or operator should use available information to estimate the depth of contamination and should then conduct sampling at appropriate depths to confirm these estimates.

Approaches to monitoring releases to soil will differ substantially depending on the depth of contamination. For investigations of both surficial and deep-soil contamination, a phased approach may be used. Initial characterization will often necessitate a judgmental approach in which sampling depths are chosen based on available information (e.g., topography, soil stratigraphy, and visual indication of a release). Information derived from this initial phase can then be used to refine estimates of contaminant distribution and transport. This information will serve as a basis for any subsequent monitoring that may be necessary.

Where the source or precise location of a suspected release has not been clearly identified, field screening methods (See Section 9.6) may be appropriate. Subsurface contamination can be detected by using geophysical methods or soil gas surveying equipment (e.g., organic vapor analyzers). Geophysical methods, for example, can help in locating buried drums. Soil gas surveys can be useful in estimating the lateral and vertical extent of soil contamination. Further delineation of the vertical extent of contamination may necessitate an additional effort such as core sampling and analysis. Sampling approaches for locating and delineating subsurface contaminant sources include systematic and random grid sampling. These approaches are discussed in Section 3. Geophysical methods are discussed in Section 10 (Ground Water) and in Appendix C (Geophysical Techniques).

#### 9.3.2.4 Magnitude of the Release

Information on the magnitude of the release can be estimated from site operating records, unit design features, and other sources. The quantity (mass) of waste released to soil and the rate of release can affect the geographical extent and

nature of the contamination. Each soil type has a specific sorptive capacity to bind contaminants. If the sorptive capacity is exceeded, contaminants tend to migrate through the soil toward the ground water. Therefore, a "minor" release may be, at least temporarily, immobilized in shallow soils, whereas a "major" release is more likely to result in ground-water contamination. The physical processes of volatilization and dissolution in water are also affected by contaminant concentrations and should, therefore, be considered in assessing the potential for inter-media transport. Section 9.4.4.3 provides additional guidance on estimating the mobility of constituents within contaminated soils.

#### 9.3.2.5 Timing of the Release

Time-related factors that should be considered in characterizing a release include:

- Age of the release;
- Duration of the release;
- Frequency of the release; and
- Season (time of year).

The length of time that has passed since a release occurred can affect the extent of contamination, the chemical composition of the contaminants present in soil, and the potential for inter-media transport. Recent releases tend to be more similar in composition to the parent waste material and may also be more concentrated within the original boundaries of the release. If a recent release occurred at the land surface, contaminant volatilization to air or dissolution in overland runoff may be important transport mechanisms. Older releases are more likely to have undergone extensive chemical or biological changes that altered their original composition and may have migrated a considerable distance from their original location. If the contaminants are relatively mobile in soil, transport to ground water may be a concern; whereas soil-bound contaminants may be more likely affected by surface transport, such as overland runoff or wind action. These

factors should be considered in the selection of monitoring constituents and sampling locations.

The duration and frequency of the release can affect the amounts of waste released to the soil and its distribution in the soil. For example, a release that consisted of a single episode, such as a ruptured tank, may move as a discrete "slug" of contamination through the soil. On the other hand, intermittent or continuous releases may present a situation in which contaminants exist at different distances from the source and/or have undergone considerable chemical and biological decomposition. Therefore, the design of monitoring procedures and estimations of contaminant fate and transport should consider release duration and frequency.

The time of year or season may also affect release fate and transport. Volatile constituents are more likely to be released to the air or to migrate as subsurface gas during the warmer summer months. During the colder winter months, releases may be less mobile, especially if freezing occurs.

### **9.3.3 Characterization of the Environmental Setting**

The nature and extent of contamination is affected by environmental processes such as dispersion and degradation acting after the release has occurred. Factors which should be considered include soil physical and chemical properties, subsurface geology and hydrology, and climatic or meteorologic patterns. These factors are discussed below.

Characteristics of the soil medium which should be considered in order to obtain representative samples for chemical or physical analysis include:

- The potentially large spatial variability of soil properties and contaminant distribution;
- Spatial and temporal fluctuations in soil moisture content; and
- The presence of solid, liquid, and gaseous phases in the unsaturated zone.

### 9.3.3.1 Spatial Variability

Spatial variability, or heterogeneity, can be defined as horizontal and vertical differences in soil properties occurring within the scale of the area under consideration. Vertical discontinuities are found in most soil profiles as a result of climatic changes during soil formation, alterations in topography or vegetative cover, etc. Soil layers show wide differences in their tendency to sorb contaminants or to transmit contaminants in a liquid form; therefore, a monitoring program that fails to consider vertical stratification will likely result in an inaccurate assessment of contaminant distribution. Variability in soil properties may also occur in the horizontal plane as a result of factors such as drainage, slope, land use history, and plant cover.

Soil and site maps will aid in designing sampling procedures by identifying drainage patterns, areas of high or low surface permeability, and areas susceptible to wind erosion and contaminant volatilization. Maps of unconsolidated deposits may be prepared from existing soil core information, well drilling logs, or from previous geological studies. Alternately, the information can be obtained from new soil borings. Because soil coring can be a resource-intensive activity, it is generally more efficient to also obtain samples from these cores for preliminary chemical analyses and to conduct such activity concurrent with investigation of releases to other media (e.g., ground water).

The number of cores necessary to characterize site soils depends on the site's geological complexity and size, the potential areal extent of the release, and the importance of defining small-scale discontinuities in surficial materials. Another consideration is the potential risk of spreading the contamination as a result of the sampling effort. For example, an improperly installed well casing could lead to leakage of contaminated water through a formerly low permeability clay layer. The risks of disturbing the subsurface should be considered when determining the need for obtaining more data.

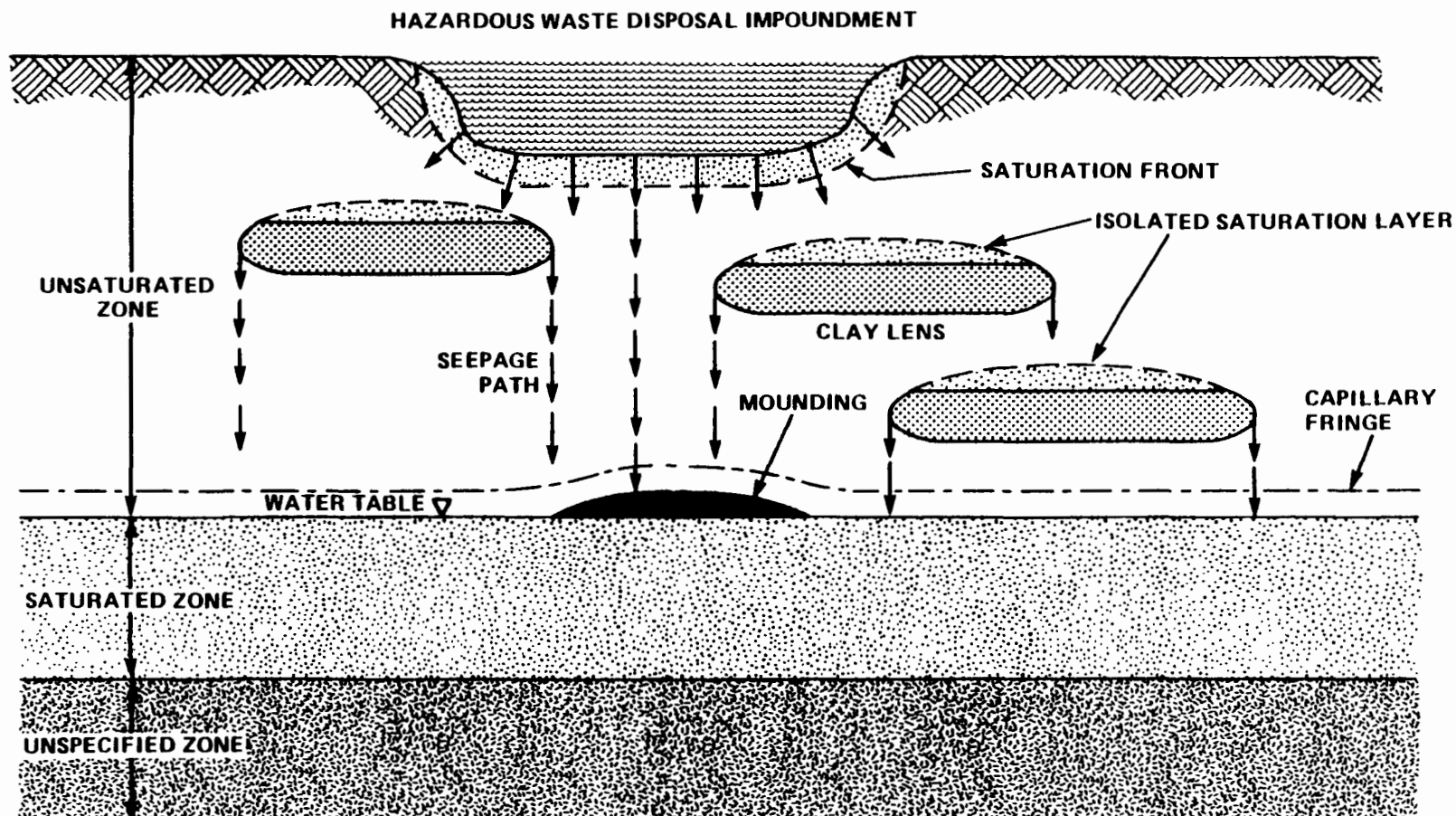
Chemical and physical measurements should be made for each distinct soil layer, or boundary between layers, that may be affected by a release. During drilling, the investigator should note on the drilling log the depths of soil horizons, soil types and textures, and the presence of joints, channels, and zones containing

plant roots or animal burrows. Soil variability, if apparent, should generally be accounted for by increasing the number of sample points for measurement of soil chemical and physical properties. Determination of the range and variability of values for soil properties and parameters will allow more accurate prediction of the mobility of contaminants in the soil.

#### 9.3.3.2 Spatial and Temporal Fluctuations in Soil Moisture Content

As described earlier in this section, there are several mechanisms for transport of waste constituents in the soil. Release migration can be increased by the physical disturbance of the soil during freeze/thaw cycles or by burrowing animals. Movement can also be influenced by microbial-induced transformations. In addition, movement can occur through diffusion and mass flow of gases and liquids. Although all of these mechanisms exist, movement of hazardous waste or constituents through soil toward ground water occurs primarily by aqueous transport of dissolved chemicals in soil pore water. Soil moisture content affects the hydraulic conductivity of the soil and the transport of dissolved wastes through the unsaturated zone. Therefore, characterizing the storage and flow of water in the unsaturated zone is very important. Moisture in the unsaturated zone is in a dynamic state and is constantly acted upon by competing physical forces.

Water applied to the soil surface (primarily through precipitation) infiltrates downward under the influence of gravity until the soil moisture content reaches equilibrium with capillary forces. A zone of saturation ( or wetting front) may occur beneath the bottom of a unit (e.g., an unlined lagoon) if the unit is providing a constant source of moisture. In a low porosity soil, such a saturation front may migrate downward through the unsaturated zone to the water table, and create a ground-water or liquid "mound" (see Figure 9-1). In a higher porosity soil, the saturation front may only extend a small distance below the unit, with liquid below this distance then moving through the soil under unsaturated conditions toward ground water (see Figure 9-1). In many cases, this area will remain partially saturated until the capillary fringe area is reached. The capillary fringe can be defined as the zone immediately above the water table where the pressure is less than atmospheric and where water and other liquids are held within the pore spaces against the force of gravity by interfacial forces (attractive forces between different molecules).



**Figure 9-1. Hydrogeologic conditions affecting soil moisture transport**



In certain cases, soil moisture characterization can also be affected by the presence of isolated zones of saturation and fluctuations in the depth to ground water, as illustrated in Figure 9-1. Where there is evidence of migration below the soil surface, these factors should be considered in the investigation by careful characterization of subsurface geology and measurement of hydraulic conductivity in each layer of soil that could be affected by subsurface contamination.

#### 9.3.3.3 Solid, Liquid, and Gaseous Materials in the Unsaturated Zone

Soil in the unsaturated zone generally contains solid, liquid, and gaseous phases. Depending upon the physical and chemical properties of the waste or its constituents, contaminants of concern may be bound to the soil, dissolved in the pore water, as a vapor within the soil pores or interstitial spaces, or as a distinct liquid phase. The investigation should therefore take into consideration the predominant form of the contaminant in the soil. For example, some whole-soil sampling methods may lead to losses of volatile chemicals, whereas analysis of soil-pore water may not be able to detect low solubility compounds such as PCBs that remain primarily adsorbed in the solid phase. Release characterization procedures should consider chemical and physical properties of both the soil and the waste constituents to assist in determining the nature and extent of contamination.

Soil classification--The owner or operator should classify each soil layer potentially affected by the release. One or more of the classification systems discussed below should be used, based on the objectives of the investigation.

- **USDA Soil Classification System (USDA, 1975)**--Primarily developed for agricultural purposes, the USDA system also provides information on typical soil profiles (e.g., 1-foot fine sandy loam over gravelly sand, depth to bedrock 12 feet), ranges of permeabilities for each layer, and approximate particle size ranges. These values are not generally accurate enough for predictive purposes, however, and should not be used to replace information collected on site. Existing information on regional soil types is available but suitable for initial planning purposes only. U.S. Department of Agriculture (USDA) county soil surveys may be obtained for most areas.

- Unified Soil Classification Systems (USCS) (Lambe and Whitman, 1979)-- A procedure for qualitative field classification of soils according to ASTM D2487-69, this system should be used to identify materials in soil boring logs. The USCS is based on field determination of the percentages of gravel, sand and fines in the soil, and on the plasticity and compressibility of fine-grained soils. Figure 9-2 displays the decision matrix used in classifying soils by this system.

The above classification systems are adequate for descriptive purposes and for qualitative estimates of the fluid transport properties of soil layers. Quantitative estimation of fluid transport properties of soil layers requires determination of the particle size distribution for each soil layer, as described below.

Particle size distribution--A measurement of particle size distribution should be made for each layer of soil potentially affected by the release. The recommended method for measurement of particle size distribution is a sieve/hydrometer analysis according to ASTM D422 (ASTM, 1984).

The particle size distribution has two major uses in a soils investigation: (1) estimation of the hydraulic conductivity of the soil by use of the Hazen (or similar) formula, and (2) assessment of soil sorptive capacity.

1. The hydraulic conductivity(K) may be estimated from the particle size distribution using the Hazen formula:

$$K = A (d_{10})^2$$

where  $d_{10}$  is equal to the effective grain size, which is that grain-size diameter at which 10 percent by weight of the particles are finer and 90 percent are coarser (Freeze and Cherry, 1979). The coefficient A is equal to 1.0 when K is in units of cm/sec and  $d_{10}$  is in mm. Results should be verified with in-situ hydraulic conductivity techniques.

2. Particle size can affect sorptive capacity and, therefore, the potential for retardation of contaminants in the soil. Sandy soils generally have a low sorptive capacity whereas clays generally have a high affinity for heavy

Figure 9-2. Soil Terms

UNIFIED SOIL CLASSIFICATION ( USCS )															
COARSE GRAINED SOILS More than half of material is LARGER than No. 200 sieve size						FINE GRAINED SOILS More than half of material is SMALLER than No. 200 sieve size									
FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3" & basing fractions on estimated weights)				GROUP SYM - BOLS	TYPICAL NAMES		FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3" & basing fractions on estimated weights)				GROUP SYM- BOLS	TYPICAL NAMES			
GRAVELS 50%(G) > 1/4" ø	CLEAN GRAVELS Low & High % fines	Wide range in grain size and substantial amounts of all intermediate particle sizes		GW	Well graded gravels, gravel sand mixtures, little or no fines		Identification procedures on fraction smaller than No. 40 sieve size								
		Predominantly one size or a range of sizes with some intermediate sizes missing		GP	Poorly graded gravels, gravel sand mixtures, little or no fines		SLTS & CLAYS Liquid limit < 50	DRY STRENGTH (Crushing Characteristics)	DILATANCY (Reaction to Shaking)	TOUGHNESS (Consistency Near Plastic Limit)					
	GRAVELS W/FINES High % fines	Non plastic fines (for identification procedures see ML)		GM	Silty gravels, poorly graded gravel-sand-silt mixtures			None to slight	Quick to slow	None	ML			Inorganic silt and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	
		Plastic fines (for identification procedures see CL)		GC	Clayey gravels, poorly graded gravel-sand-clay mixtures			Medium to high	None to very slow	Medium	CL			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
SANDS 50% (S) < 1/4" ø	CLEAN SANDS Low & High % fines	Wide range in grain size and substantial amounts of all intermediate particle sizes		SW	Well graded sand, gravelly sands, little or no fines		SLTS & CLAYS Liquid limit > 50 A	Slight to medium	Slow	Slight	OL	Organic silt and organic silt-clays of low plasticity			
		Predominantly one size or a range of sizes with some intermediate sizes missing		SP	Poorly graded sands, gravelly sands, little or no fines			High to very high	None	High	MH	Inorganic silt, micaceous or diatomaceous fine sandy or silty soils, elastic silt			
	SANDS W/FINES High % fines	Non plastic fines (for identification procedures see ML)		SM	Silty sands, poorly graded sand-silt mixtures			Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity			
		Plastic fines (for identification procedures see CL)		SC	Clayey sands, poorly graded sand-clay mixtures		HIGHLY ORGANIC SOILS Readily identified by color, odor, spongy feel and frequently by fibrous texture				PT	Peat and other organic soils			

Boundary classifications—Soils possessing characteristics of two groups are designated by combining group symbols. For example GW-GC, well graded gravel-sand mixture with clay binder. All sieve sizes on this chart are U.S. standard.

09-6

DENSITY OF GRANULAR SOILS	
DESIGNATION	STANDARD PENETRATION RESISTANCE — BLOWS/FOOT
Very loose	0 - 4
Loose	5 - 10
Medium dense	11 - 30
Dense	31 - 50
Very dense	Over 50

CONSISTENCY OF COHESIVE SOILS			
CONSISTENCY	UNC. COMPRESSIVE STR. TONS /SQ. FT.	STANDARD PENETRATION RESISTANCE — BLOWS/FOOT	FIELD IDENTIFICATION METHODS
Very soft	Less than 0.25	0 to 2	Easily penetrated several inches by fist
Soft	0.25 to 0.50	2 to 4	Easily penetrated several inches by thumb
Medium stiff	0.50 to 1.0	4 to 8	Can be penetrated several inches by thumb
Stiff	1.0 to 2.0	8 to 15	Readily indented by thumb
Very stiff	2.0 to 4.0	15 to 30	Readily indented by thumbnail
Hard	More than 4.0	Over 30	Indented with difficulty by thumbnail

### ROCK TERMS

ROCK HARDNESS ( FROM CORE SAMPLES )		
DESCRIPTIVE TERMS	SCREWDRIVER OR KNIFE EFFECTS	HAMMER EFFECTS
Soft	Easily gouged	Crushes when pressed with hammer
Medium soft	Can be gouged	Breaks (one blow) Crumbly edges
Medium hard	Can be scratched	Breaks (one blow) Sharp edges
Hard	Cannot be scratched	Breaks conchoidally (several blows) Sharp edges

ROCK BROKENNESS		
DESCRIPTIVE TERMS	ABBREVIATION	SPACING
Very broken	(V. Br.)	0 - 2"
Broken	(Br.)	2" - 1'
Blocky	(Bl.)	1' - 3'
Massive	(M.)	3' - 10'

### LEGEND

#### SOIL SAMPLES - TYPES

S - 2" O.D. Split Barrel Sample  
SI - 3" O.D. Undisturbed Sample

#### ROCK SAMPLES - TYPES

X - NX ( Conventional ) Core ( ~ 2 1/8" O.D. )  
Q - NO ( Washed ) Core ( ~ 2 1/8" O.D. )

#### WATER LEVELS

12/18  
∇ 12.6' Initial Level w/Date & Depth

metals and some organic contaminants. This is due in part to the fact that small clay particles have a larger surface area in relation to their volume than do larger sand particles. This larger surface area can result in stronger interactions with waste molecules. Clays may also bind contaminants due to the chemical structure of the clay matrix.

Porosity--Soil porosity is the percentage of the total soil volume not occupied by solid particles (i.e., the volume of the voids). In general, the greater the porosity, the more readily fluids may flow through the soil. An exception is clayey soils that tightly hold fluids by capillary forces. Porosity is usually measured by oven-drying an undisturbed sample and weighing it. It is then saturated with liquid and weighed again. Finally, the saturated sample is immersed in the same liquid, and the weight of the displaced liquid is measured. Porosity is the weight of liquid required to saturate the sample divided by the weight of liquid displaced, expressed as a decimal fraction.

Hydraulic conductivity--An essential physical property affecting contaminant mobility in soil is hydraulic conductivity. This property indicates the ease with which water at the prevailing viscosity will flow through the soil and is dependent on the porosity of the soil, grain size, degree of consolidation and cementation, and other soil factors.

Measurement of hydraulic conductivity in soil within the saturated zone is fairly routine. Field and laboratory methods to determine saturated conductivity are discussed in the section on ground-water investigations (Section 10). Measurement of unsaturated conductivity is usually more difficult because the value changes with changing soil moisture content. Therefore, conductivities for a range of moisture contents may need to be determined for each type of soil at the facility.

Techniques for determining saturated hydraulic conductivity are provided in Method 9100 (Saturated Hydraulic Conductivity, Saturated Leachate Conductivity, and Intrinsic Permeability) from SW-846, Test Methods for Evaluating Solid Waste, EPA, 3rd edition, September, 1986. Method 9100 includes techniques for:

- Laboratory

- constant head methods; and
  - falling head methods.
- Field
    - sample collection;
    - well construction;
    - well development;
    - single well tests (slug tests); and
    - references for multiple well (pumping tests).

A detailed discussion of field and laboratory methods for determining saturated and unsaturated hydraulic conductivity is also contained in Soil Properties Classification and Hydraulic Conductivity Testing (U.S. EPA, 1984). In general, field tests are recommended when the soil is heterogeneous, while laboratory tests may suffice for a soil without significant stratigraphic changes. Estimation of hydraulic conductivity from the particle size distribution may be used as a rough estimate for comparison purposes and if precise values are not needed.

Relative permeability--The hydraulic conductivity of a soil is usually established using water as the infiltrating liquid. However, at sites where there is the likelihood of a highly contaminated leachate or a separate liquid waste phase, the owner or operator should also consider determining conductivity with that liquid. The ratio of the permeability of a soil to a non-aqueous solution and its permeability to water is known as relative permeability.

The importance of determining this value is due to the potential effects of leachate on soil hydraulic properties. Changes in conductivity from infiltration of leachate may result from differences in the viscosity or surface tension of the waste, or the leachate may affect the soil structure so as to alter its permeability. For example, studies of waste migration through landfill liners made of clay have demonstrated that certain wastes may cause shrinking or expansion of the clay molecular structures, dissolve clays and organic matter, clog soil pores with fine particles, and cause other changes that affect permeability.

Soil sorptive capacity and soil-water partition coefficient ( $K_d$ )--The mobility of contaminants in soil depends not only on properties related to the physical structure of the soil, but also on the extent to which the soil material will retain, or adsorb, the hazardous constituents. The extent to which a constituent is adsorbed depends on chemical properties of the constituent and of the soil. Therefore, the sorptive capacity must be determined with reference to particular constituent and soil pairs. The soil-water partition coefficient ( $K_d$ ) is generally used to quantify soil sorption.  $K_d$  is the ratio of the adsorbed contaminant concentration to the dissolved concentration, at equilibrium.

There are two basic approaches to determining  $K_d$ : (1) soil adsorption laboratory tests, and (2) prediction from soil and constituent properties. The Soil Adsorption Isotherm (AI) test is widely used to estimate the extent of adsorption of a chemical (i.e., constituent) in soil systems. Adsorption is measured by equilibrating aqueous solutions containing varying concentrations of the test chemical with a known quantity of uncontaminated soil. After equilibrium is reached, the distribution of the chemical between the soil and water ( $K_d$ ) is measured by a suitable analytical method.

The AI test has several desirable features. Adsorption results are highly reproducible. The test provides excellent quantitative data that are readily amenable to statistical analysis. In addition, it has relatively modest reagent, soils, laboratory space and equipment requirements. The ease of performing this test will depend on the physical/chemical properties of the contaminant and the availability of suitable analytical techniques to measure the chemical.

The AI test can be used to determine the soil adsorption potential of slightly water soluble to infinitely water soluble chemicals. In general, a chemical having a water solubility of less than 0.5 mg/l is not tested with this method because these chemicals are relatively immobile in soil. The U.S. EPA Office of Pesticides and Toxic Substances (U.S. EPA 1982a, 1982b) has compiled information on the use of the AI test, including a detailed discussion of apparatus, procedures, sources of error, statistical requirements, calculation methods, and limitations of the test.

A second approach for determining  $K_d$  is to estimate the value from soil and waste properties. Soil properties that should be considered when using this

approach are particle size distribution, cation exchange capacity, and soil organic carbon content. The waste properties that should be determined will vary depending on the type of waste. Lyman et al. (1981) discuss several methods for estimating  $K_d$  from chemical properties of the constituent (e.g.,  $K_{ow}$  and water solubility) and the soil organic content. Data collection needs for waste properties were discussed earlier in this section.

Cation exchange capacity (CEC)--This parameter represents the extent to which the clay and humic fractions of the soil will retain charged species such as metal ions. The CEC is an important factor in evaluating transport of lead, cadmium, and other toxic metals. Soils with a high CEC will retain correspondingly high levels of these inorganics. Although hazardous constituents may be immobilized by such soils in the short-term, such conditions do not rule out the possibility of future releases given certain conditions (e.g., action of additional releases of low pH). A method for the determination of CEC is detailed in SW-846, Method 9081 (U.S. EPA, 1986).

Organic carbon content--The amount of natural organic material in a soil can have a strong effect on retention of organic pollutants. The greater the fraction by weight of organic carbon ( $F_{oc}$ ), the greater the adsorption of organics. Soil  $F_{oc}$  ranges from under 2 percent for many subsurface soils to over 20 percent for a peat soil. An estimate of  $F_{oc}$  should be made based on literature values for similar soils if site-specific information is not available.

Soil pH--Soil pH affects the mobility of potentially ionized organic and inorganic chemicals in the soil. Compounds in these groups include organic and inorganic acids and bases, and metals.

Depth to ground water--The thickness of the unsaturated zone may affect the attenuation capacity of the soil and the time taken for contaminants to migrate to ground water. If significant, seasonal fluctuations in ground-water elevations should be identified as well as elevation changes due to pumping or other factors (e.g., tidal influences).

Pore-water velocity--Pore water velocity affects the time of travel of contaminants in unsaturated soil to ground water. For steady state flow and a unit

hydraulic gradient (i.e., moisture content does not change with depth), the pore-water velocity can be calculated by the following equation:

$$V = q/\theta$$

where:  $V$  = pore water velocity, cm/day  
 $q$  = volumetric flux/unit area, cm/day  
 $\theta$  = volumetric water content, dimensionless

A simple approximation of volumetric flux ( $q$ ) can be made by assuming that it is equal to percolation at the site. Percolation can be estimated by performing a water balance as described below. This approach for calculating pore-water velocity is limited by simplifying assumptions; however, the method may be used to develop an initial estimate for time of travel of contaminants. More detailed methods, which account for unsteady flow and differences in moisture content are described in the following reference:

U.S. EPA. 1986. Criteria for Identifying Areas of Vulnerable Hydrogeology Under the Resource Conservation and Recovery Act. NTIS PB86-224953. Office of Solid Waste. Washington, D.C. 20460.

Percolation (volumetric flux per unit area)--Movement of contaminants from unsaturated soil to ground water occurs primarily via dissolution and transport with percolating soil water. It is important, therefore, to determine the volume of water passing through the soil. The percolation rate, or volumetric flux, must be determined in order to calculate pore-water velocity through the unsaturated zone. The rate of percolation can be estimated from the water balance equation:

$$PER = P - ET - DR$$

where:  $PER$  = Percolation/recharge to ground water  
 $P$  = Precipitation and irrigation  
 $ET$  = Evapotranspiration  
 $DR$  = Direct surface runoff



Annual averages for P, ET and DR should be obtained from existing local sources. Sources of information to estimate PER include:

- State or Regional water agencies;
- Federal water agencies (Geological Survey, Forest Service); and
- National Weather Service stations.

It is recommended that site-specific ET and DR data be used if possible, because local conditions can vary significantly from regional estimates. More information on percolation and ground-water recharge can be found in standard ground-water texts, such as Freeze and Cherry, 1979. Information on evapotranspiration and direct surface runoff may be found in the following references:

U.S. EPA. 1975. Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites. EPA/530/SW-168. Office of Solid Waste. Washington, D.C. 20460.

U.S. Geological Survey. 1982. National Handbook of Recommended Methods for Water Data Acquisition.

Volumetric water content--The volumetric water content is the percent of total soil volume that is filled with water. It is equal to the amount of water lost from the soil upon drying to constant weight at 105°C, expressed as the volume of water/bulk volume of soil. This parameter affects the unsaturated hydraulic conductivity and is required for calculation of pore-water velocity. At saturation, the volumetric water content is equal to the porosity of the soil.

Additional soil conditions--Additional soil conditions that may require special consideration in investigating releases to soil are discussed below.

- In certain dense, cohesive soils, water may move primarily through narrow solution channels or fracture zones rather than by permeating the bulk of the soil. This condition can sometimes be recognized by dark-

colored deposits indicating the fractures or by the tendency of soil cores to break apart at the discontinuity.

- Decomposed rock (e.g., transitional soils) may have a low primary porosity but a high secondary porosity due to relict joints or fractures or solution channels. Therefore, most flow may occur through these cracks and channels rather than through the soil pores. As a result, the rate of fluid flow is likely to be high, and the low surface area within the joint or fracture system generally results in a low sorptive capacity. Because field conditions are highly variable, the characterization of soil structure should be sufficiently detailed to identify such joints or fractures that may provide contaminant pathways.
- Certain clay soils known as vertisols, or expandable clays, may fracture into large blocks when dry. These cracks can be a direct route for ground-water contamination. Soil surveys should be consulted to determine whether these soils are present at the site. They occur in, but are not limited to, eastern Mississippi and central and southern Texas. Other clay soils may also develop desiccation cracks to a lesser degree. In these cases, it may be advisable to sample during both wet and dry seasons.
- Sampling saturated soils may be accomplished with the same drilling techniques used for unsaturated soil sampling. Particular care must be taken to prevent contamination between soil layers. Methods of telescoping smaller diameter casing downward through larger diameter, grouted casing are useful for minimizing cross-contamination between soil layers (See Section 9.6 for additional information on telescoping methods).
- Frequently, the choice of sampling technique is dictated by mechanical factors. Hard, rocky, or dense soils may prevent the use of manual tube samplers or augers. Power-driven auger drill rigs equipped with split-spoon samplers can penetrate most soils. Power augers can penetrate most unconsolidated materials, but will not drill through rock, for which an air-driven rotary drill is the recommended method. Loose sandy soils

will fail to be retained in a tube sampler; therefore a sampler equipped with a retaining device should be used in such cases. Core sampling should generally be carried out under the supervision of an experienced driller, in order to avoid poor results or damaged equipment.

- Where unfavorable soil conditions interfere with a proposed sampling location, the sampling point may have to be moved to a nearby location. In the event that such conditions are encountered, new locations should be chosen that are adequate to characterize the release.

### **9.3.4 Sources of Existing Information**

Considerable information may already be available to assist in characterizing a release. Existing information should be reviewed to avoid duplication of previous efforts and to aid in scoping the RFI. Any existing information relating to releases from the unit and to hydrogeological, meteorological, and environmental factors that could influence the persistence, transport, or location of contaminants should be reviewed. This information may aid in:

- Delineating the boundaries of the sampling area;
- Choosing sampling and analytical techniques; and
- Identifying information needs for later phases of the investigation, if necessary.

Information may be obtained from readily available sources of geological and meteorological data, waste characteristics, and facility operating records. (See also Sections 2, 3, 7 and Appendix A).

#### **9.3.4.1 Geological and Climatological Data**

The Federal government and most state governments compile geological data, soil surveys, land use records, and climatological information. These sources should be consulted for local geology, soil types, historical precipitation, ground-water elevation records, and other useful data. Sources which may be consulted for soils

data include the Soil Conservation Service (SCS), Agricultural Stabilization and Conservation Service (ASCS), the U.S. Geological Survey (USGS), state soils bureaus and agricultural extension services, university soil science departments, and private consultants. Additional sources of geologic information include geotechnical boring logs for foundation studies, well logs made during drilling of water supply wells, and previous hydrogeologic investigation monitoring wells. These logs should indicate the depth, thickness, and character of geologic materials, and the depth to the water table. Climate and weather information can be obtained from:

National Climatic Center  
Department of Commerce  
Federal Building  
Asheville, North Carolina 28801  
Tel: (704)258-2850

#### **9.3.4.2 Facility Records and Site Investigations**

The owner or operator should plan investigation activities by focusing on the conditions specified in the permit or enforcement order. Facility records, the facility's RCRA permit application, and any previous site reports (e.g., the RFA report) should also be examined for any other information on unit characteristics, wastes produced at the facility, and other factors relevant to releases to soil. Facility operating records should have data on wastes treated, stored, or disposed of at the facility. Wastes regulated under RCRA are identified by a waste code that may also aid in identifying constituents of concern (see 40 CFR Part 261). Wastes originating within the facility may be identified through analysis of process control records. Unit releases (e.g., losses from leaking tanks) can sometimes be estimated from storage records.

### **9.4 Design of a Monitoring Program to Characterize Releases**

#### **9.4.1 Objectives of the Monitoring Program**

Monitoring procedures that specify locations, numbers, depths, and collection techniques for soil samples should be prepared by the owner or operator prior to each sampling effort. These procedures should provide the justification for the

proposed samples, in terms of their expected contribution to the investigation. Examples of soil monitoring objectives include:

- Describing soil contamination in a drainage channel where a release is known to have occurred;
- Establishing a random or systematic grid sampling network to determine soil contamination concentrations in all zones of a large area affected by airborne deposition; and
- Filling in data gaps concerning the transport of waste constituents within a permeable soil layer.

In preparing soil monitoring procedures, the owner or operator should take into consideration those factors discussed in Sections 9.3.1 through 9.3.4 that apply to the facility. Also see Section 9.4.4.3 (Predicting Mobility of Hazardous Constituents in Soil).

As discussed previously, the release characterization may be conducted in phases. The objectives of the initial soil characterization are generally to verify suspected releases or to begin characterizing known releases. This characterization should use relevant soil physical and chemical measurements and other information as described earlier. In developing the approach, the owner or operator should determine the following:

- Constituents and indicator parameters to be monitored;
- Role of field screening methods, if any;
- Sampling methods;
- Approximate study and background areas;
- Sampling locations and approach (e.g., judgmental or systematic); and
- Number of samples to be collected.

The owner or operator may propose the use of field screening methods to aid in delineating the zone affected by a contaminant release to soil and/or ground water. Such methods may be applied just below the land surface or at greater depths, as within soil bore holes. An increasingly used method to detect organic vapors is generally known as a soil gas survey. Such a survey can yield qualitative and relative quantitative data on volatile constituents present in the soil gas, depending on the instrumentation used. For example, a total photoionization detector will provide an integrated value for the volatile organics present; whereas a portable gas chromatograph can identify and quantitate specific compounds present in the soil vapor. Field screening can also include chemical analyses of soil samples performed onsite in mobile laboratories.

When conducting a soil gas survey, it should be realized that any measured soil vapor concentrations of specific compounds cannot be directly correlated with their actual concentrations in the soil zone of concern. The concentrations in soil vapor resulting from a soil with given volatile contaminant concentrations will vary, depending on several factors, including barometric pressure, relative humidity in the soil, weather conditions (e.g., precipitation events, soil inhomogeneities, and temperature). Therefore, the results of a soil gas survey can reveal the relative abundances of volatile compounds in the soil gas, but not their actual concentrations in the soil.

The soil gas survey technique may also be applied when drilling boreholes to characterize site geology or when drilling to install ground-water monitoring wells. Soil samples taken at various depths within the borehole can be placed in separate sample bottles with septums.

A sample of the gas in the headspace can then be withdrawn with a syringe and injected into a portable gas chromatograph to identify the presence and relative abundances of specific volatile compounds in the soil gas. Analysis of drill cuttings in the open air is not as effective as the headspace technique in detecting volatile organic compounds; therefore, the headspace method is preferred.

Additional information on soil gas monitoring may be obtained from the following reference:

U.S. EPA. 1987. Soil Gas Monitoring Techniques Videotape. National Audio Visual Center. Capital Heights, Maryland 20743.

Screening methods may help to reduce the number of soil and/or ground-water samples needed to characterize a release by better delineating the area of concern in a relatively rapid manner. However, due to limitations (e.g., relatively high detection limits and inability to identify all the potential hazardous constituents of concern), some screening methods may not be adequate to verify the absence of a release. For such verification, an appropriate number of soil samples would need to be analyzed in the laboratory. Additional information on field screening methods is presented later in this section and in the Compendium of Field Operations Methods, (EPA, 1987).

Depending on the outcome of the initial characterization effort, the owner or operator may be required to obtain additional data to characterize the release. The findings of the initial phase will dictate the objectives of any later phases. Such subsequent phases will generally involve the following:

- Expanding the number of sampling locations to a wider area and/or depth, or increasing sampling density where data are sparse;
- Institution of a refined grid sampling approach to further assess releases identified by judgmental sampling (see Section 3);
- Addition or deletion of specific monitoring constituents or indicator parameters; and
- Sampling in areas of interest based on previous sampling or model predictions to confirm the suspected extent of the release.

There is no specified or recommended number of phases to complete a soil investigation. The owner or operator should determine through consultation with the regulatory agency whether the collected data are sufficient to meet the objectives of the investigation.

#### **9.4.2 Monitoring Constituents and Indicator Parameters**

The owner or operator should propose hazardous constituents for monitoring based on the composition of wastes known or suspected to be present or released to soils at the site (see Sections 3 and 7 and Appendix B). Additional measurements may include nonhazardous chemicals that could serve as indicators of the presence of hazardous constituents or that could mobilize or otherwise affect the fate and transport of hazardous constituents. Chemical and physical properties of the soil that can be measured from soil samples should also be included in the list of parameters (see Section 9.3.3.3).

Justification of monitoring constituent selection may be provided through detailed facility records or waste analyses, as explained in Section 3. If such justification is inadequate, it may be necessary to perform a broader analytical program (See Section 3 and Appendix B).

During or after the selection of monitoring constituents, the owner or operator should review guidance on compound-specific requirements for sampling and sample preservation. The laboratory should use EPA protocols and analytical procedures when available, and accepted QA/QC practices. Guidance and specific references in these areas are provided in Sections 2, 3, 4, and 7.

#### **9.4.3 Monitoring Schedule**

Monitoring frequency and duration determinations should be based primarily on the type of release to the soil. A single episode or intermittent release, as with any release, would require monitoring until the nature and extent of contamination has been characterized. This may be accomplished with one or two sample sets in some cases. Longer-term releases will usually necessitate a greater duration of sampling. Soil-pore liquid may require more frequent monitoring than in soil solids because changes generally occur faster in these fluids. Frequency may also be adjusted, if appropriate, as sampling results become available. As with single episode releases, longer-term releases are monitored until the nature and extent of contamination has been adequately characterized.



## **9.4.4 Monitoring Locations**

### **9.4.4.1 Determine Study and Background Areas**

Determination of the area of interest will depend on the facility layout, topography, the distribution of surface soils, soil stratigraphy, and information on the nature and source of the release. The size and type of unit may affect the area under consideration. For example, a small landfill may only require monitoring of the surrounding soil whereas an inactive land treatment facility may require sampling over the entire unit surface and beyond.

High variability in the chemical composition of soils makes determination of background levels for the constituents of concern essential. This is particularly important for quantification of toxic metals, because such metals commonly occur naturally in soil. Background areas not affected by any facility release should be selected based on their similarity to the study area in terms of soil type, drainage, and other physical factors. Background soil samples should be taken from areas that are not near a suspected source of contamination and from the same stratigraphic layer as the study area samples, if possible. Selection and sampling of appropriate background areas may be important because verification of a release in a contaminated area may involve a comparison of study and background concentrations.

The owner or operator may increase efficiency in the initial characterization effort by using rapid, field-screening methods (e.g., soil gas surveys using HNu, OVA or portable gas chromatograph) or through indicator parameter measurements to establish the extent of the study area. Subsurface soil contamination can sometimes be identified by geophysical techniques such as electromagnetic and resistivity techniques (See Section 10 and Appendix C). Indicator parameters can also be helpful in establishing the extent of the monitoring area. For example, Total Organic Halogen (TOX) or Total Organic Carbon (TOC) analysis may be useful in detecting total chlorinated and nonchlorinated organic solvents. Such parameters may be used to characterize the nature and extent of a release but should always be verified by an adequate number of specific constituent analyses.

It is generally recommended that a sampling grid be developed for the site, even for judgmental sampling. Gridding of the area to be sampled prior to the sampling effort will aid in determining appropriate sampling locations and in describing these locations. Refer to Section 3.6 for additional information on gridding of a study site.

#### **9.4.4.2 Determine Location and Number of Samples**

The owner or operator should propose monitoring locations and the number of samples to be collected and analyzed. Samples should be taken from the vicinity of all units identified in the conditions of the permit or order as suspected or known sources of soil contamination. The total number of samples necessary for the initial investigation will depend on the extent of prior information, the suspected extent and severity of the release, and the objectives of the characterization. However, the following general guidance should aid the owner or operator to sample efficiently.

- Sampling efficiency may be increased by use of a proportional sampling approach, which involves dividing the area of concern into zones, based on proximity to the release source and/or other factors. The number of samples taken in each zone should be proportional to the area of a zone.
- Use of composite samples may be able to allow detection of contamination over an area of concern with a smaller number of analyses. Compositing involves pooling and homogenization of multiple soil samples. The composite is then analyzed to give an average value for soil contamination in that area. However, as discussed in Sections 3 and 7, composites should have very limited application during the RFI and should always be accompanied by an appropriate number of individual grab samples. The following additional limitations on compositing should be observed:
  - Compositing is most useful when large numbers of soil samples can be easily collected (e.g., for surficial contamination). In order to obtain the maximum information from deep soil coring, individual grab samples are preferred over composites.

- Compositing should not be used when analyzing soils for volatile organics because the constituents of interest may be lost during homogenization and sample handling.
- The owner or operator should employ appropriate procedures for the evaluation and reporting of monitoring data. These procedures can vary in a site-specific manner but should result in determinations of the nature, extent, and rate of migration of the release. Where the release is obvious and/or chemically simple, it may be possible to characterize it readily from a descriptive presentation of concentrations found. However, where contamination is less obvious or the release is chemically complex, a statistical inference approach may be proposed. The owner or operator should plan initially to take a descriptive approach to data evaluation in order to broadly delineate the extent of contamination. Statistical comparisons of monitoring data among monitoring locations and over time may be appropriate if a descriptive approach does not provide a clear characterization of the release. Further guidance on use of statistical methods in soil investigations is provided in the following documents:

Barth, D.S. and B.J. Mason. 1984. Soil Sampling Quality Assurance User's Guide. U.S. EPA 600/4-84-043. NTIS PB84-198621. Washington, D.C. 20460.

Mason, B.J. 1983. Preparation of a Soil Sampling Protocol: Techniques and Strategies. NTIS PB83-206979. U.S. EPA 600/4-83-020. Washington, D.C. 20460.

- Characterization of contaminant distribution with depth necessitates sampling of each distinct soil layer that might be affected by the release and from boundaries between soil layers. If the soil profile contains thick layers of homogeneous soil, samples should be taken at regular intervals (e.g., every 5 feet). In addition, samples should be taken where borings intersect fracture systems, at interfaces of zones of high and low permeability materials, or at other features that could affect contaminant transport. The owner or operator should consider

measurement of soil physical and hydraulic properties in each distinct soil layer. The objective of such measurements in the initial release characterization effort is to identify properties that vary with depth. This approach may indicate the use of stratified sampling in any future sampling phases. Determination of soil properties will also aid in refining conceptual models of contaminant transport and can be input for mathematical models of soil transport.

Modeling--Prediction of contaminant fate and transport can range from a "conceptual" model of contaminant behavior in the soil to complex computer programs requiring extensive input of soil and water budget data. The primary uses of predictive modeling in soil investigations are to locate appropriate sampling locations using site-specific input data and to estimate the future rate, extent, and concentration of contaminant releases.

Modeling of contaminant transport in the unsaturated zone is often difficult due to the generally high spatial variability in soil physical and hydraulic properties. Therefore, modeling should not be used to replace actual measured values (e.g., when establishing the limits of waste leaching or diffusion in soil). However, if used with caution, models can act as useful tools to guide sampling efforts by directing sampling towards site areas identified as preferred soil/water flowpaths (e.g., a permeable soil layer). The owner or operator should discuss the use of specific models with the regulatory agency prior to use.

Numerous models, including computer models, have been developed to calculate water flow and contaminant transport under saturated and unsaturated soil conditions. In using such models, site-specific data on soils and wastes should be used. Ground-water (saturated flow) models are discussed in Section 10. A U.S. Nuclear Regulatory Commission Report (Oster, 1982) may be reviewed for information on the applicability of 55 unsaturated flow and transport models. Use of the RITZ Model (found in U.S. EPA. 1986. Permit Guidance Manual on Hazardous Waste Land Treatment Demonstration. NTIS PB86-229192) may be particularly appropriate in certain situations. The RITZ model describes a soil column, 1 meter square, with a depth equal to the land treatment zone (usually 1.5 m). The soil column consists of a plow zone and lower treatment zone that are made up of four phases: soil grains, pore water, pore air, and pore oil. Mobilization of constituents

within the soil is accounted for by dispersion, advection, and migration between phases. The constituent may also be degraded by biochemical processes represented in the model. Output from the model includes the concentration (C) of a constituent at the bottom of the treatment zone, and the time (T) required for a constituent to travel a distance equal to the treatment zone depth. Although the RITZ model was developed for evaluating the effectiveness of land treatment units, the model may be used for other applications, as appropriate (see above referenced document).

EPA is in the process of developing a more sophisticated version of the RITZ model, known as the RITZ-VIP model. The VIP version differs in that it is designed to provide information for multiple waste loadings in a land treatment situation. The initial version of the RITZ model only applies where the waste or material in question is applied to the land once. The RITZ-VIP version is currently in the review/verification process. More information on this model may be obtained by writing to EPA at the following address:

U.S. Environmental Protection Agency  
Robert S. Kerr Environmental Research Laboratory/ORD  
P.O. Box 1198  
Ada, Oklahoma 74820

Computer models if proposed for use in the RFI should (1) be well-documented; (2) have been peer reviewed; and (3) have undergone extensive field testing. As indicated previously, model documentation (e.g., model theory, structure, use, and testing) should be provided to the regulatory agency for review prior to use. Access to the relevant data sets should also be available upon request. The regulatory agency may also recommend that a sensitivity analysis be performed and that the results of the analysis be submitted with the model results. In selecting a model, the owner or operator should consider its applicability, limitations, data requirements, and resource requirements.

#### **9.4.4.3 Predicting Mobility of Hazardous Constituents in Soil**

Predicting the mobility of hazardous constituents in soil may be necessary in an RFI. The prediction may then be used to estimate the probable vertical or lateral

extent of contamination, which can be used to identify potential sampling locations. Mobility predictions may also be used in determining potential inter-media transfers from the soil to ground or surface water. Finally, mobility predictions may provide information that can be used during the Corrective Measures Study to differentiate between contaminated soil that should be removed from the site and that which may remain at the site without adversely affecting human health or the environment. Predicting mobility of soil constituents may be particularly relevant, as indicated in Section 8, for determining whether deep-soil contamination, or in some cases surficial-soil contamination, can lead to ground-water contamination at a level above health and environmental criteria (if such an impact has not already occurred).

There is no universally accepted, straightforward method for predicting the mobility of all hazardous constituents within soils under all possible sets of environmental conditions. Nor is there a fully tested method of estimating the impact of constituents originating in the unsaturated zone on ground-water quality. Therefore, to avoid unneeded efforts, the first question the owner or operator should address is whether this task is necessary. For example, the characterization of ground-water quality (conducted following the guidance in Section 10) may provide information sufficient to describe the extent of the release in soils as well, and to determine that a Corrective Measures Study is necessary. This may be the case in situations where contaminated soils are located solely within the ground water and when the contaminants are relatively mobile. The most recent ground-water impact characterization data may not, however, provide information on the future impact of contaminated soils on ground water (e.g., due to different leaching rates for different contaminants).

This section presents various approaches for predicting constituent mobility in both saturated and unsaturated soils; it also discusses how to estimate the impact on ground-water quality of the constituents leached from unsaturated soils. The limitations of these methods are also reviewed.

#### 9.4.4.3.1 Constituent Mobility

There are several means of investigating mobility, including a descriptive approach (i.e., consideration of constituent and soil properties), the use of

mathematical models, and the use of laboratory models or leaching tests. Leaching tests have the advantage of being the only approach that integrates soil and constituent properties in a single evaluation. They may, in certain cases, provide a conservative (reasonable worst case) estimate of the concentration within leachate of waste constituents that may eventually impact ground water. Leaching test results must be coupled with site-specific factors, (e.g., soil cation exchange capacity, ground-water pH, and depth to ground water) when used to design monitoring programs, determine potential for inter-media impacts, and evaluate options for contaminated-soil corrective measures. When assessing leach test results, specific hazardous constituent concentrations in the leachate will be compared with the health and environmental criteria concentrations for water described in Section 8.

The descriptive approach and the use of mathematical models (such as the RITZ Model, discussed previously) may be appropriate in those cases where assumptions implicit in the use of leaching tests may not be applicable. For example, leaching tests may be overpredictive of leachate concentrations where extensive channeling (e.g., because of root zone or joints) through the contaminated zone is present; in this case, the contact time between the leaching fluid (e.g., infiltrating precipitation) and the soil, as well as the surface area of the soil exposed to the fluid, would be less than that simulated by the leaching test. Leaching tests may also not be applicable where low redox (reduction/oxidation) conditions are identified. Consideration of redox conditions is particularly relevant for inorganics.

The Agency has devised a soils/waste mixture leaching procedure, known as the Synthetic Precipitation Leach Test (Method 1312) that it generally believes may be appropriate for evaluating the potential impact of contaminated soils on ground-water quality. (See Appendix F for a description of this procedure). Although neither Method 1312 nor any other leaching test (such as the Toxicity Characteristic Leaching Procedure (Method 1311) have been validated for use on a wide range of contaminated-soil types, the Agency believes that Method 1312 may have the broadest applicability. Method 1312 may be particularly appropriate when no future waste management or other industrial activities likely to produce an acidic leaching medium are likely to be conducted at the site of the release.

However, other leaching tests may be appropriate under certain case-specific circumstances. For example, a test such as Method 1311 may be appropriate at a release site that will be used for management of municipal refuse or a similar waste in the future, because the refuse could produce an acidic leaching medium, which Method 1311 has been designed to simulate. The evaluation of leaching from cyanide-containing soils should be performed with neutral water, rather than an acidic leaching medium, because leaching of cyanide-containing waste under acidic conditions may result in the formation of toxic hydrogen cyanide gas. Other leaching test variations may be necessary if interactive effects on mobility are caused by non-aqueous solvents, for example, or if an aqueous phase leaching medium may underpredict potential mobility due to site and waste constituent characteristics.

#### 9.4.4.3.2 Estimating Impact on Ground-Water Quality

In evaluating results obtained using the leach test for the evaluation of contaminants of concern at a specific release site, the Agency will consider relevant hazardous constituent properties, the physical and chemical characteristics of the soil/waste matrix at the site, and local climatological factors. Factors that will be considered include the following:

- Chemical structure, classification, and bonding (organic vs. inorganic, ionic vs. covalent, etc);
- Solubility of the constituents;
- Octanol/water or other partitioning coefficients;
- Density;
- Organic carbon adsorption coefficient;
- Volatility (e.g., Henry's Law constant);
- Dissociation constants ( $P_k$ );



- Degradation potential (hydrolysis, biodegradation);
- Soil/waste matrix characteristics;
- Cation exchange capacity;
- Soil pH and Eh;
- Soil classification (e.g., clay, silt, and sand content);
- Particle-size distribution;
- Porosity;
- Unsaturated hydraulic conductivity;
- Climatological characteristics;
- Precipitation patterns (volume, frequency, etc.); and
- pH of local or regional precipitation.

The results obtained from a specific leach test must be supported by an analysis of the relevant factors, such as those listed above, and considering the likely future use of the site (industrial, waste management, residential, etc.).

As an alternative approach to the use of a leach test for evaluating contaminated soil, the owner or operator may propose to perform an analysis of the waste, soil, and climatological conditions, considering such factors as are listed above, to demonstrate that the expected concentrations of any constituents that could leach from any contaminated section of the subsurface soils would not exceed the action levels for ground-water. This analysis, which would require appropriate technical justification and should rely as much as possible on data (such as the results of published field studies conducted under environmental conditions similar to those at the release site), must be based on conservative assumptions related to

future changes in environmental conditions and land use (e.g., the use of the site for future non-hazardous waste management).

At the present time, studies are being designed to more fully examine various methods for evaluating leaching of hazardous constituents from contaminated soils. Further guidance will be provided by the Agency upon completion of these studies. It is recommended that the owner or operator review the procedures and methods described in Sections 8 and 9 and Appendix J of Petitions to Delist Hazardous waste, EPA/530-SW-85-003, as well as SW-846, to assist in determining the appropriateness of any particular leaching procedures for evaluating contaminated soils. Until more definitive guidance is available, the owner or operator may propose what he believes to be the most appropriate leaching procedure, and provide technical justification to support the proposed procedure based on site and waste conditions at the time of the investigation. For additional assistance on selection of a leaching procedure, the owner or operator may contact the Technical Assessment Branch of the Office of Solid Waste in Washington, D.C. (202/382-4764).

As indicated above, waste and site-specific factors should be evaluated, together with leaching test concentrations, to arrive at predictions of the potential impacts to ground water. For example, if the depth to ground water is great enough, and the soil cation exchange capacity is high, the owner or operator may be able to predict that metal species would be adsorbed by the soil before the soil leachate reaches the ground water. Particular attention, in this example, would be needed to ensure that the cation exchange capacity of the soil could not be exceeded. The characteristics of the metal ions that are displaced from the exchange sites should also be considered.

As another example, the soil-water partition coefficient ( $K_d$ ) is useful for describing chemical mobility in the subsurface environment, and is widely used in studies of ground-water contamination. For primarily aqueous solutions, the partitioning between the aqueous solution and the solid medium can be derived from thermodynamic principles (Freeze and Cherry, 1979).

More commonly,  $K_d$  is determined from batch experiments in which the contaminated solution and geologic material of interest are brought into contact.

After a period of time has elapsed (e.g., 24-hours), the degree of partitioning of the contaminant between the solution and the geologic material is determined. The partition coefficient is then calculated using the following equation:

$$K_d = \frac{\text{mass of sorbed chemical/gram of solid}}{\text{mass of chemical/ml of solution}}$$

The relative mobility of attenuated constituents in ground water can then be estimated as follows (after Mills, et al., 1985):

$$v = \frac{V_s}{(1 + K_d b)/n_e}$$

where

- $v$  = average linear velocity of attenuated constituent along centerline of plume, distance/time;
- $V_s$  = ground-water velocity, distance/time;
- $b$  = soil bulk density, mass/volume;
- $n_e$  = effective porosity, dimensionless; and
- $K_d$  = soil-water partition coefficient, volume/mass.

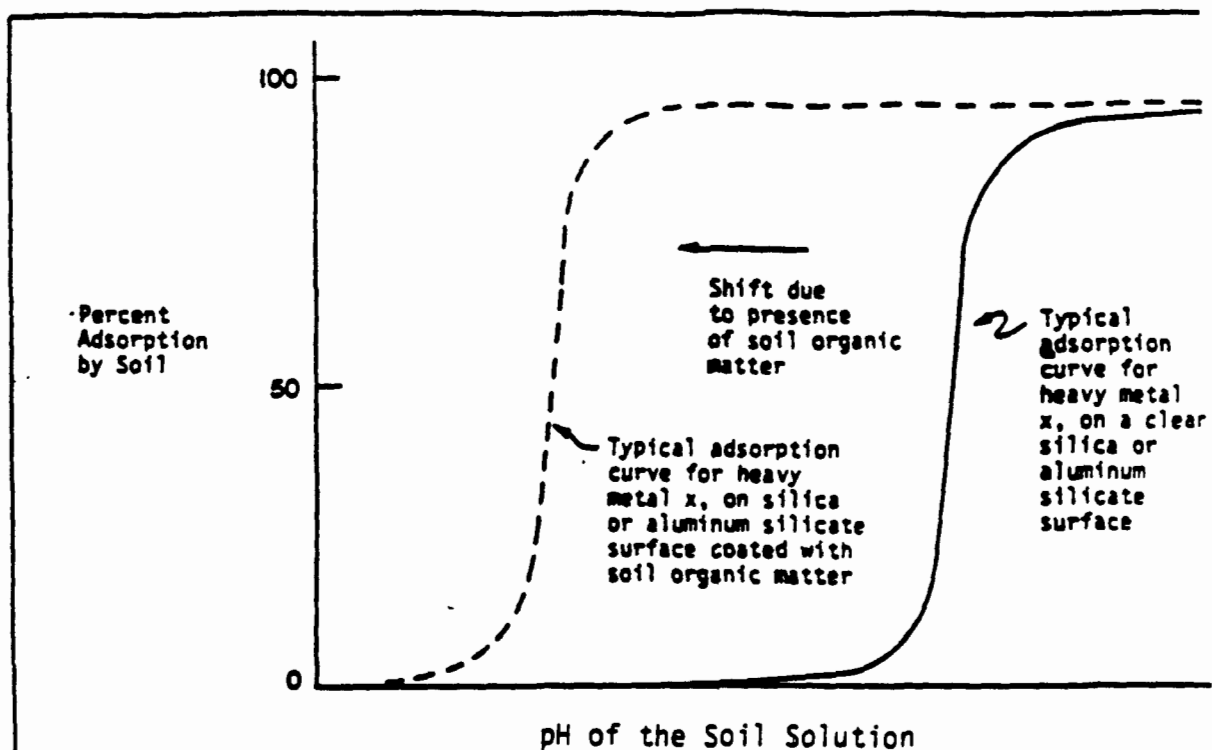
The relative mobility of selected constituents, based on typical partition coefficients, is shown in Table 9-6. It is important to note that  $K_d$  is a simplified measure of the relative affinity of a chemical for the solution and the soil.  $K_d$  is highly site-specific, varying as a function of pH, redox conditions, soil characteristics, and the availability of alternate solution phases (organic and inorganic liquids, or colloidal solids). The general effect of pH and organic matter content on partition coefficients for metals is shown in Figure 9-3.

The  $K_d$  value selected for use in estimating chemical mobility should reflect the predominant chemical species in solution. One approach to estimating solution composition is to use thermodynamic stability diagrams, commonly illustrated as

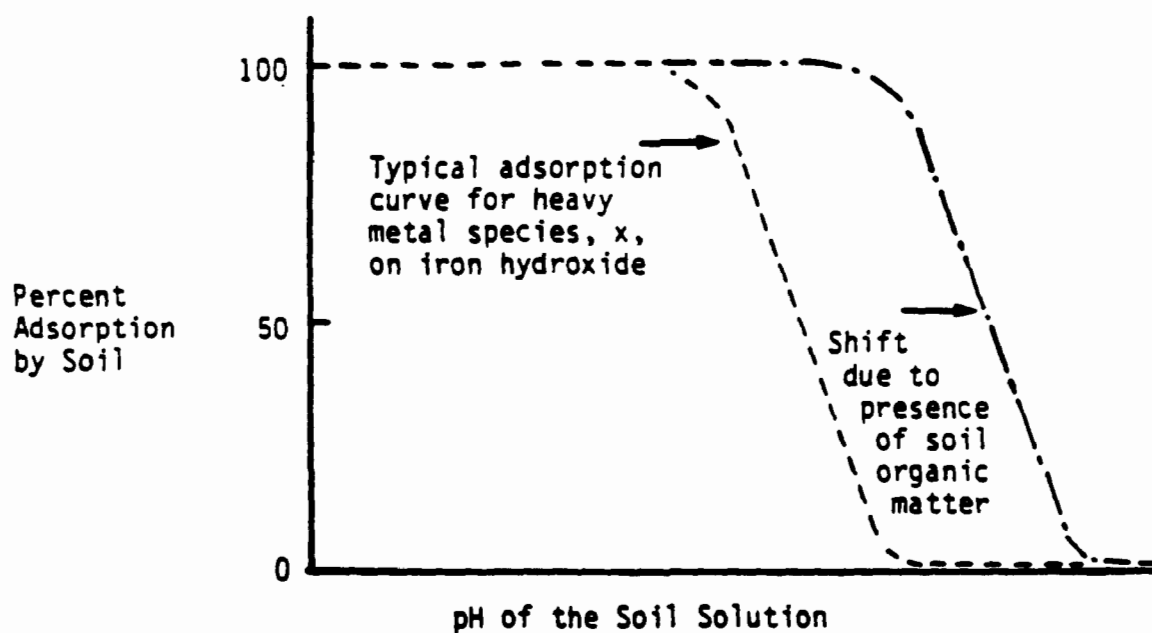
**TABLE 9-6 RELATIVE MOBILITY OF SOLUTES<sup>1</sup>**

Group	Examples	Master Variables <sup>2</sup>
Conservative	Total Dissolved Solids	V
	Chloride	V
	Bromide	V
	Nitrate	V, Redox Conditions
	Sulfate	V, Redox Conditions
Slightly Attenuated	Boron	V, pH, organic matter
	Trichloroethylene	V, organic matter
Moderately Attenuated	Selenium	V, pH, Iron hydroxides,
	Arsenic	V, pH, Iron hydroxides,
	Benzene	V, organic matter
More Strongly Attenuated	Lead	V, pH, Sulfate
	Mercury	V, pH, Chloride
	Penta-chlorophenol	V, organic matter

- 1 Under typical ground-water conditions (i.e., neutral pH and oxidizing conditions). Under other conditions mobility may differ substantially. For example, acidic conditions can enhance the mobility of metals by several orders of magnitude.
- 2 Variables which strongly influence the fate of the indicated solute groups. Based on data from Mills *et al.*, 1985 and Rai and Zachara, 1984. (V = Average Linear Velocity)



a) Generalized Heavy Metal Adsorption Curve for Cationic Species  
(e.g.,  $\text{CuOH}^+$ )



b) Generalized Heavy Metal Adsorption Curve for Anionic Species  
(e.g.,  $\text{CrO}_4^{2-}$ )

**Figure 9-3. Hypothetical Adsorption Curves for A) Cations and B) Anions Showing Effect of pH and Organic Matter (Mills et al., 1985)**

Eh-pH diagrams. These diagrams represent solution composition for specified chemicals as a function of redox potential (Eh) and of pH under equilibrium conditions.

Many metals of interest in ground-water contamination problems are influenced by redox conditions that result from changes in the oxidation state of the metal or from nonmetallic elements with which the metal can form complexes. Garrels and Christ (1965) present a comprehensive treatment of the subject and provide numerous Eh-pH diagrams that can be used for analysis of geological systems.

For any particular point in an Eh-pH diagram, a chemical reaction can be written that describes the equilibrium between the solid and dissolved phases of a particular constituent. The following equation represents the general form of the equilibrium reaction:



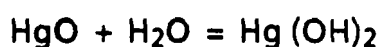
where:                      a, b, c, d = number of moles of constituent  
                                  A and B = reactants  
                                  C and D = products

At equilibrium, the solubility constant (K) expresses the relation between the reactants and the products following the law of mass action:

$$K = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

The brackets signify an effective concentration, or activity, that is reported as molality (moles per liter). Solubility constants for many reactions in water are reported by Stumm and Morgan (1981). Alternatively, solubility constants can be calculated from thermodynamic data (Gibbs free energy) for products and reactants. Freeze and Cherry (1979) describe the use of thermodynamic data to calculate solubility constants for several constituents common in ground water.

An example illustrating the use of Eh-pH diagrams and the influence of redox conditions on solution composition is shown for mercury (Hg) in Figure 9-4. The stability diagram shown in Figure 9-4 is constructed for mercury-contaminated water that contains chloride (Cl) and dissolved sulfur species. The solid lines in the diagram represent the Eh-pH values at which the various phases are in equilibrium. For pH values of less than about 7 and Eh values greater than 0.5 volts (strong oxidizing conditions),  $\text{HgCl}_2$  is the dominant dissolved species. For pH values greater than 7, and at a high redox potential,  $\text{Hg}(\text{OH})_2$  is the dominant dissolved species. The main equilibrium reaction in this Eh-pH environment is:



From the law of mass action, the solubility relationship for this reaction is written as follows:

$$K = \frac{[\text{Hg}(\text{OH})_2]}{[\text{HgO}][\text{H}_2\text{O}]}$$

At 25°C, the solubility constant (log K) for this reaction is -3.7 (Freeze and Cherry, 1979). The activity coefficients for a solid (HgO) and  $\text{H}_2\text{O}$  are assumed to be one; therefore, the concentration of  $\text{Hg}(\text{OH})_2$  in solution is calculated as follows:

$$[\text{Hg}(\text{OH})_2] = K = 10^{-3.7} = 1.995 \times 10^{-4} \text{ moles/l} = 47 \text{ mg/l (mol. wgt.} = 235 \text{ g/mole)}$$

The Eh-pH diagram can be used to estimate the concentration of mercury in solution at any particular point in the diagram if the solubility constant for the appropriate equilibrium reaction is known. For lower redox conditions (pH = 6.0, Eh = 0.0), the concentration of mercury in solution would be approximately 0.025 mg/l (Callahan et al., 1979).

Several limitations are associated with the use of Eh-pH diagrams to predict dissolved chemical species, including the accuracy of thermodynamic data, the assumption of equilibrium conditions, and of other chemical processes such as adsorption that can maintain concentrations below those that would exist as a result of only solubility constraints. However, the Eh-pH diagrams serve to illustrate

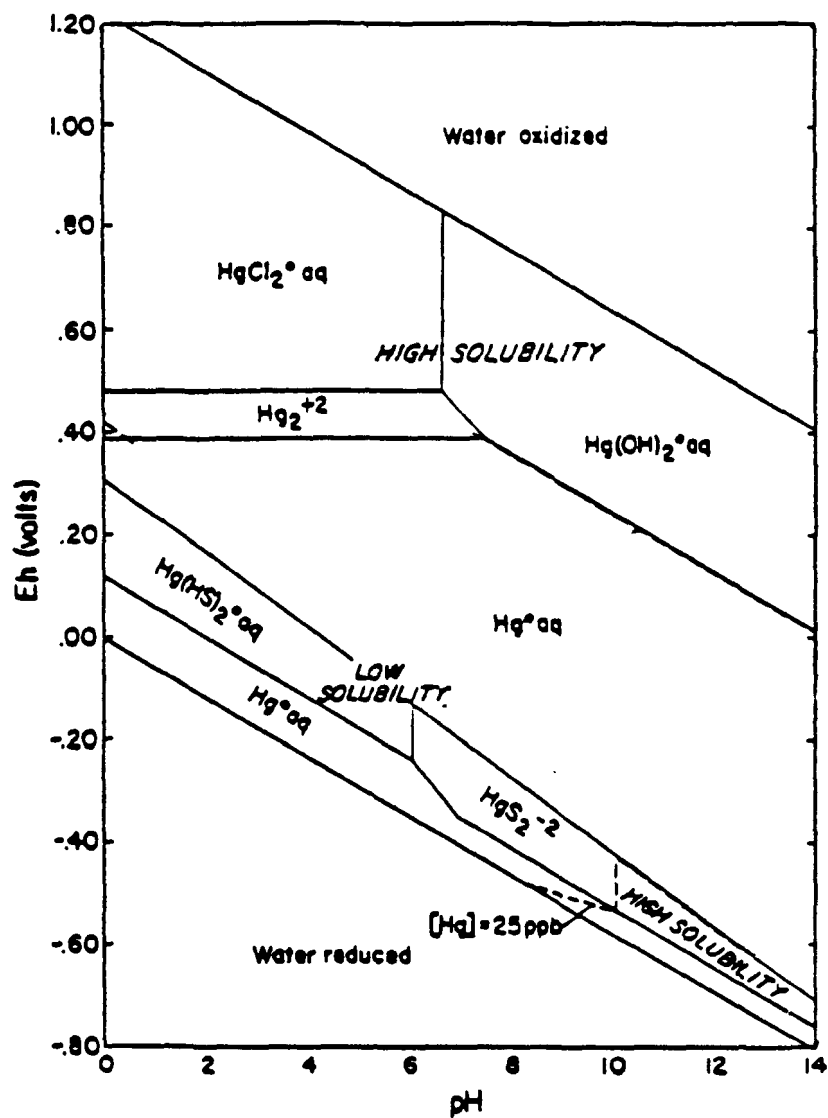


Figure 9-4. Fields of Stability for Aqueous Mercury at 25°C and Atmospheric Pressure (Callahan et al., 1979)



that solution composition depends on redox potential and that chemical mobility within a ground-water system may vary from one zone to another.

## **9.5 Data Presentation**

The owner or operator will be required to report on the progress of the RFI at appropriate intervals during the investigation. The data should be reported in a clear and concise manner, with interpretations supported by the data. The following data presentation methods are suggested for soil investigations. Further information is provided in Section 5.

### **9.5.1 Waste and Unit Characterization**

Waste and unit characteristics may be presented as:

- Tables of waste constituents and concentrations;
- Tables of relevant physical and chemical properties of waste and constituents;
- Narrative description of unit operations; and
- Surface map and plan drawings of the facility and waste unit(s).

### **9.5.2 Environmental Setting Characterization**

Environmental characteristics may be presented as:

- A map and narrative description of soil classifications;
- Soil boring logs;
- Measurements of soil physical or hydrologic characteristics; and
- Onsite survey results (e.g., OVA, portable gas chromatograph, geophysical techniques).

Soil and site map(s)--In addition to the required RCRA permit site topographic map, the owner or operator should prepare a map(s) displaying the location of surface soil types (described according to the appropriate classification system), paved areas, areas of artificially compacted soil, fill or other disturbed soil, and other features that could affect contaminant distribution. Specific guidance on the use of maps and other techniques such as aerial photographs and geophysical surveys is provided in Appendices A and C.

The owner or operator should develop maps of unconsolidated geologic materials at the site. These maps should identify the thicknesses, depths, and textures of soils, and the presence of saturated regions and other hydrogeological features. Subsurface soils should be identified according to accepted methods for description of soils (See Section 9.3.3.3). Figure 9-5 displays a typical soil boring log.

Graphical methods commonly used to display soil boring data are cross-sections, fence diagrams, and isopach maps. Cross-sections are typically derived from borings taken along a straight line through the site. Plotting the stratigraphy of surficial deposits against horizontal distance between sampling points gives a vertical profile or transect. Fence diagrams can depict the same type of information between points that are not in a straight line. An isopach map resembles a topographic map, however, the isopleth lines on an isopach map represent units of thickness of a particular soil layer rather than elevations. For example, a map of clay isopachs may be used to show the thickness in feet of a low permeability layer below a waste lagoon. Generally, to verify lateral continuity, more than one transect through a site will be necessary. When it is important to indicate the areal extent of a layer (e.g., where a clay lens is suspected to cause lateral transport in the unsaturated zone) both vertical and horizontal presentations may be necessary. Graphical methods are discussed in detail in Section 5 (Data Management and Presentation).

### **9.5.3 Characterization of the Release**

Graphical displays of contaminant distributions in soil may include:



BORING LOG										PROJECT		SHEET NO		SHEET NO	
										1-619-078		2		3 148	
SAMPLE TYPE AND LOCATION	SAMPLE DEPTH FROM SURFACE	SAMPLE DEPTH FROM TOP OF LAST SAMPLE	SAMPLE DEPTH FROM BOTTOM OF LAST SAMPLE	PENETRATION BLows	ELEVATION	DEPTH IN FEET	GRAPHIC LOG	SOUNDING	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVEL, WATER RETURN, CHARACTER OF SOIL, etc.					
											1st	2nd	3rd	4th	
SS	2'	.8	129	140	47	37	45		43.3-46.3 (before <u>logs</u> and <u>logs</u> to medium <u>gravel</u> and some <u>silt</u> at greater depths. Heavily contaminated at shallower depths.						
SS	2'	1.3	162	102	73	46	43								
SS	2'	1.0	138	50	47	46	47								
SS	2'	.8	52	24	18	18	16								
SS	.3	.3	50*	195	50*	-	-		68.3' <u>bedrock</u> bottom of hole.	Hole backed up to 67.8' before piezometer was placed.					

**Figure 9-5 (Continued)**

- Area/site maps with concentrations indicated by numerical values, symbols, or isoconcentration lines;
- Three-dimensional isopleth plots of concentrations (including stack maps), such as are produced by computer graphics; and
- Vertical concentration contours (isopleths) plotted along a transect or fence diagram.

All graphical displays should be accompanied by data tables showing concentrations for each sampling location.

## **9.6 Field Methods**

Both soil and soil-pore water sampling may be utilized in the investigation. Chemical analysis of soil core samples may be used to characterize constituents of concern that are adsorbed to the solid matrix. Lysimeters can be installed in boreholes created during core sampling to identify mobile constituents that may migrate to ground water. In addition, field screening methods may be used to help determine the presence and extent of releases.

Appropriate sample collection and preservation techniques should be specified. When a soil sample is removed from its surroundings, chemical and physical changes can begin immediately. These changes include moisture loss, oxidation, gas exchange, loss of volatile components, increased or decreased biological activity, and potential contamination of the sample. Therefore, appropriate measures must be taken to store and preserve samples to minimize their degradation. Sampling techniques should not adversely affect analytical procedures and hence results. For example, use of fluids other than water during drilling can introduce organic or inorganic contaminants that may make quantification of the contaminants of concern impossible. The practice of coating metal parts of drilling equipment with oils or greases to prevent rust will have a similar effect.

Volatile compounds can sometimes be detected near the soil surface using rapid, field screening methods (e.g., portable photoionization detector such as HNu

or Photovac or an organic vapor analyzer (OVA)). Organic vapors can also be detected and measured in shallow boreholes or in ground-water monitoring wells. Vapor sampling is especially useful for initial characterization because it is a rapid, semi-quantitative technique. Benefits of field screening methods include:

- The investigator can, in certain cases, quickly determine whether a sample is contaminated, thus, aiding in the identification of areas of concern;
- Samples that may undergo chemical changes with storage can be evaluated immediately; and
- These techniques can be used to investigate releases to several media simultaneously (e.g., subsurface gas, ground water and soil).

However, there are limitations in using field screening methods, including:

- They cannot always account for all constituents that may be present in the release;
- They may not be able to quantify concentrations of specific constituents of concern; and
- Constituents may be present at levels below detection capability.

Field-screening methods are described in the Compendium of Field Operations Methods (EPA, 1987).

Soil sampling methods will commonly vary with the depth of interest. For purposes of the RFI, these methods are described as "surficial" or "subsurface". Surficial sampling in the upper 20 cm of soil can usually be accomplished with simple tools, including shovels, spatulas, soil punches, and ring samplers. Contaminants that have moved further downward in the soil profile often require tools such as tube samplers and augers. Manually operated tools are commonly useful to about 1 to 2 meters in depth, depending on the soil type. Below this depth, hydraulically or mechanically driven equipment is generally needed (See Everett et al, 1984 for

additional information on soil sampling techniques, as well as Sections 3 and 7 of this Guidance for discussions of additional sampling methods and references).

Methods to sample soil-pore water or other fluids are presented in Section 9.6.3.

#### **9.6.1      Surficial Sampling Techniques**

Surficial soils may also contain various materials, including rocks, vegetation, and man-made items. The owner or operator should propose how these materials will be treated (i.e., whether they will be discarded or analyzed separately). Care should be taken in choosing sampling equipment that will not adversely affect the analytical objectives (e.g., painted or chrome/nickel plated equipment may adversely affect metals analyses). Some commonly used surficial soil sampling techniques are discussed below.

##### **9.6.1.1      Soil Punch**

A soil punch is a thin-walled steel tube that is commonly 15 to 20 cm long and 1.3 cm to 5.1 cm in diameter. The tube is driven into the ground with a wooden mallet and twisted to free the sample. The punch is pulled out and the soil pushed or shaken from the tube. This technique is rapid but is generally not useful in rocky areas or in loose, granular soils that will not remain in the punch. Soil punching is not useful for soil structure descriptions because the method causes compaction that destroys natural fractures.

##### **9.6.1.2      Ring Samplers**

A ring sampler consists of a 15 to 30 cm diameter steel ring that is driven into the ground. The soil is subsequently removed for analysis. This technique is useful when results are to be expressed on a unit area basis, because the soil ring contains a known area of soil. Ring samplers will generally not be useful in loose, sandy soils or stiff clays.

#### 9.6.1.3 Shovels, Spatulas, and Scoops

Collection of grab samples by shovel, spatula, or scoop is not recommended if sample area or volume determinations are required (the two previous methods are more accurate). The reproducibility of sample size is limited and subject to sample bias. The principal advantages of grab sampling are the efficiency of collection and the fact that samples may indicate the range of contaminant concentrations at the site.

#### 9.6.1.4 Soil Probes (tube samplers)

Manual soil probes are designed to obtain samples from the upper two meters of the soil profile. The soil probe is commonly a stainless-steel or brass tube that is sharpened and beveled on one end and fitted with a T-handle. Soil probes are common agricultural tools and can be obtained in several diameters. The probe is pushed into the soil in 20 to 30 cm increments. At the desired depth, the tube is pulled out and the soil sample extruded. The sample may be considered "disturbed" or "undisturbed" depending on whether it can be removed intact. The samples, however, are generally considered to be disturbed for the purposes of engineering or physical measurements. Loose soils will be difficult to sample with this tool, and the borehole will tend to collapse when the tube is withdrawn to obtain samples.

#### 9.6.1.5 Hand Augers

Augers have a spiral cutting blade that transports soil cuttings upwards. Hand-operated augers are generally used to a depth of approximately 6 feet. Single flight augers are pulled from the ground periodically and soil samples are taken from the threads of the auger. Continuous flight augers transport the loosened soil to the top of the borehole, where it can be collected. Augers provide highly disturbed samples. Limited information can be obtained on soil structure, bulk density, or permeability. Cross-contamination between soil layers is likely and depth information on various soil layers is not reliable. Therefore, reliance on augering as a sole sampling technique is not recommended. Augering may be used, however, in conjunction with tube sampling that obtains undisturbed samples.



## **9.6.2 Deep Sampling Methods**

The subject of deep drilling is discussed more extensively in the section on ground-water sampling (see Section 10), because deep cores will generally be taken in conjunction with drilling for monitoring well emplacement. There are some techniques that are of particular importance to soil sampling and, therefore, a brief discussion is included here. Procedures for sampling with split-spoon and thin-wall tube corers and other equipment are presented in Section 7.

### **9.6.2.1 Hollow-Stem Augers**

Hollow-stem augers have a continuous flight-cutting blade around a hollow metal cylinder. A stem with a plug is ordinarily kept inside the auger barrel to prevent soil from entering. When core samples are desired, the stem is withdrawn and a tube sampler may be inserted to the bottom of the borehole. This drilling method may be used for continuous soil sampling. An additional advantage of hollow-stem augers is that they do not require drilling fluids.

### **9.6.2.2 Solid-Stem Augers**

Solid-stem augers, as the name implies, are augers that do not have an inner barrel. As with the manual variety, single-flight augers must be withdrawn each time a sample is desired, or samples may be taken from the cuttings brought to the surface by augers of the continuous flight type. Augers may be used in conjunction with tube samplers by withdrawing the auger and obtaining a sample from the bottom of the borehole. This sampling approach is only useful with soils that do not cave in or crumble after drilling.

### **9.6.2.3 Core Samplers**

Soil coring devices that may be used with hydraulically or mechanically-driven drilling rigs include thin-walled Shelby tubes and split-spoon samplers. These are two of the most common samplers and are discussed below.

#### 9.6.2.3.1 Thin-Walled Tube Samplers

The Shelby tube is a metal cylinder with the end sharpened and beveled for cutting into the soil. Common sizes used for field investigations are 1 to 3 inches in diameter. The tube is pushed down into the soil with a smooth even motion by applying downward pressure from a drilling rig or other apparatus. Thin-walled tubes produce high quality undisturbed cores that can be used for engineering and hydraulics testing but are useful only in cohesive soils as loose soils may fall out of the tube during removal. The soil must be extruded from the tube in a laboratory or in a field extruding unit because core removal is generally difficult. For rapid characterization of the soil stratigraphy in the field, split-spoon samplers are recommended.

#### 9.6.2.3.2 Split-Spoon Samplers

A split-spoon consists of a hollow steel cylinder split in half and screwed into an "unsplit" outer tube and tip. This assembly can be connected to drill rods. The tube is commonly forced into the soil by applying a 140 pound sliding hammer, dropping 30 inches along the drill rod (ASTM, 1986). The number of hammer blows required to advance the sampler in six inch increments is recorded. The total blow count number for the second and third increments is related to a standard engineering parameter indicating soil density. After the tube is pulled from the soil, the cylinder is removed from the drill rod and opened, exposing the soil core. Core samples may be used to determine stratigraphy, for chemical and grain-size analysis, or for pore water extraction. Split-spoons are the preferred method for obtaining unconsolidated soil samples and may also be used to penetrate some types of rock.

#### 9.6.2.4 Trenching

Trenches and test pits are useful where detailed examination of soil stratigraphy and geology is required. Trenching is generally limited for practicality to the top eight feet of soil. Shallow trenches may be dug manually, but in most instances, a backhoe will be faster and easier. Bulk soil samples may be obtained with this method.

### **9.6.3 Pore Water Sampling**

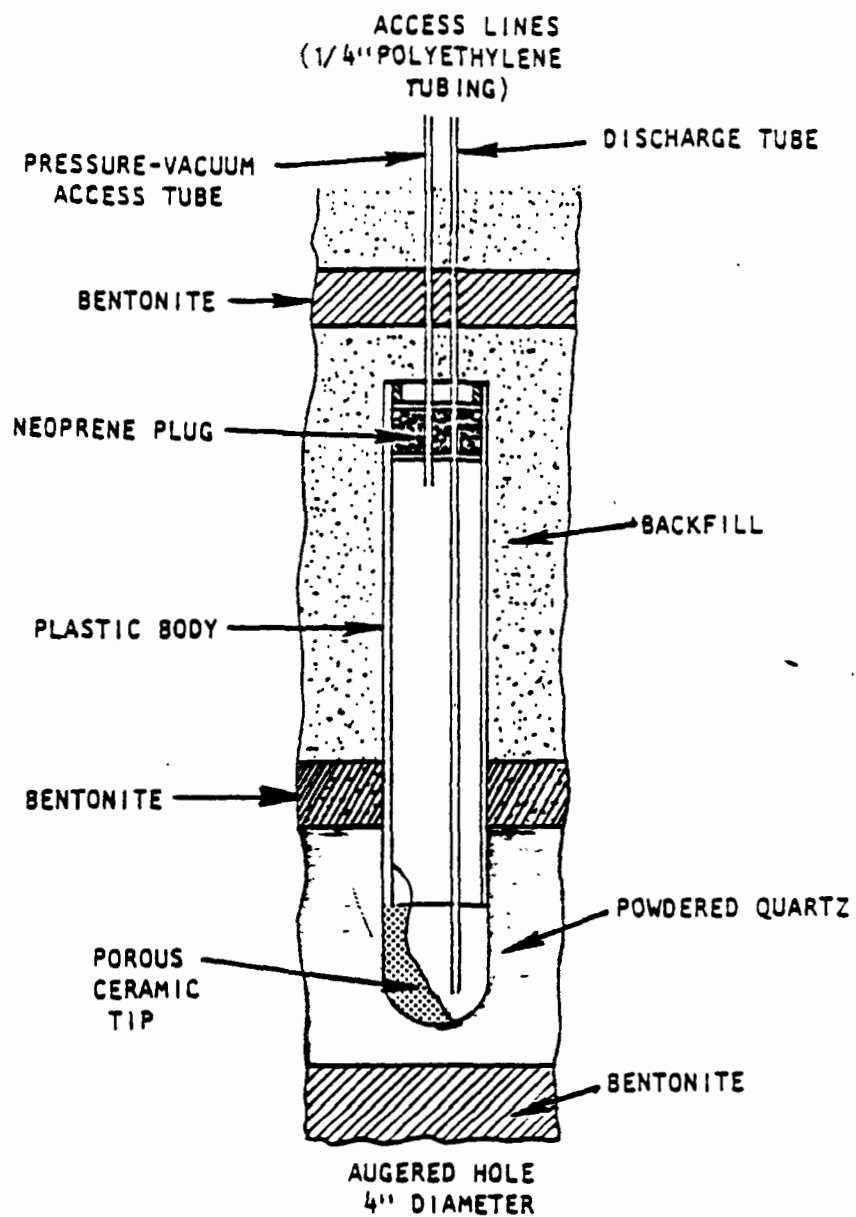
When contaminants are suspected of migrating readily through the soil with infiltrating water, monitoring of water or other fluids in the unsaturated zone may be appropriate. Sampling soil pore water before it reaches the water table can provide an early warning of threats to ground water.

Compounds for which pore water sampling may be useful are those that are moderately to highly water soluble and thus are not appreciably retained on soil particles. Examples include poorly adsorbed inorganics such as cyanide or sulfate, halogenated solvents such as TCE, and organic acids. Due to the mobility of these compounds, pore water sampling will be most useful for current releases.

A common pore water collection technique uses a suction device called a pressure vacuum lysimeter, which consists of a porous ceramic cup connected by tubing to a collection flask and vacuum pump (Figure 9-6). The lysimeter cup may be permanently installed in a borehole of the appropriate depth, and if the hole is properly backfilled. Suction from the pump works against soil suction to pull water out of the silica flour surrounding the cup. This method will not work well in relatively dry soils.

An advantage of this method is that the installation is "permanent," allowing multiple samples from one spot to measure changes in pore water quality with time. Limitations include:

- Measurements cannot be correlated accurately with soil concentrations because the sample is obtained from an unknown volume of soil;
- Lysimeters are subject to plugging and are difficult to install in fractured or rocky soils;
- Some organic and inorganic constituents may be adsorbed by the ceramic cup (Teflon porous suction lysimeters may overcome this problem); and



**Figure 9-6. Typical Ceramic Cup Pressure/Vacuum Lysimeter**

- Volatile organics will be lost unless a special organics trap is installed in the system.

## 9.7 Site Remediation

Although the RFI Guidance is not intended to provide detailed guidance on site remediation, it should be recognized that certain data collection activities that may be necessary for a Corrective Measures Study may be collected during the RFI. EPA has developed a practical guide for assessing and remediating contaminated sites that directs users toward technical support, potential data requirements and technologies that may be applicable to EPA programs such as RCRA and CERCLA. The reference for this guide is provided below.

U.S. EPA. 1988. Practical Guide for Assessing and Remediating Contaminated Sites. Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

The guide is designed to address releases to ground water as well as soil, surface water and air. A short description of the guide is provided in Section 1.2 (Overall RCRA Corrective Action Process), under the discussion of Corrective Measures Study.

## 9.8 Checklist

### RFI CHECKLIST - SOILS

Site Name/Location \_\_\_\_\_

Type of unit \_\_\_\_\_

1. Does waste characterization include the following information? (Y/N)

- Identity and composition of contaminants \_\_\_\_\_
- Physical state of contaminants \_\_\_\_\_
- Viscosity \_\_\_\_\_
- pH \_\_\_\_\_
- pKa \_\_\_\_\_
- Density \_\_\_\_\_
- Water Solubility \_\_\_\_\_
- Henry's Law Constant \_\_\_\_\_
- K<sub>ow</sub> \_\_\_\_\_
- Biodegradability \_\_\_\_\_
- Rates of hydrolysis, photolysis and oxidation \_\_\_\_\_

2. Does unit characterization include the following information? (Y/N)

- Age of unit \_\_\_\_\_
- Construction integrity \_\_\_\_\_
- Presence of liner (natural or synthetic) \_\_\_\_\_
- Location relative to ground-water table or bedrock or other confining barriers \_\_\_\_\_
- Unit operation data \_\_\_\_\_
- Presence of cover \_\_\_\_\_
- Presence of on/offsite buildings \_\_\_\_\_
- Depth and dimensions of unit \_\_\_\_\_
- Inspection records \_\_\_\_\_
- Operation logs \_\_\_\_\_
- Presence of natural or engineered barriers near unit \_\_\_\_\_

3. Does environmental setting information include the following information? (Y/N)

- Site soil characteristics \_\_\_\_\_
- Surface soil distribution map \_\_\_\_\_
- Soil moisture content \_\_\_\_\_
- Predominant soil phase to sample (solid, liquid, gaseous) \_\_\_\_\_
- Soil classification \_\_\_\_\_
- Particle size distribution \_\_\_\_\_

RFI CHECKLIST - SOILS  
(Continued)

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- |    |  |  |
|----|--|--|
|    | <ul style="list-style-type: none"><li>● Porosity</li><li>● Hydraulic conductivity (saturated and unsaturated)</li><li>● Relative permeability</li><li>● Soil sorptive capacity</li><li>● Cation exchange capacity</li><li>● Organic carbon content</li><li>● Soil pH</li><li>● Depth to water table</li><li>● Pore water velocity</li><li>● Percolation</li><li>● Volumetric water content</li></ul>   | <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div>   |
| 4. | Have the following data on the initial phase of the release characterization been collected?   | (Y/N)  |
|    | <ul style="list-style-type: none"><li>● Geological and climatological data</li><li>● Facility records and site-specific investigations</li><li>● Area of contamination</li><li>● Distribution of contaminants within study area</li><li>● Depth of contamination</li><li>● Chemistry of contaminants</li><li>● Vertical rate of transport</li><li>● Lateral rate of transport in each stratum</li><li>● Persistence of contaminants in soil</li><li>● Potential for release from surface soils to air</li><li>● Potential for release from surface soils to surface water</li><li>● Existing soil/ground-water monitoring data</li><li>● Evidence of vegetative stress</li><li>● Potential for release to ground water</li><li>● Potential receptors</li></ul> | <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> |
| 5. | Have the following data on the subsequent phase(s) of the release characterization been collected?   | (Y/N)  |
|    | <ul style="list-style-type: none"><li>● Further soil stratigraphic and hydrologic characterization data</li><li>● Expanded sampling data</li><li>● Geophysical data on release location</li></ul>  | <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div> <div style="border-bottom: 1px solid black; height: 10px; width: 100%;"></div>   |
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## **SECTION 10**

### **GROUND WATER**

#### **10.1 Overview**

The objective of an investigation of a release to ground water is to characterize the nature, extent, and rate of migration of a release of hazardous waste or constituents to that medium. This section provides:

- An example strategy for characterizing releases to ground water, which includes characterization of the source and the environmental setting of the release, and conducting a monitoring program which will characterize the release itself;
- Formats for data organization and presentation;
- Field methods which may be used in the investigation; and
- A checklist of information that may be needed for release characterization.

The exact type and amount of information required for sufficient release characterization will be site-specific and should be determined through interactions between the regulatory agency and the facility owner or operator during the RFI process. This guidance does not define the specific data needed in all instances; however, it identifies possible information necessary to perform release characterizations and methods for obtaining this information. The RFI Checklist, presented at the end of this section, provides a tool for planning and tracking information for release characterization. This list is not meant as a list of requirements for all releases to ground water. Some release investigations will involve the collection of only a subset of the items listed, while others may involve the collection of additional data.

## **10.2 Approach for Characterizing Releases to Ground Water**

### **10.2.1 General Approach**

A conceptual model of the release should be formulated using all available information on the waste, unit characteristics, environmental setting, and any existing monitoring data. This model (not a computer or numerical simulation model) should provide a working hypothesis of the release mechanism, transport pathway/mechanism, and exposure route (if any). The model should be testable/verifiable and flexible enough to be modified as new data become available.

For ground-water investigations, this model should account for the ability of the waste to be dissolved or to appear as a distinct phase (i.e., "sinkers" and "floaters"), as well as geologic and hydrologic factors which affect the release pathway. Both the regional and site-specific ground-water flow regimes should be considered in determining the potential magnitude of the release, migration, pathways and possible exposure routes. Exposure routes of concern include ingestion of ground water as drinking water and near-surface flow of contaminated ground water into basements of residences or other structures (see Appendix E). This "basement seepage" pathway can pose threats through direct contact, inhalation of toxic vapors and through fires and explosions if the contaminants are flammable. The model should consider the degradability (chemical and biological) of the waste and its decomposition products. The conceptual model should also address the potential for the transfer of contaminants in ground water to other environmental media (e.g., discharge to surface water and volatilization to the atmosphere).

Based on the conceptual model, the owner or operator should develop a monitoring program to determine the nature, extent, and rate of migration of contaminant releases from SWMUs\* to ground water. Three-dimensional characterization is particularly important. The initial monitoring phase should

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\* Guidance in this section applies to releases from all solid waste management units, except releases to ground water from "regulated units" as defined under 40 CFR Part 264.90(a)(2). Releases to ground water from "regulated units" must be addressed according to the requirements of 40 CFR Parts 264.91 through 264.100 for purposes of detection, characterization and appropriate response.

include a limited number of monitoring wells, located and screened in such a way that they are capable of providing background water quality and of intercepting any release. The regulatory agency will evaluate the adequacy of an existing monitoring system, if proposed for use in the initial monitoring phase. The owner or operator may be required to install new wells if the existing well system is found to be inadequate.

Initial ground-water sampling and analysis may be conducted for a limited set of monitoring constituents. This set should include a subset of the hazardous constituents of concern, and may also include indicator parameters (e.g., TOX). Guidance regarding the selection of monitoring constituents and indicator parameters is provided in Sections 3 and 7 and in Appendix B. Sampling frequency and duration should also be proposed in the RFI Work Plan.

Investigation of a suspected release may be terminated based on results from an initial monitoring phase if these results show that an actual release has not, in fact, occurred. If, however, contamination is found, the release must be adequately characterized through a subsequent monitoring phase(s).

Subsequent characterization involves determining the detailed chemical composition and the areal and vertical (i.e., three dimensional) extent of the contaminant release, as well as its rate of migration. This should be accomplished through direct sampling and analysis and, when appropriate, can be supplemented by indirect means such as geophysical methods (See Appendix C) and modeling techniques.

Table 10-1 outlines an example of strategy for characterizing releases to ground water. Table 10-2 lists the specific tasks which may be used in implementing the strategy, and the corresponding data outputs. The steps delineated in these tables should generally be performed in sequential order, although some may be accomplished concurrently. For example, the site's hydrogeology may be investigated at the same time as waste and unit characterization; soil borings installed during hydrogeologic characterization may be converted into monitoring wells; and additional wells may be installed to more accurately characterize a release while a sampling and analysis program is in effect at existing wells.

**TABLE 10-1**  
**EXAMPLE STRATEGY FOR CHARACTERIZING**  
**RELEASES TO GROUND WATER<sup>1</sup>**

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**INITIAL PHASE**

- 1. Collect and review existing information on:**
  - Waste
  - Unit
  - Environmental setting
  - Contaminant releases, including inter-media transport
- 2. Identify any additional information necessary to fully characterize release:**
  - Waste
  - Unit
  - Environmental setting
  - Contaminant releases, including inter-media transport
- 3. Develop monitoring procedures:**
  - Formulate conceptual model of release
  - Determine monitoring program objectives
  - Plan field screening if appropriate (e.g., geophysical investigations - see Appendix C)
  - Select monitoring constituents and indicator parameters
  - Identify QA/QC and analytical procedures
  - Appropriate initial area well locations (background and downgradient)
  - Collection of additional hydrogeologic data (if necessary)
  - Proper well screen interval selection
  - Borehole testing and use of test pitting
  - Sampling frequency and duration of monitoring
  - Identification of data presentation and evaluation procedures
- 4. Conduct initial monitoring phase:**
  - Conduct field screening, if appropriate
  - Collect samples and perform appropriate field measurements
  - Analyze samples for selected parameters and constituents
- 5. Collect, evaluate and report results:**
  - Compare monitoring results to health and environmental criteria and identify and respond to emergency situations and identify priority situations that warrant interim corrective measures - Notify regulatory agency
  - Determine completeness and adequacy of collected data
  - Summarize and present data in appropriate format

**TABLE 10-1 (Continued)**

**EXAMPLE STRATEGY FOR CHARACTERIZING  
RELEASES TO GROUND WATER<sup>1</sup>**

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**INITIAL PHASE (Continued)**

- Determine if monitoring program objectives were met
- Determine if monitoring locations, constituents and frequency were adequate to characterize release (nature, rate, and extent)

**SUBSEQUENT PHASES (If Necessary)**

1. Identify additional information necessary to characterize release:
  - Perform further hydrogeologic characterization, if necessary
  - Add and delete constituents or indicator parameters as appropriate
  - Employ geophysical and other methods to estimate extent of release and to determine suitable new monitoring locations
  - Inter-media transport
2. Expand monitoring network as necessary:
  - Increase density of monitoring locations
  - Expand monitoring locations to new areas
  - Install new monitoring wells
3. Conduct subsequent monitoring phases:
  - Collect samples and complete field analysis
  - Analyze samples for selected parameters and constituents
4. Collect, evaluate, and report results/identify additional information necessary to characterize release:
  - Compare monitoring results to health and environmental criteria and identify and respond to emergency situations and identify priority situations the warrant interim corrective measures - Notify regulatory agency
  - Summarize and present data in appropriate format
  - Determine if monitoring program objectives were met
  - Determine if monitoring locations, constituents, and frequency were adequate to characterize release (nature, extent, and rate)
  - Identify additional information needs
  - Determine need to expand monitoring
  - Evaluate potential role of inter-media impact
  - Report results to regulatory agency

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<sup>1</sup> The possibility for inter-media transport of contamination should be anticipated throughout the investigation.



**TABLE 10-2**  
**RELEASE CHARACTERIZATION TASKS FOR GROUND WATER**

Investigatory Tasks	Investigatory Techniques	Data Presentation Formats/Outputs
<b>1. Waste/Unit Characterization</b> <ul style="list-style-type: none"> <li>- Identify waste properties (e.g., pH, viscosity)</li> <li>- Identify constituents of concern/possible indicator parameters</li> <li>- Determine physical/chemical properties of constituents</li> <li>- Determine unit dimensions and other important design features and operational conditions</li> <li>- Investigate possible unit release mechanisms to help determine flow characteristics</li> </ul>	<ul style="list-style-type: none"> <li>- Review existing information and conduct waste sampling if necessary (See Sections 3 &amp; 7)</li> <li>- Review existing information and conduct waste sampling if necessary (See Sections 3 &amp; 7)</li> <li>- Review existing information (See Section 7)</li> <li>- Review existing information and conduct unit examinations (See Section 7)</li> <li>- Review existing information and conduct unit examinations (See Section 7)</li> </ul>	<ul style="list-style-type: none"> <li>- Tabular presentation (See Section 5)</li> <li>- Tabular presentation (See Section 5)</li> <li>- Tabular presentation (See Section 5)</li> <li>- Tabular presentations, facility maps &amp; photographs &amp; narrative discussion (See Section 5 and Appendix A)</li> <li>- Facility maps &amp; photographs &amp; narrative discussions (See Appendix A)</li> </ul>
<b>2. Environmental Setting Characterization</b> <ul style="list-style-type: none"> <li>- Examine surface features &amp; topography for indications of subsurface conditions</li> <li>- Define subsurface conditions &amp; materials, including soil and subsurface physical properties (e.g., porosity, cation exchange capacity)</li> </ul>	<ul style="list-style-type: none"> <li>- Review existing information, facility maps, aerial &amp; other photographs, site history, conduct surface geological surveys</li> <li>- Review of existing geologic information</li> <li>- Soil borings and rock corings</li> <li>- Soil &amp; subsurface material testing</li> <li>- Geophysical techniques (See Appendix C)</li> </ul>	<ul style="list-style-type: none"> <li>- Facility map &amp; photographs/text discussion (See Appendix A &amp; C)</li> <li>- Narrative discussions of geology</li> <li>- Boring and coring logs</li> <li>- Subsurface profiles, transects &amp; fence diagrams (See Appendix A &amp; Section 5)</li> <li>- Tabular presentations of soil &amp; subsurface physical &amp; chemical properties</li> <li>- Geologic cross sections &amp; geologic &amp; soil maps (See Section 5 &amp; 9 &amp; Appendix A)</li> <li>- Structure contour maps (plan view) of aquifer &amp; aquitards (See Section 5 &amp; Appendix A)</li> </ul>

**TABLE 10-2**  
**RELEASE CHARACTERIZATION TASKS FOR GROUND WATER (continued)**

Investigatory Tasks	Investigatory Techniques	Data Presentation Formats/Outputs
<p><b>Environmental Setting Characterization (Continued)</b></p> <ul style="list-style-type: none"> <li>- Identification of regional flow cells, ground-water flow paths &amp; general hydrology, including hydraulic conductivities &amp; aquifer interconnections</li> <li>- Identification of potential receptors</li> </ul>	<ul style="list-style-type: none"> <li>- Review of existing information</li> <li>- Installation of piezometers &amp; water level measurements at different depths</li> <li>- Flow cell &amp; flow net analyses using measured heads</li> <li>- Pumping &amp; slug tests &amp; tracer studies</li> <li>- Geophysical techniques (See Appendix C)</li> <li>- Review of existing information, area maps, etc.</li> </ul>	<ul style="list-style-type: none"> <li>- Narrative descriptions of ground-water conditions, flow cells, flow nets, flow patterns, including flow rates &amp; direction</li> <li>- Water table or potentiometric maps (plan view) with flow lines (See Section 5)</li> <li>- hydrologic cross sectional maps (See Section 5)</li> <li>- Flow nets for vertical &amp; horizontal flow</li> <li>- Tabular presentations of raw data &amp; interpretive analysis</li> <li>- Narrative discussion &amp; area maps</li> </ul>
<p><b>Release Characterization</b></p> <ul style="list-style-type: none"> <li>- Determine background levels &amp; determine vertical and horizontal extent of release, including concentrations of constituents &amp; determine rate &amp; directions of release migration</li> </ul>	<ul style="list-style-type: none"> <li>- Sampling &amp; analysis of ground-water samples from monitoring system</li> <li>- Geophysical methods (See Appendix C) for detecting &amp; tracking plume</li> <li>- Modeling to estimate extent of plume &amp; rate &amp; direction of plume migration</li> </ul>	<ul style="list-style-type: none"> <li>- Tabular presentations of constituent &amp; indicator parameter analyses (See Section 5)</li> <li>- Iso-concentrations maps of contamination (See Section 5)</li> <li>- Maps of rates of release migration &amp; direction showing locations of possible receptors (See Section 5)</li> <li>- Narrative discussion &amp; interpretations of tabular &amp; graphical presentations</li> </ul>

The specific tasks to be conducted for each release will be determined on a site-specific basis. It should be noted that some of the characterization tasks may have been previously accomplished in conjunction with the 40 CFR Parts 264 and 265, Subpart F (ground-water monitoring) regulations.

As monitoring data become available, both within and at the conclusion of discrete investigation phases, it should be reported to the regulatory agency as directed. The regulatory agency will compare the monitoring data to applicable health and environmental criteria to determine the need for (1) interim corrective measures; and/or (2) a Corrective Measures Study. In addition, the regulatory agency will evaluate the monitoring data with respect to adequacy and completeness to determine the need for any additional monitoring efforts. The health and environmental criteria and a general discussion of how the regulatory agency will apply them are supplied in Section 8. A flow diagram illustrating RFI decision points is provided in Section 3 (See Figure 3-2).

Notwithstanding the above process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For these situations, the owner or operator is directed to obtain and follow the RCRA Contingency Plan under 40 CFR Part 264, Subpart D.

Case Study numbers 10, 18, 19, 20, 21 and 22 in Volume IV (Case Study Examples) illustrate the conduct of various aspects of ground-water investigations.

### **10.2.2 Inter-media Transport**

Indirect releases (inter-media transfer) to ground water may occur as a result of contaminant releases to soil and/or surface water that percolate or discharge to ground water. These releases may be recurrent or intermittent in nature, as in the case of overland run-off, and can vary considerably in areal extent. Direct releases to ground water may occur when waste materials are in direct contact with ground water ( e.g., when a landfill rests below the water table).

Releases of contaminated ground water to other media may also occur, for example, in those cases where ground and surface waters are hydraulically

connected. Volatilization of contaminated ground water to the air within residential and other structures may occur via the basement seepage pathway, as described previously. It is important for the owner or operator to be aware of the potential for such occurrences, and to communicate these to the regulatory agency when discovered.

This section provides guidance on characterizing ground-water releases from units, as well as those cases where inter-media transport has contaminated ground water. The owner or operator should be aware that releases to several media can often be investigated using concurrent techniques. For example, soil gas surveys may help to characterize the extent of soil and subsurface gas releases and, at the same time, be used to estimate the extent of a ground-water release. Further guidance on the use of soil gas surveys for investigating releases to soil and ground water are presented in the Soil Section (Section 9).

### **10.3 Characterization of the Contaminant Source and the Environmental Setting**

#### **10.3.1 Waste Characterization**

Knowledge of the waste constituents (historical and current) and their characteristics at the units of concern is essential in selecting monitoring constituents and well locations. Waste (source) information should include identifying volumes and concentrations of hazardous waste or constituents present, and their physical and chemical characteristics.

Identification of hazardous constituents may be a relatively simple matter of reviewing records of unit operations, but generally will require direct sampling and analysis of the waste in the unit. Hazardous constituents may be grouped by similar chemical and physical properties to aid in developing a more focused monitoring program. Knowledge of physical and chemical properties of hazardous constituents can help to determine their mobility, and their ability to degrade or persist in the environment. The mobility of chemicals in ground water is commonly related to their solubility, volatility, sorption, partitioning, and density.

Section 3 provides additional guidance on monitoring constituent selection and Section 7 provides additional guidance on waste characterization. The

following discussion describes several waste-related factors and properties which can aid in developing ground-water monitoring procedures:

- The mobility of a waste is highly influenced by its physical form. Solid and gaseous wastes are less likely to come in contact with ground water than liquid wastes, except in situations where the ground-water surface directly intersects the waste, or where infiltrating liquids are leaching through the unsaturated zone.
- The concentration of any constituent at the waste source may provide an indication of the concentration at which it may appear in the ground water.
- The chemical class (i.e., organic, inorganic, acid, base, etc.) provides an indication of how the waste might be detected in the ground water, and how the various components might react with the subsurface geologic materials, the ground water, and each other.
- The pH of a waste can provide an indication of the pH at which it would be expected to appear in the ground water. A low pH waste could also be expected to cause dissolution of some subsurface geologic materials (e.g., limestone), causing channelization and differential ground-water flow, as in karst areas.
- The acid dissociation constant of a chemical (pKa) is a value which indicates its equilibrium potential in water, and is equal to the pH at which the hydrogen ion is in equilibrium with its associated base. If direct pH measurements are not feasible, the concentration of a waste in combination with its pKa can be used to estimate the likely pH which will occur at equilibrium (in ground water), at a given temperature. Acid dissociation values can be found in most standard chemistry handbooks, and values for varying temperatures can be calculated using the Van't Hoff equation (Snoeyink and Jenkins, 1980).
- Viscosity is a measure of a liquid's resistance to flow at a given temperature. The more viscous a fluid is, the more resistant it is to flow.

Highly viscous wastes may travel more slowly than the ground water, while low-viscosity wastes may travel more quickly than the ground water.

- Water solubility describes the mass of a compound that dissolves in or is miscible with water at a given temperature and pressure. Water solubility is important in assessing the fate and transport of the contaminants in ground water because it indicates the chemical's affinity for the aqueous medium. High water solubility permits greater amounts of the hazardous constituent to enter the aqueous phase, whereas low water solubility indicates that a contaminant can be present in ground water as a separate phase. Therefore, this parameter can be used to establish the potential for a constituent to enter and remain in the ground water.
- The density of a substance (solid or liquid) is its weight per unit volume. The density of a waste will determine whether it sinks or floats when it encounters ground water, and will assist in locating well screen depths when attempting to monitor for specific hazardous constituents released to ground water.
- The log of the octanol/water partition coefficient ( $K_{ow}$ ) is a measure of the relative affinity of a constituent for the neutral organic and inorganic phases represented by n-octanol and water, respectively. It is calculated from a ratio (P) of the equilibrium concentrations (C) of the constituent in each phase:

$$P = \frac{C_{\text{octanol}}}{C_{\text{water}}} \text{ and } K_{ow} = \log P$$

The  $K_{ow}$  has been correlated to a number of factors for determining contaminant fate and transport. These include adsorption onto soil organic matter, bioaccumulation, and biological uptake. It also bears a relationship to aqueous solubility.

- The Henry's Law Constant of a constituent is the relative equilibrium ratio of a compound in air and water at a constant temperature. It can be estimated from the equilibrium vapor pressure divided by the solubility in water and has the units of atm-m<sup>3</sup>/mole. The Henry's Law Constant expresses the equilibrium distribution of the constituent between air and water and indicates the relative ease with which the constituent may be removed from aqueous solution.
- Other influences of the waste constituents should also be considered. Constituents may react with soils, thereby altering the physical properties of the soil, most notably hydraulic conductivity. Chemical interactions among waste constituents should also be considered. Such interactions may affect mobility, reactivity, solubility, or toxicity of the constituents. The potential for wastes or reaction products to interact with unit construction materials (e.g., synthetic liners) should also be considered.

The references listed in Section 7 may be used to obtain information on the parameters discussed above. Other waste information may be found in facility records, permits, or permit applications. It should be noted that mixtures of chemicals may exhibit characteristics different than those of any single chemical.

### 10.3.2 Unit Characterization

Unsound unit design and operating practices can allow waste to migrate from a unit and possibly mix with natural runoff. Examples include surface impoundments with insufficient freeboard allowing for periodic overtopping; leaking tanks or containers; or land based units above shallow, low permeability materials which, if not properly designed and operated, can fill up with water and spill over. In addition, precipitation falling on exposed wastes can dissolve and thereby mobilize hazardous constituents. For example, at uncapped active or inactive waste piles and landfills, precipitation and leachate are likely to mix at the toe of the active face or the low point of the trench floor.

Unit dimensions (e.g., depth and surface area) and configuration (e.g., rectangular, parallel trenches), as well as volume (e.g., capacity) should also be

described, because these factors will have a bearing on predicting the extent of the release and the development of a suitable monitoring network.

### **10.3.3 Characterization of the Environmental Setting**

Hydrogeologic conditions at the site to be monitored should be evaluated for the potential impacts the setting may have on the development of a monitoring program and the quality of the resulting data. Several hydrogeologic parameters should be evaluated, including:

- Types and distribution of geologic materials;
- Occurrence and movement of ground water through these materials;
- Location of the facility with respect to the regional ground-water flow system;
- Relative permeability of the materials; and
- Potential interactions between contaminants and the geochemical parameters within the formation(s) of interest.

These conditions are interrelated and are therefore discussed collectively below.

There are three basic types of geologic materials through which ground water normally flows. These are: (1) porous media; (2) fractured media; and (3) fractured porous media. In porous media (e.g., sand and gravels, silt, loess, clay, till, and sandstone), ground water and contaminants move through the pore spaces between individual grains. In fractured media (e.g., dolomites, some shales, granites, and crystalline rocks), ground water and contaminants move predominantly through cracks or solution crevices in otherwise relatively impermeable rock. In fractured porous media (e.g., fractured tills, fractured sandstone, and some fractured shales), ground water and contaminants can move through both the intergranular pore spaces as well as cracks or crevices in the rock or soil. The occurrence and movement of ground water through pores and cracks or solution crevices depends on the relative effective porosity and degree of

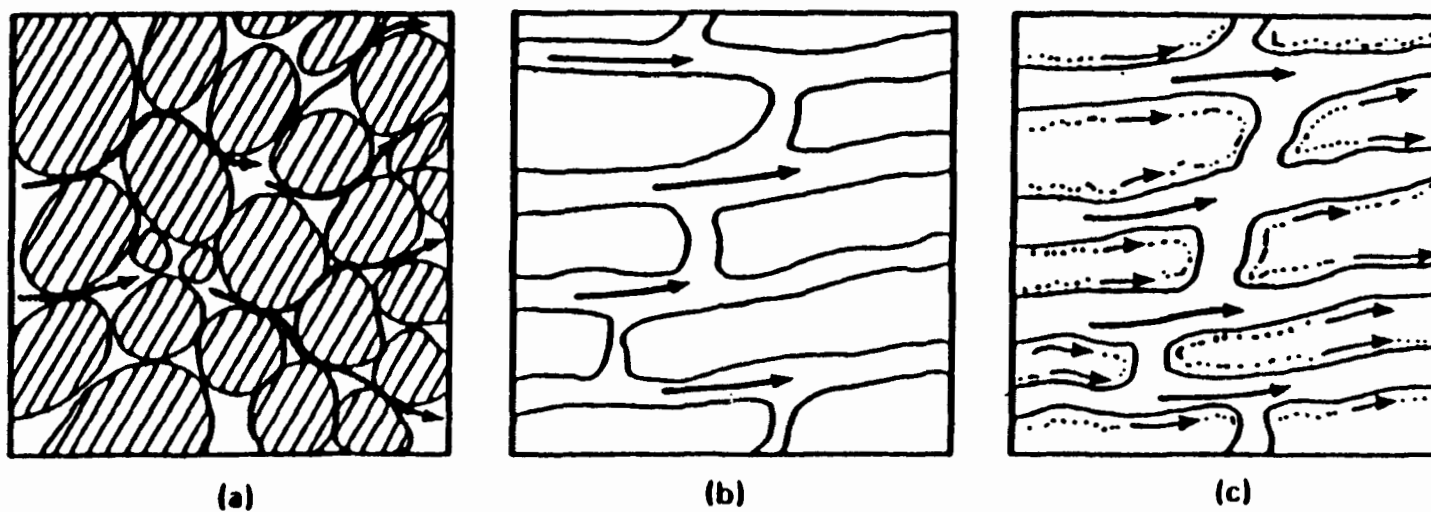


channeling occurring in cracks or crevices. Figure 10-1 illustrates the occurrence and movement of ground water and contaminants in the three types of geologic materials presented above.

The distribution of these three basic types of geologic materials is seldom homogeneous or uniform. In most settings, two or more types of materials will be present. Even for one type of material at a given site, large differences in hydrologic characteristics may be encountered. The heterogeneity of the materials can play a significant role in the rate of contaminant transport, as well as in developing appropriate monitoring procedures for a site.

Once the geologic setting is understood, the site hydrology should be evaluated. The location of the site within the regional ground-water flow system, or regional flow net, should be determined to evaluate the potential for contaminant migration on the regional scale. Potentiometric surface data (water level information) for each applicable geologic formation at properly selected, vertical and horizontal locations is needed to determine the horizontal and vertical ground-water flow paths (gradients) at the site. Figure 10-2(a) and (b) illustrate two geohydrologic settings commonly encountered in eastern regions of the United States, where ground water recharge exceeds evapotranspirational rates. Figure 10-2(c) illustrates a common geohydrologic setting for the arid western regions of the United States. The potential dimensions of a contaminant release would depend on a number of factors including ground-water recharge and discharge patterns, net precipitation, topography, surface water body locations, and the regional geologic setting.

Table 10-3 and Figures 10-3 through 10-16 illustrate regional, intermediate, and local ground water regimes for the major ground-water regions in the United States. Ground-water flow paths, and where possible, generalized flow nets are shown superimposed on cross-sections of the geological units. Much of the information presented in the figures and following text descriptions were taken from Heath et. al., 1984 (Ground Water Regions of the U.S., U.S.G.S. Water Supply



**Figure 10-1.** Occurrence and movement of ground water and contaminants through (a) porous media, (b) fractured or creviced media, (c) fractured porous media.

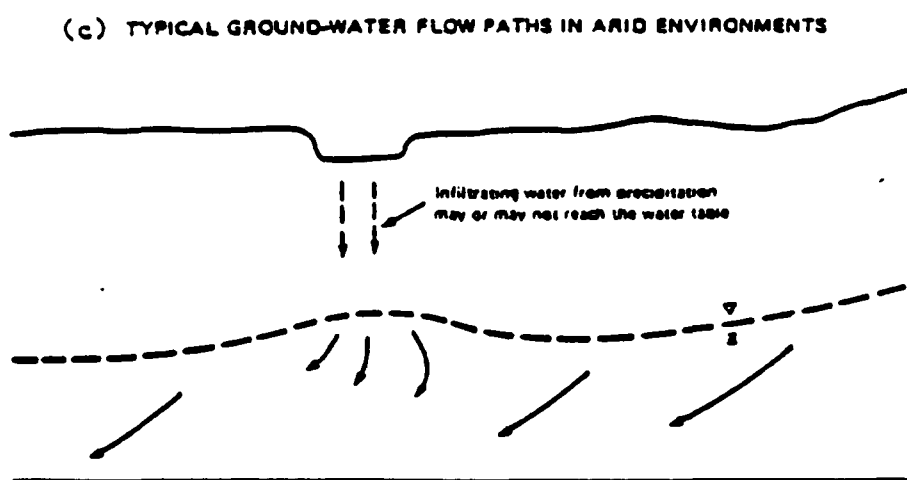
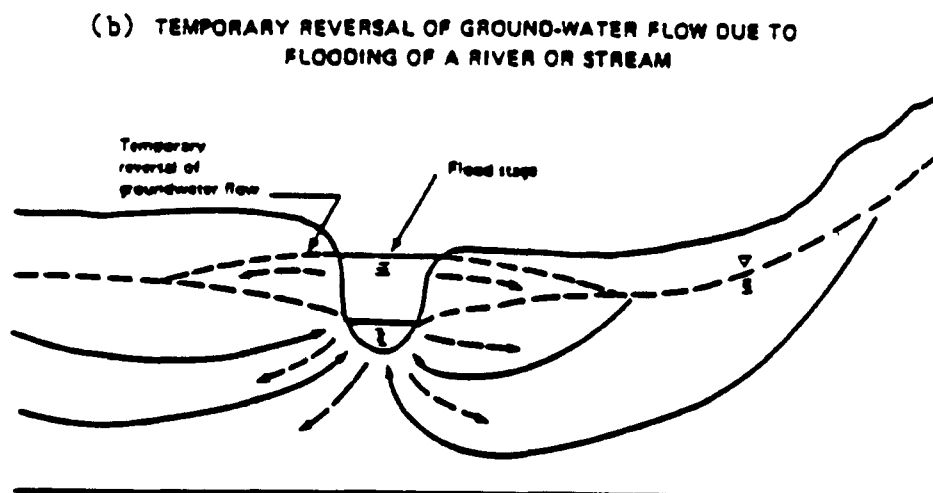
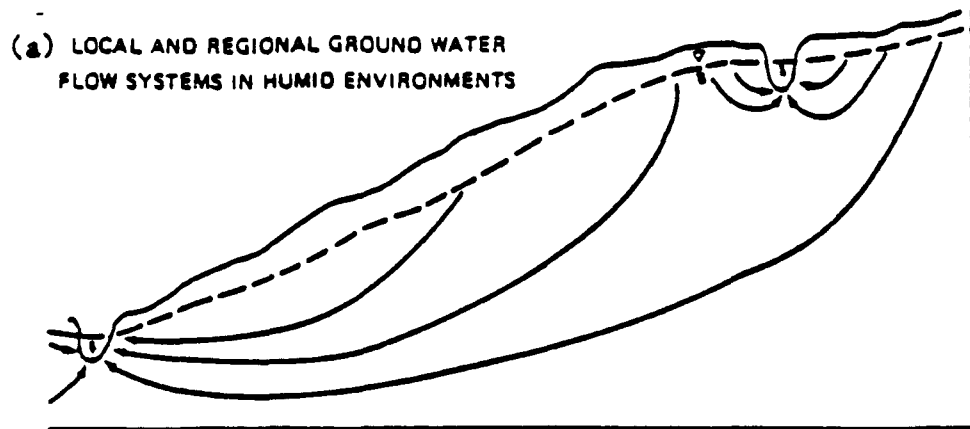


Figure 10-2. Ground-water flow paths in some different hydrogeologic settings.

TABLE 10-3. SUMMARY OF U.S GROUND WATER REGIONS

Region	Region Name (Heath, 1984)	Recharge Area	Discharge Area	Dimensions (miles)	Example
1	Western Mountain Ranges	infiltration in mountains and mountain fronts	streams and rivers	< 1-5 unconfined 5-60 confined	Wasatch Range, Utah
2	Alluvial Basins	plateau uplands	streams and rivers, some enclosed basins, localized springs and seeps in steeper terrain	< 1-20 unconfined 5-80 confined	Nevada
3	Columbia Lava Plateau	surface infiltration	rivers and streams	10-200 miles	Snake River Plain
4	Colorado Plateau	infiltration in plateau uplands; infiltration from surface waters	seeps, springs, and surface waters	5-80 miles	Southeast Utah
5	High Plains	surface infiltration	rivers and streams, seeps and springs along eastern escarpments	2-300 miles	Nebraska
6	Non-glaciated central	upland infiltration	springs, seeps, streams and rivers	< 1-40 miles	Ohio Great Miami
7	Glaciated Central	surface infiltration	springs, streams, rivers, and lakes	< 1-20 miles	Minnesota
8	Piedmont and Blue Ridge	surface infiltration	springs, seeps, and surface waters	< 1-5 miles	West Virginia
9	Northeast and Superior Uplands	upland infiltration	surface water	< 1-20 miles	Massachusetts
10	Atlantic & Gulf Coastal Plain	infiltration in outcrop areas	surface water or subsea leakage	10-150 miles	New Jersey
11	Southeast Coastal Plain	infiltration in outcrop areas	surface water or subsea leakage	1-80 miles	South Georgia
12	Hawaiian Islands	surface infiltration	springs, seeps, and surface waters	< 1-30 miles	Oahu, Hawaii
13	Alaska	variable*	variable*	variable*	North Slope

\* The recharge area, discharge area, and dimensions of the flow cells within Alaska are highly variable due to the wide range in topography and geology found in this region.

## WESTERN MOUNTAIN RANGES

(Mountains with thin soils over fractured rocks, alternating with narrow alluvial and, in part, glaciated valleys)

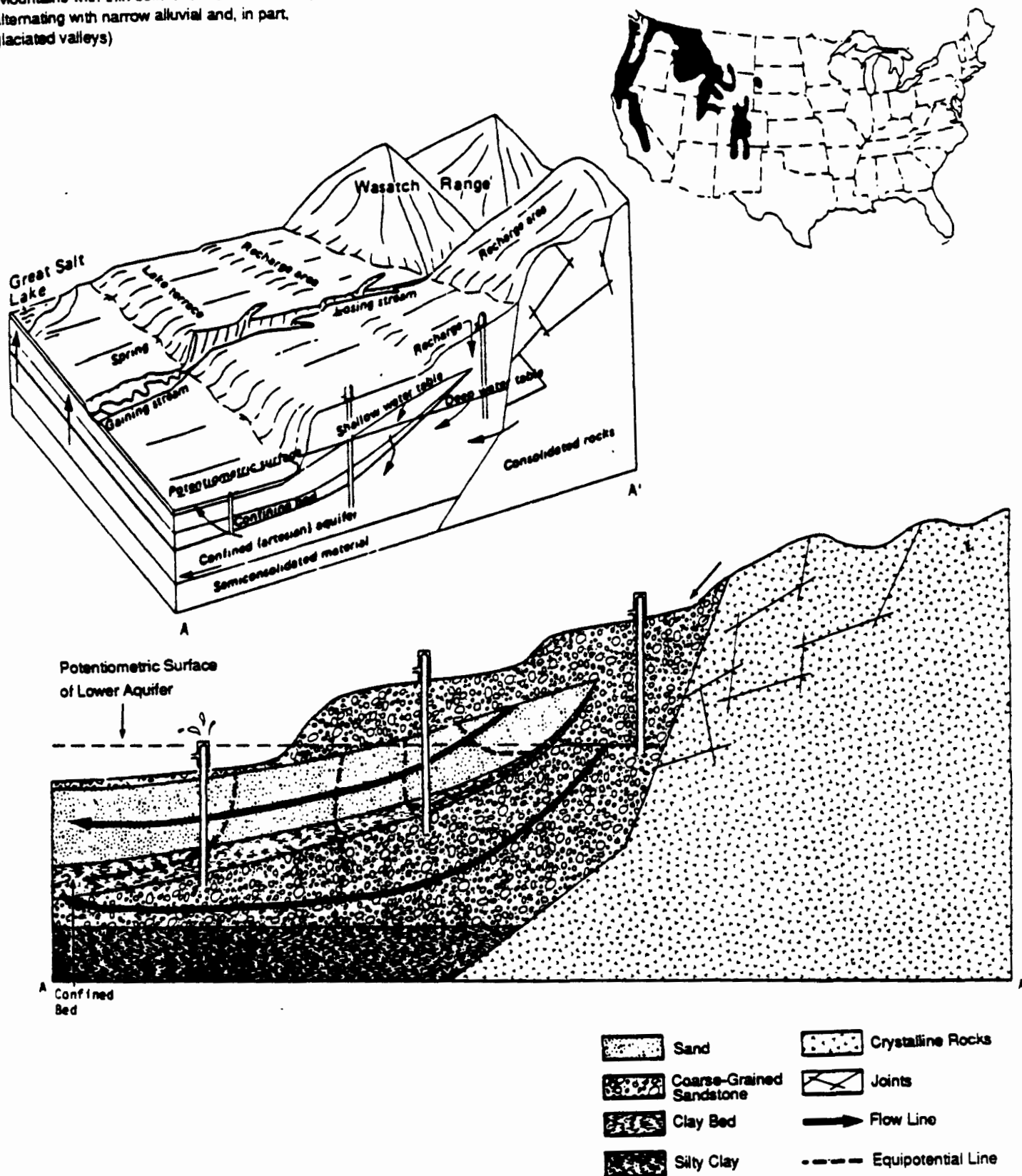
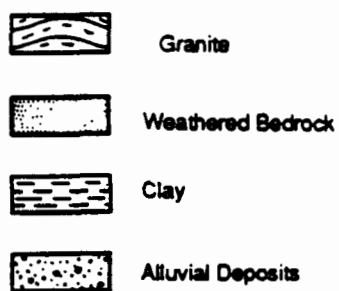
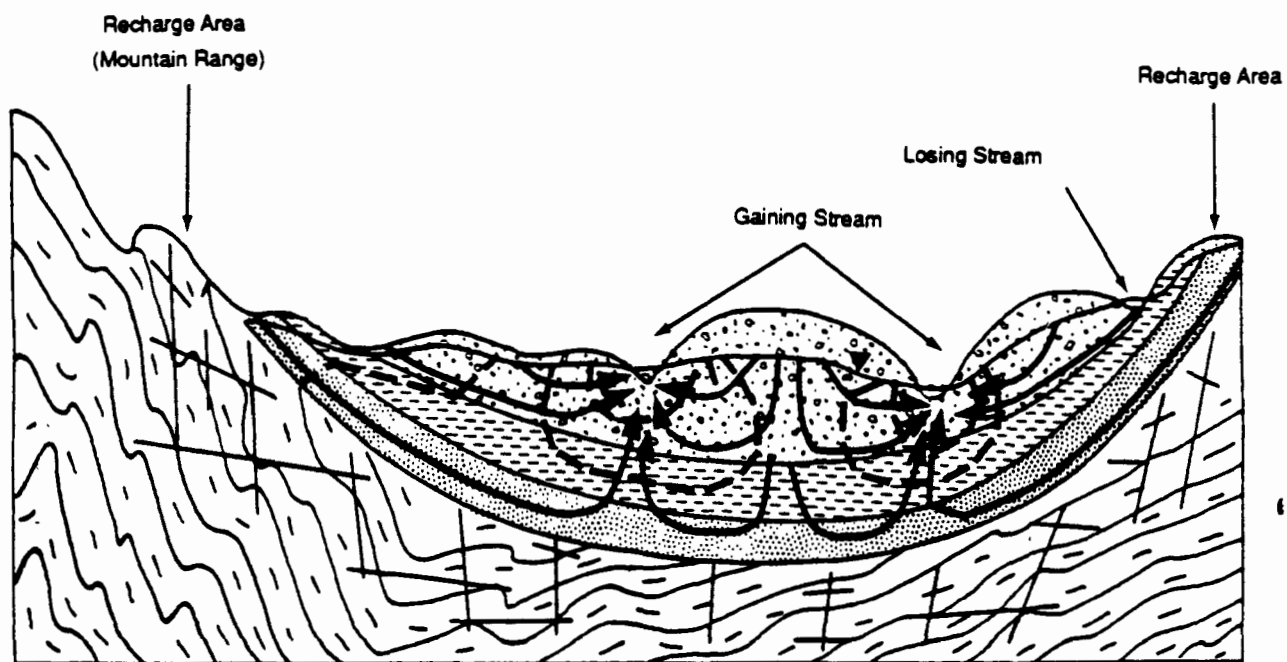


Figure 10-3. Western Mountain Ranges



**Figure 10-3. Western Mountain Ranges (continued)**

## ALLUVIAL BASINS

(Thick alluvial deposits in basins and valleys bordered by mountains)

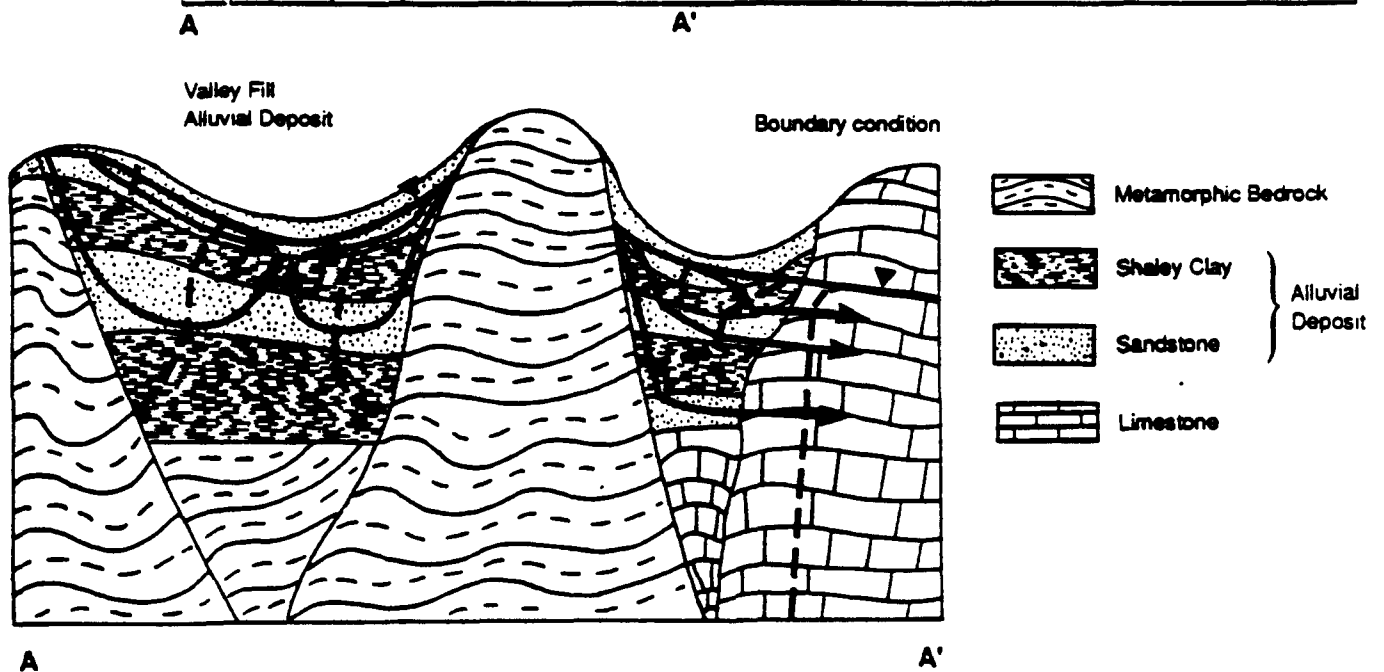
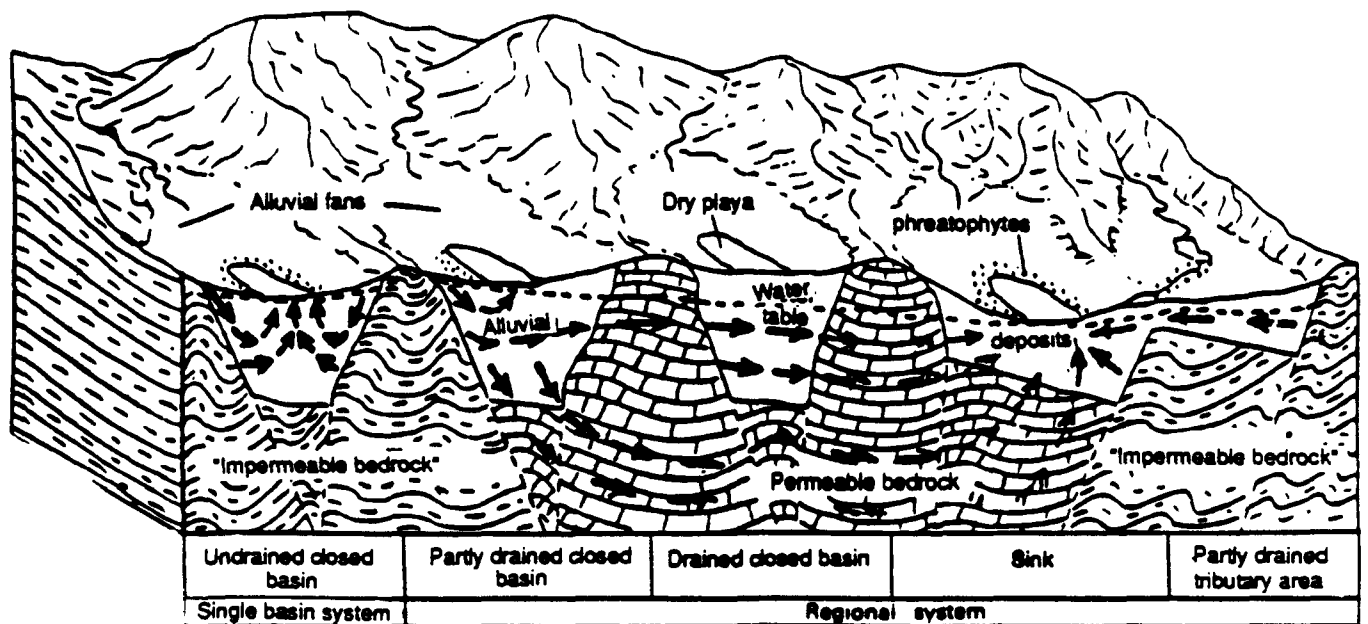
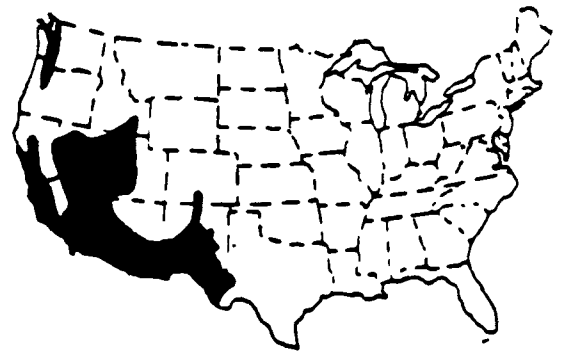
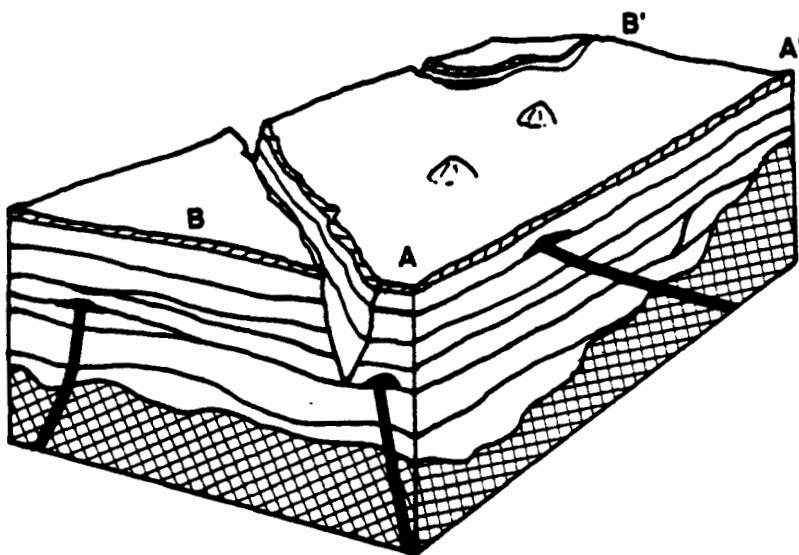







Figure 10-4. Alluvial Basins

## COLUMBIA LAVA PLATEAU

(Thick sequence of lava flows irregularly interbedded with thin unconsolidated deposits and overlain by thin soils)



-  Unconsolidated Holocene-Pliocene Sediments
-  Basalt
-  Laccolith-Basalt Dike
-  Interbedded Basalt and Sediments
-  Basement Rocks

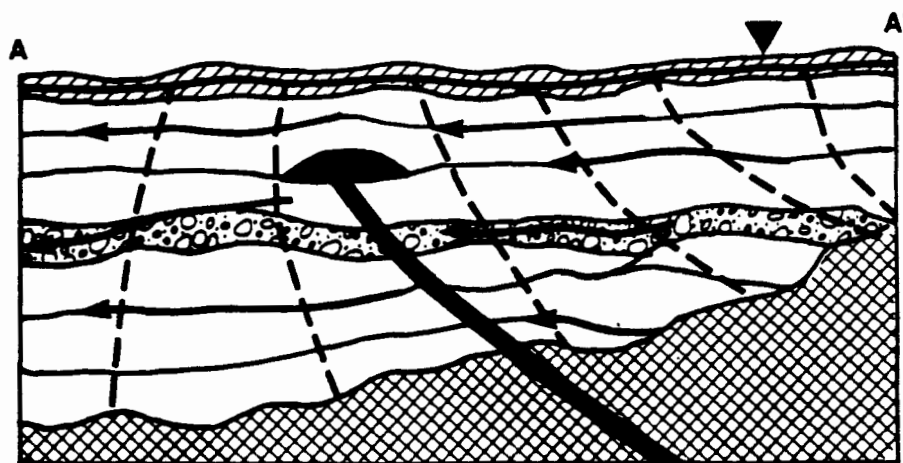
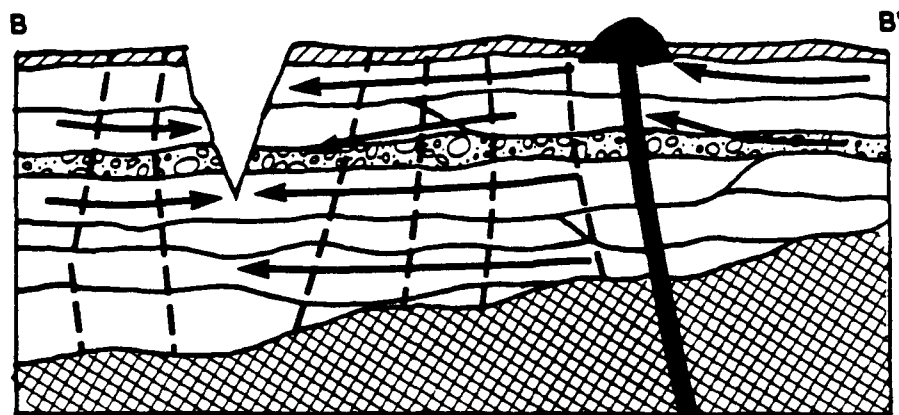


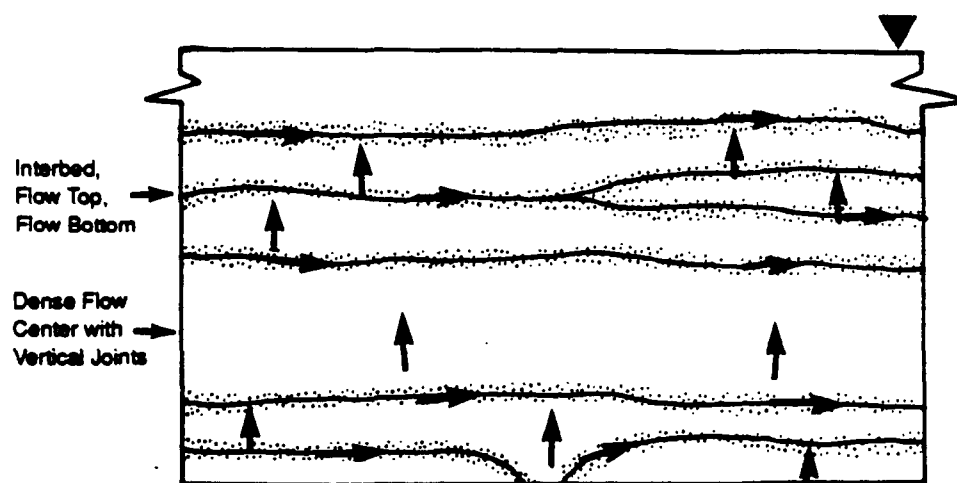
Figure 10-5. Columbia Lava Plateau





Schematic Diagram of  
Ground Water Flow Regime Through a Saturated Cross Section

Note: Assume hydraulic heads increase with depth.



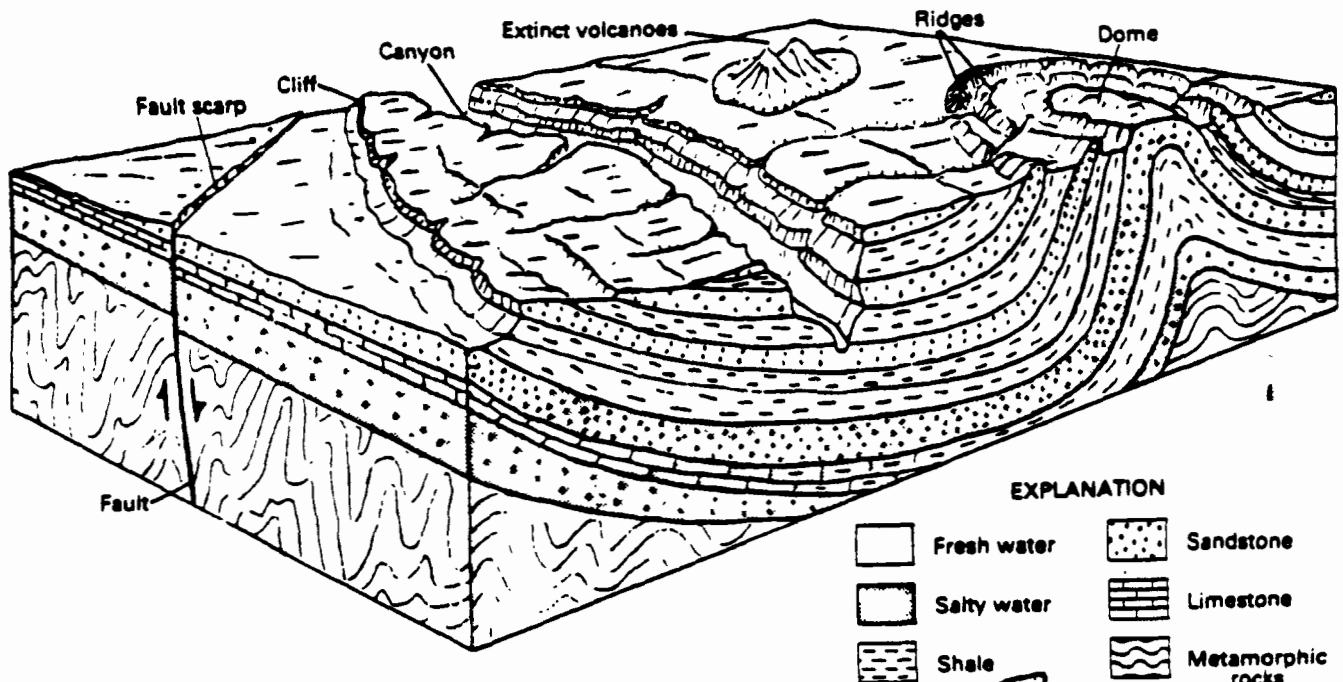
—High horizontal flow along flow tops

—Low vertical leakage through basalt interiors

Figure 10-5. Columbia Lava Plateau (continued)

## COLORADO PLATEAU AND WYOMING BASIN

(Thin soils over consolidated sedimentary rocks)



### EXPLANATION

	Fresh water		Sandstone
	Salty water		Limestone
	Shale		Metamorphic rocks
			Silt

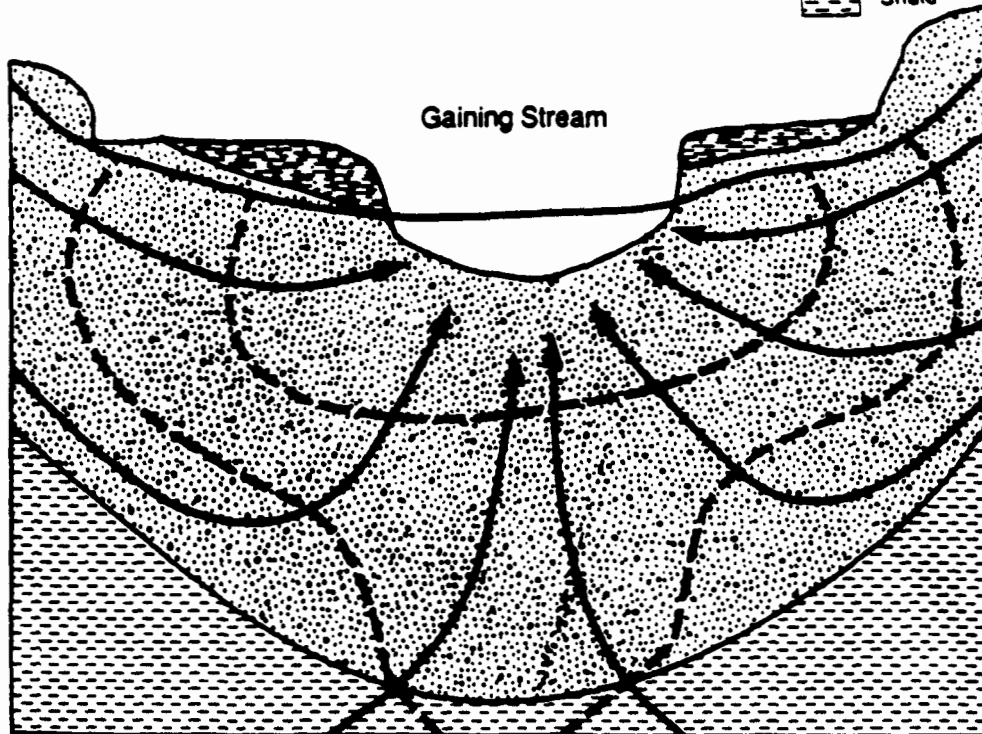
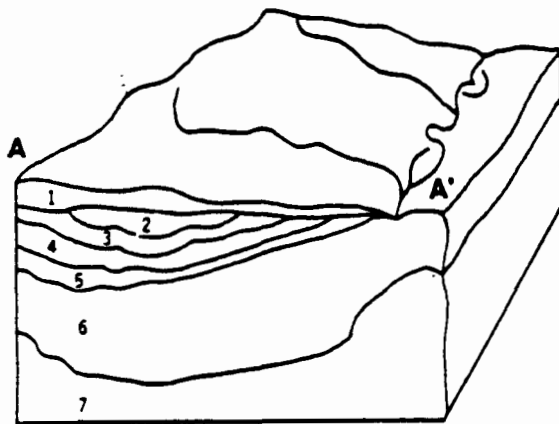


Figure 10-6. Colorado Plateau

## HIGH PLAINS

(Thick Alluvial deposits over fractured sedimentary rocks)



1. Paleovalley Alluvial Aquifers
2. High Plains Aquifer System
3. Niobrara Sandstone Aquifer
4. Pierre Shale Aquitard
5. Dakota Sandstone Aquifer
6. Undifferentiated Aquifers in Cretaceous Rocks
7. Undifferentiated Aquifers in Paleozoic Rocks

Generalized local ground water regime for site within the High Plains Region.



Figure 10-7. High Plains

Ground water flow in  
sandstone and clay lenses

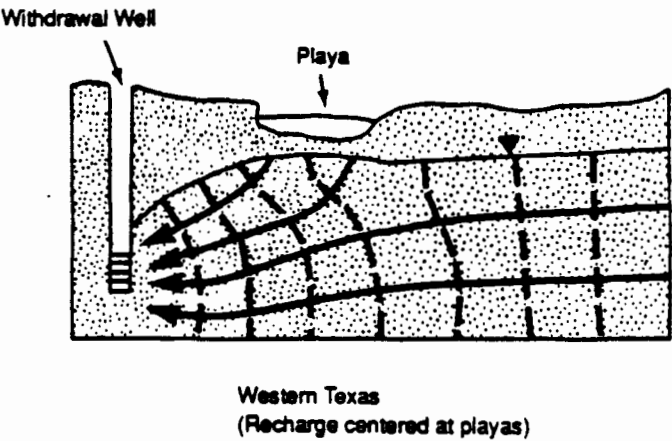
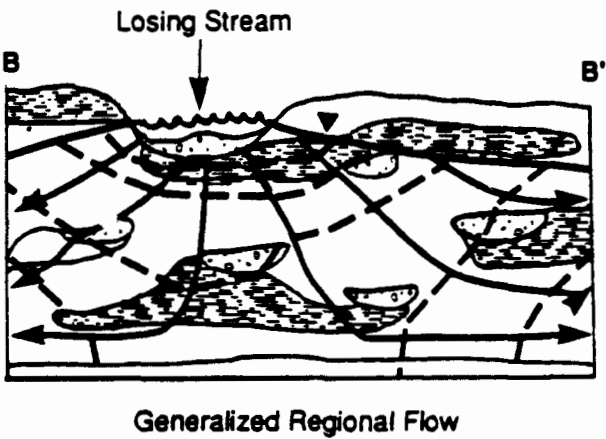
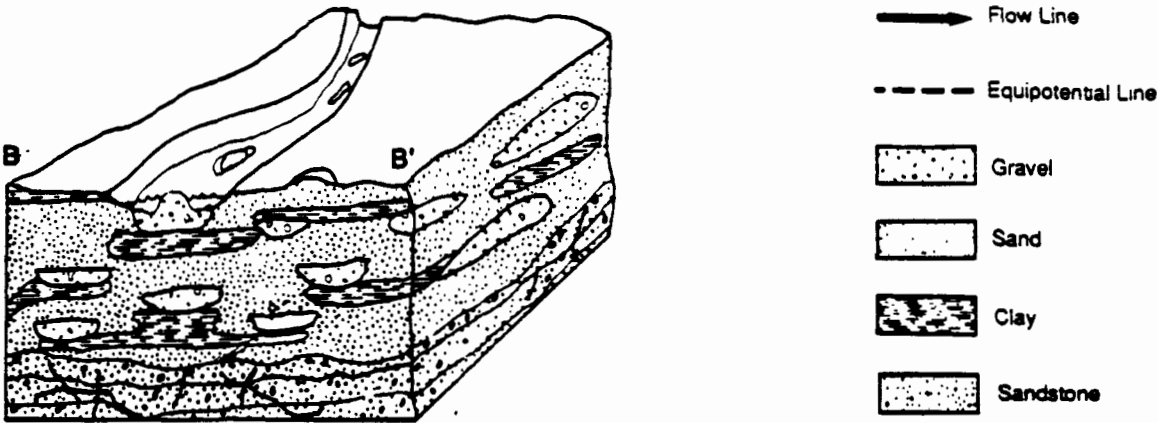


Figure 10-7. High Plains (continued)

NONGLACIATED CENTRAL REGION  
(Thin regolith over fractured sedimentary rocks)

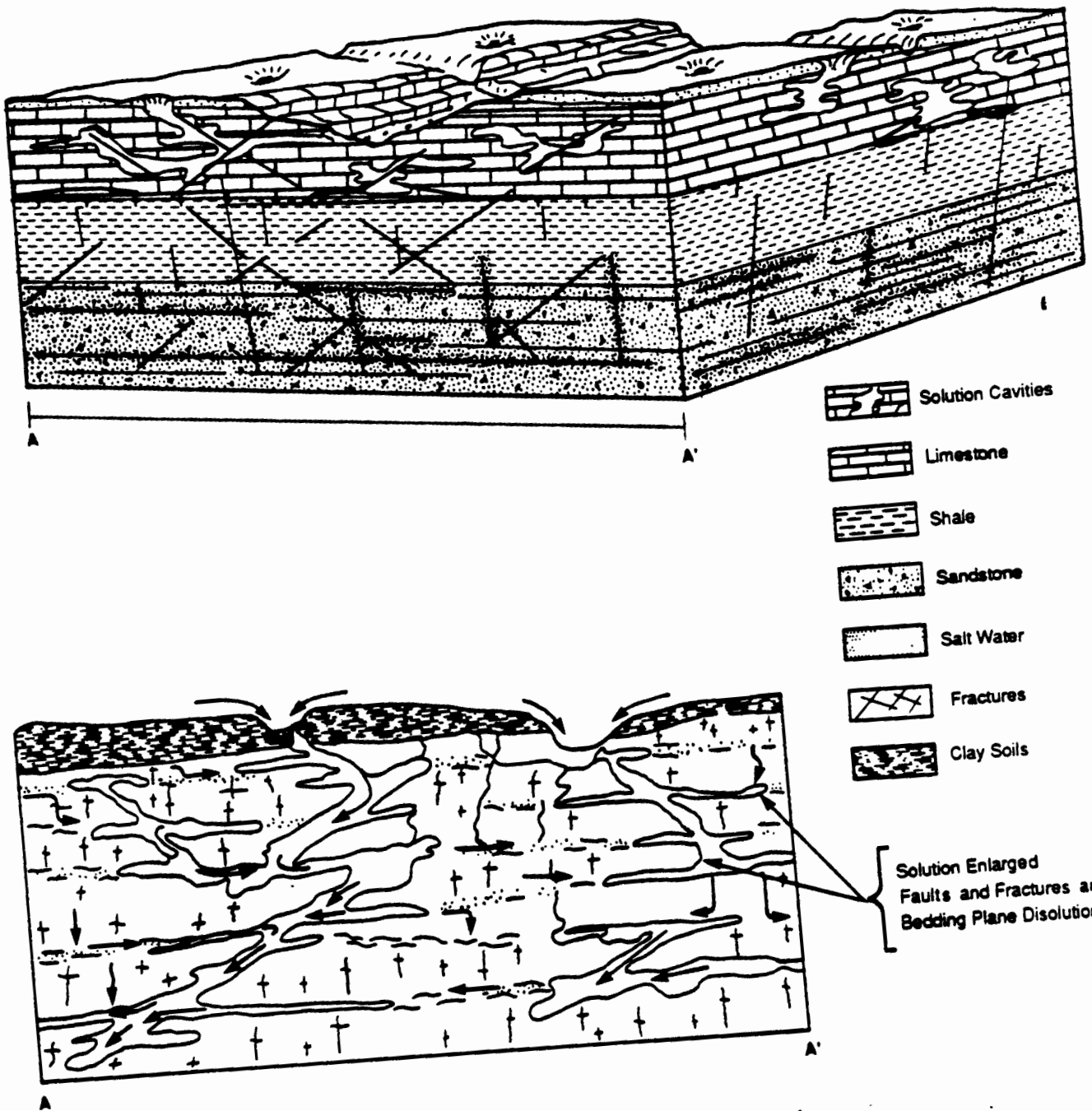
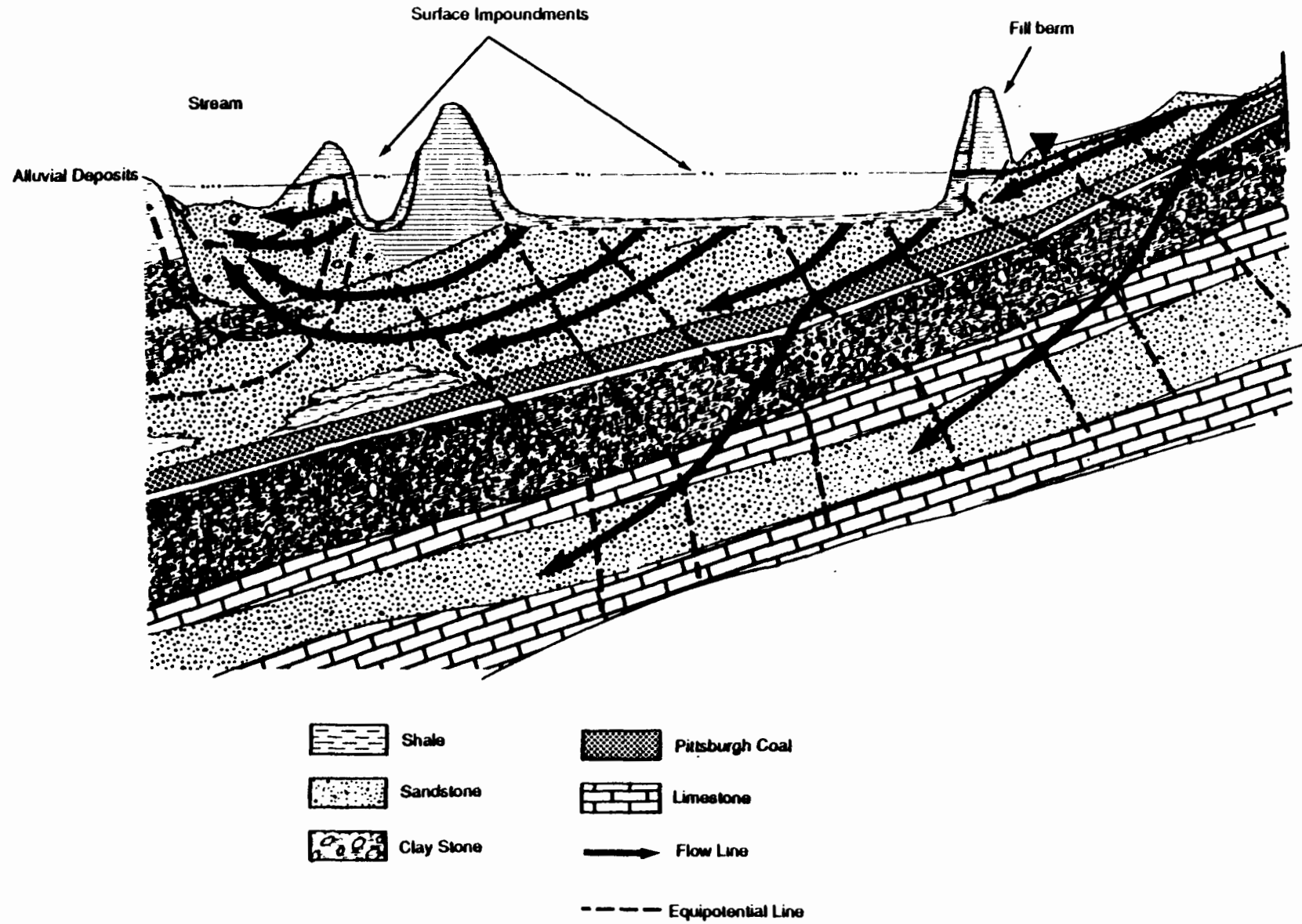
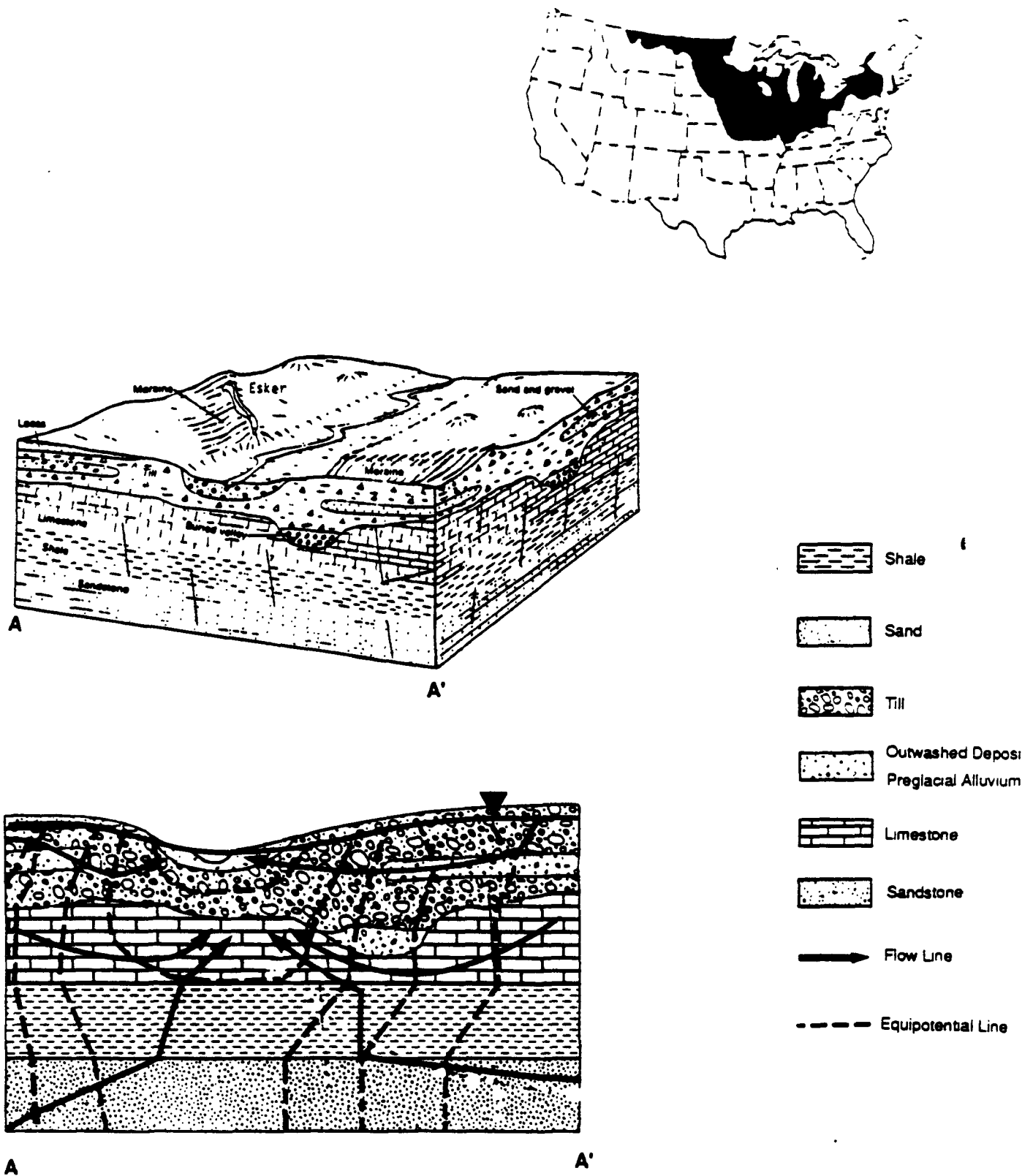


Figure 10-8. Non-glaciated Central



**Figure 10-8. Example of a surface impoundment site in Non-Glaciaded Central Region(continued)**

**GLACIATED CENTRAL REGION**  
(Glacial deposits over fractured sedimentary rocks)



**Figure 10-9. Glaciated Central**

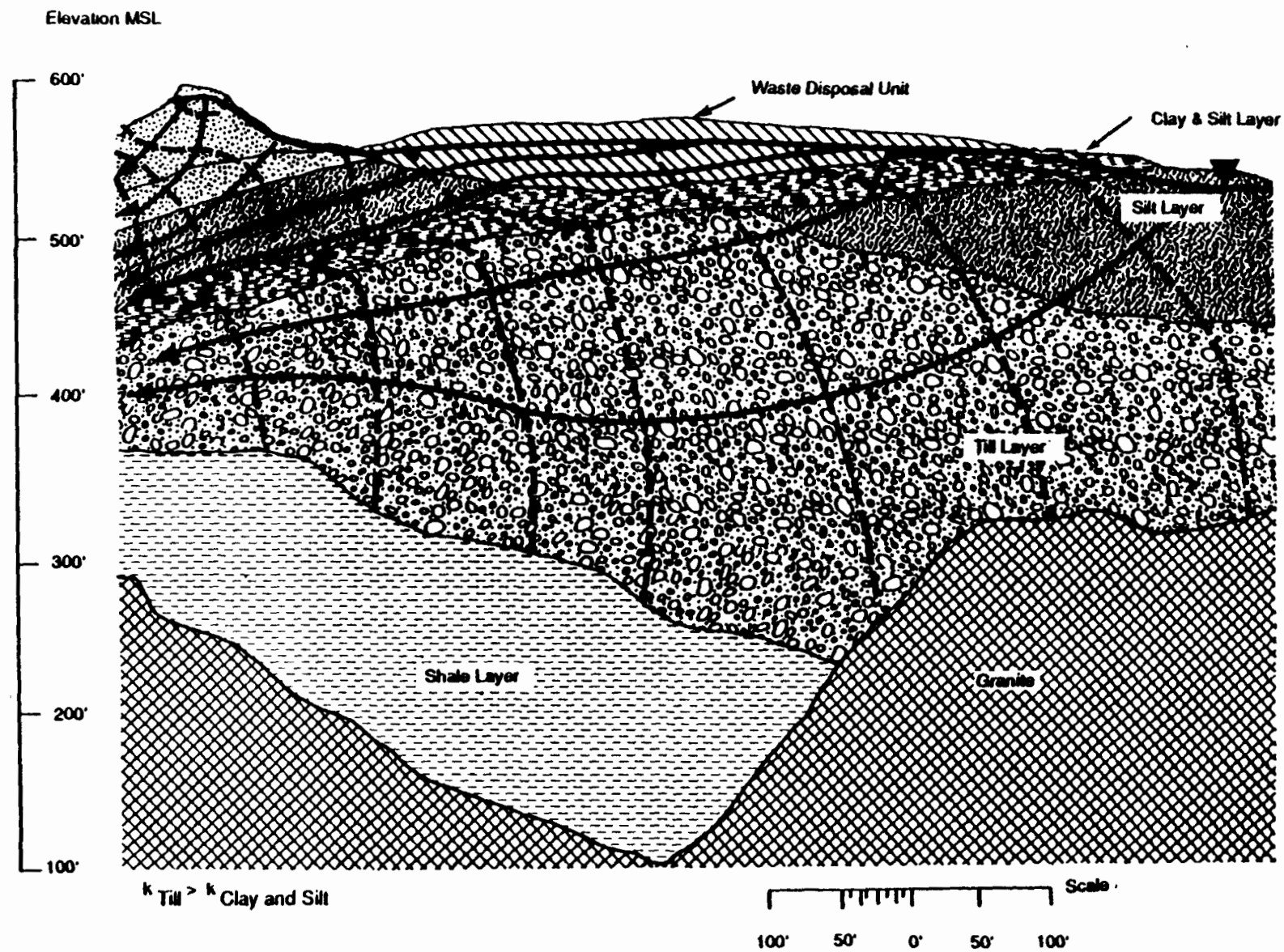


Figure 10-9. Glaciated Central (continued)



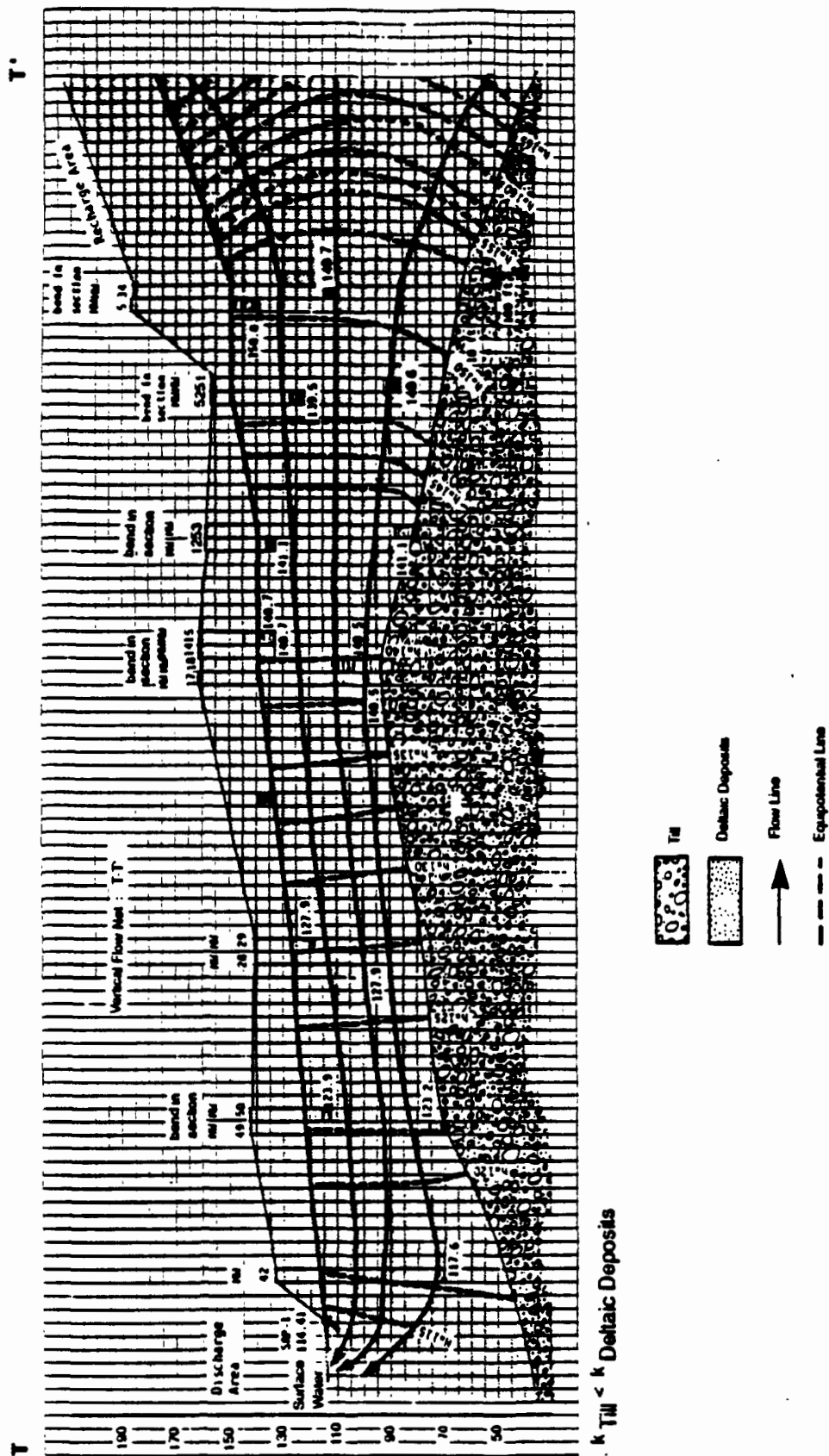
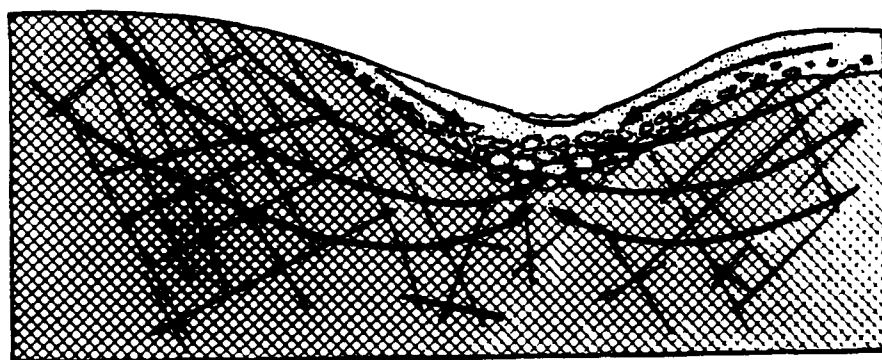
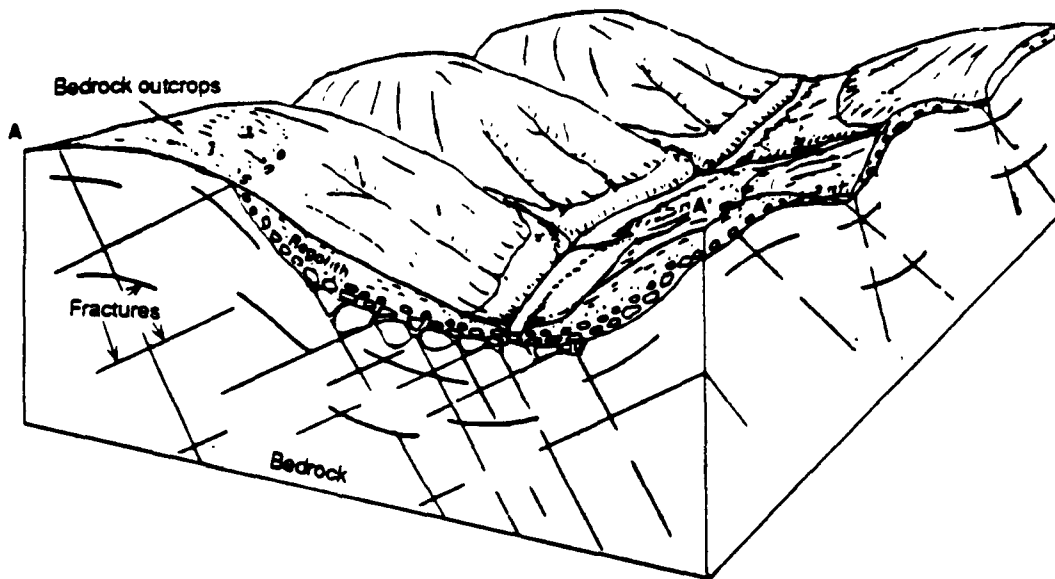
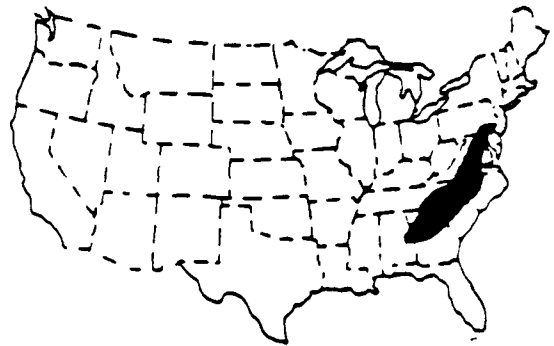





Figure 10-9. Glaciated Central (continued)

PIEDMONT BLUE RIDGE REGION  
(Thick regolith over fractured crystalline and metamorphosed sedimentary rocks)

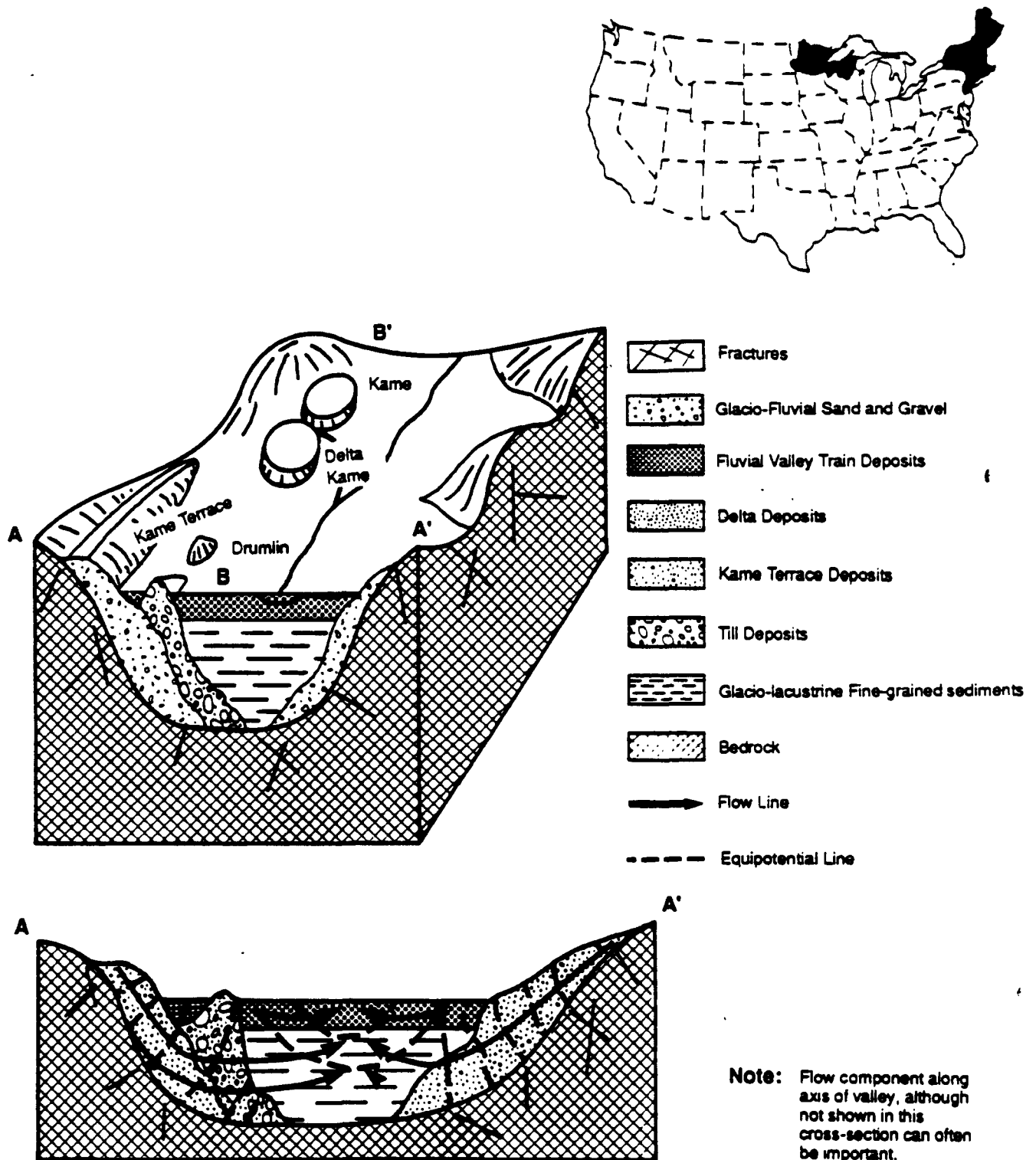


-  Fractures
-  Saprolite
-  Crystalline Bedrock

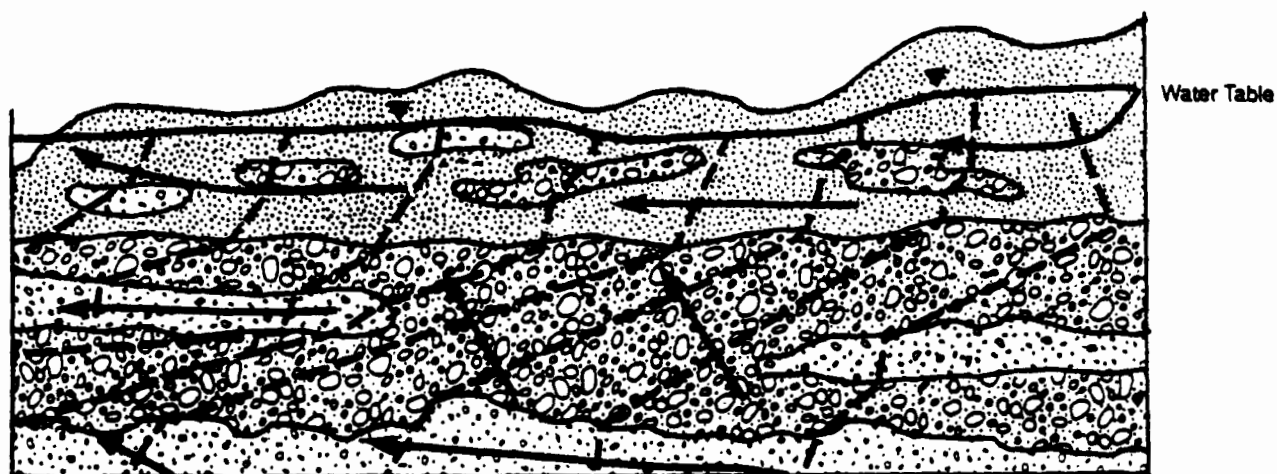
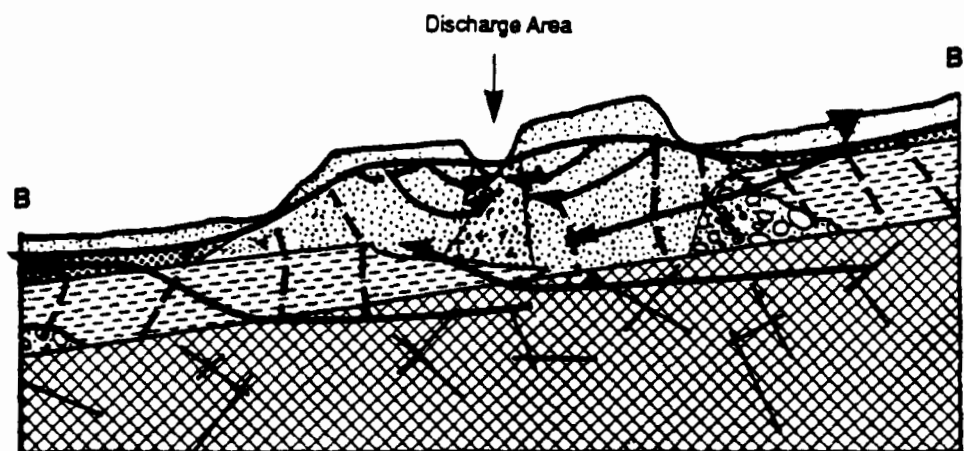
Note: In areas of fractured bedrock, flow through fractures is often greater than flow through the bedrock matrix. Flow through these fractures may not conform to Darcy's Law. The above flow lines represent generalized flow paths rather than quantitative flow lines used in a flow net.

Figure 10-10. Piedmont and Blue Ridge

**NORTHEAST AND SUPERIOR UPLANDS**  
(Glacial Deposits Over Fractured  
Crystalline rocks)



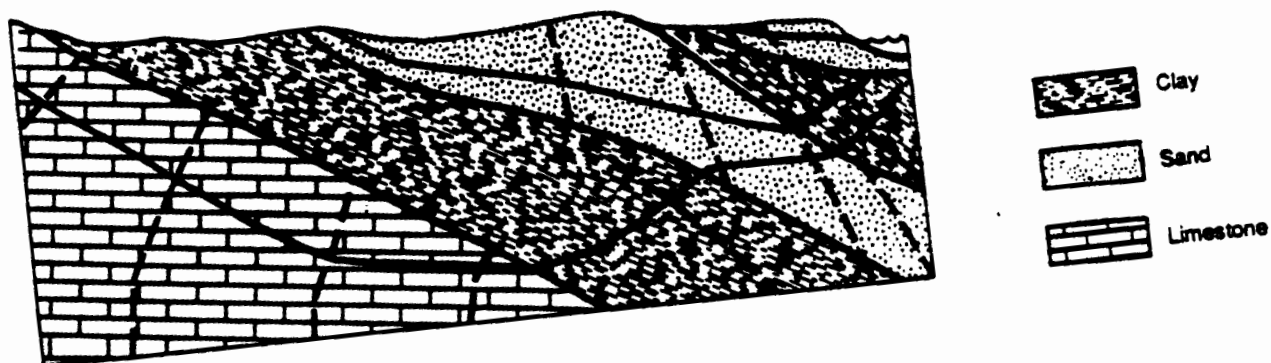
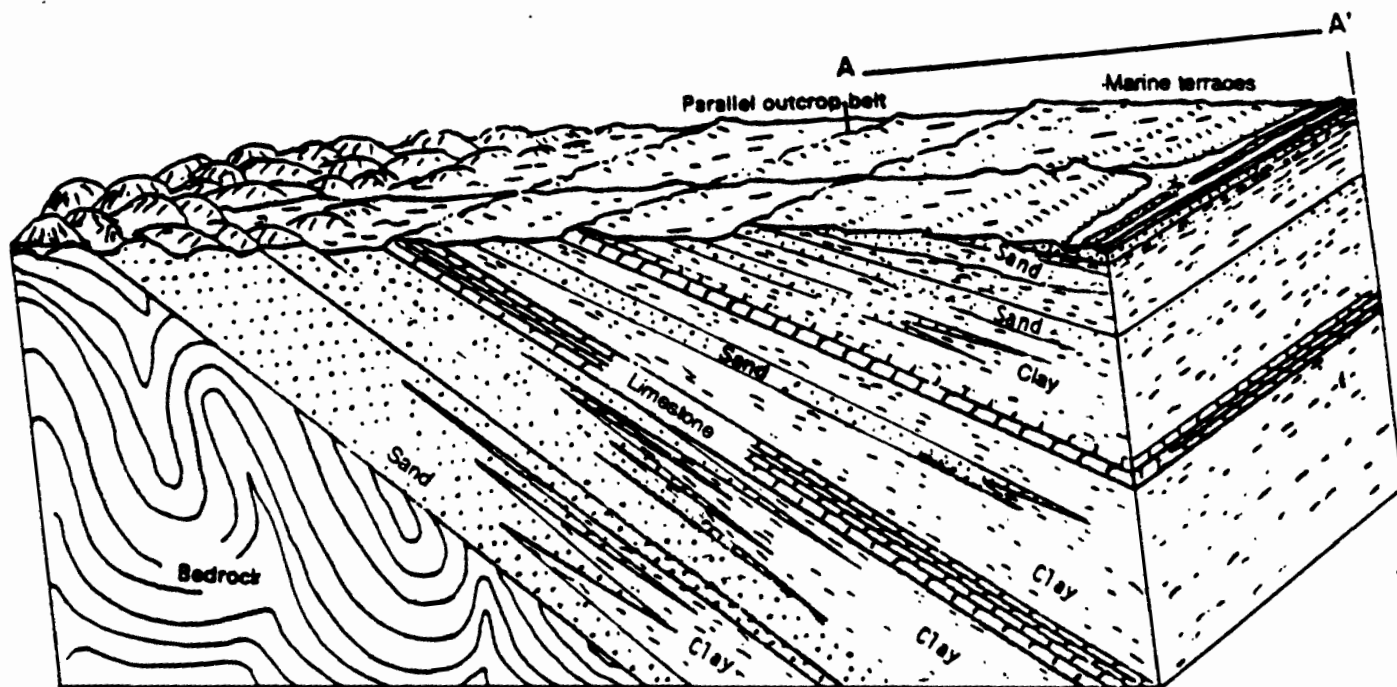
**Figure 10-11. Northeast and Superior Uplands**



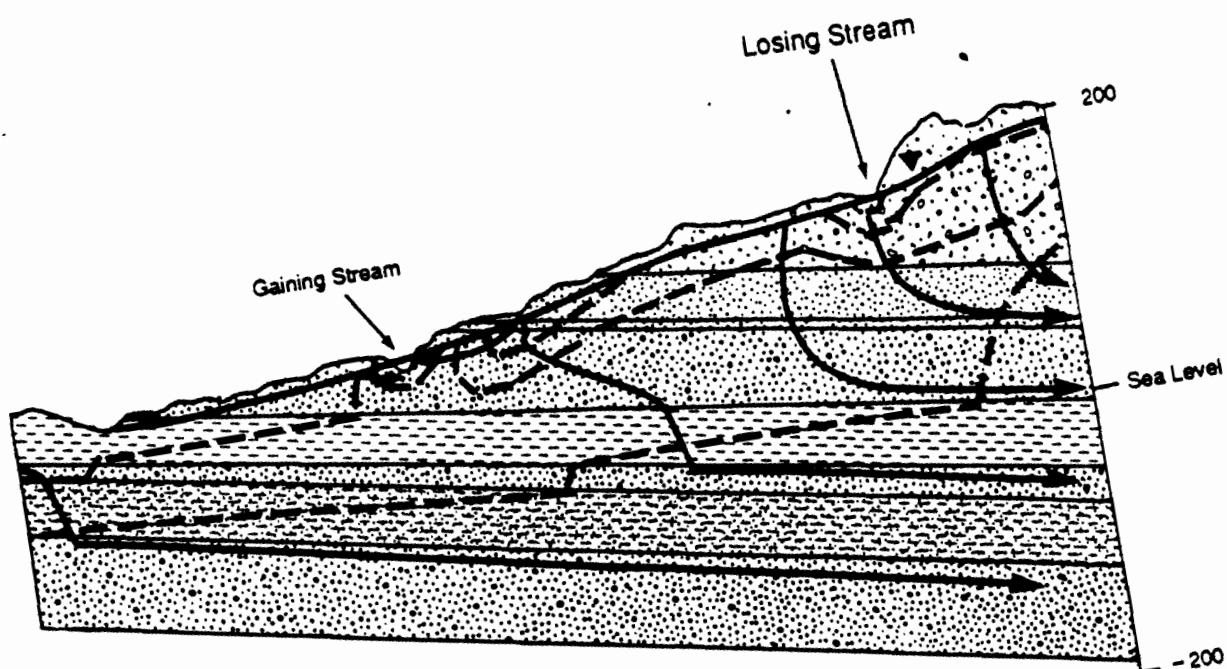
Generalized local ground water regime within the Northeast and Superior Uplands Region showing a confining layer of till.






Figure 10-11. Northeast and Superior Uplands (continued)

**ATLANTIC AND GULF COASTAL PLAIN**  
(Complexly interbedded sand, silt, and clay)



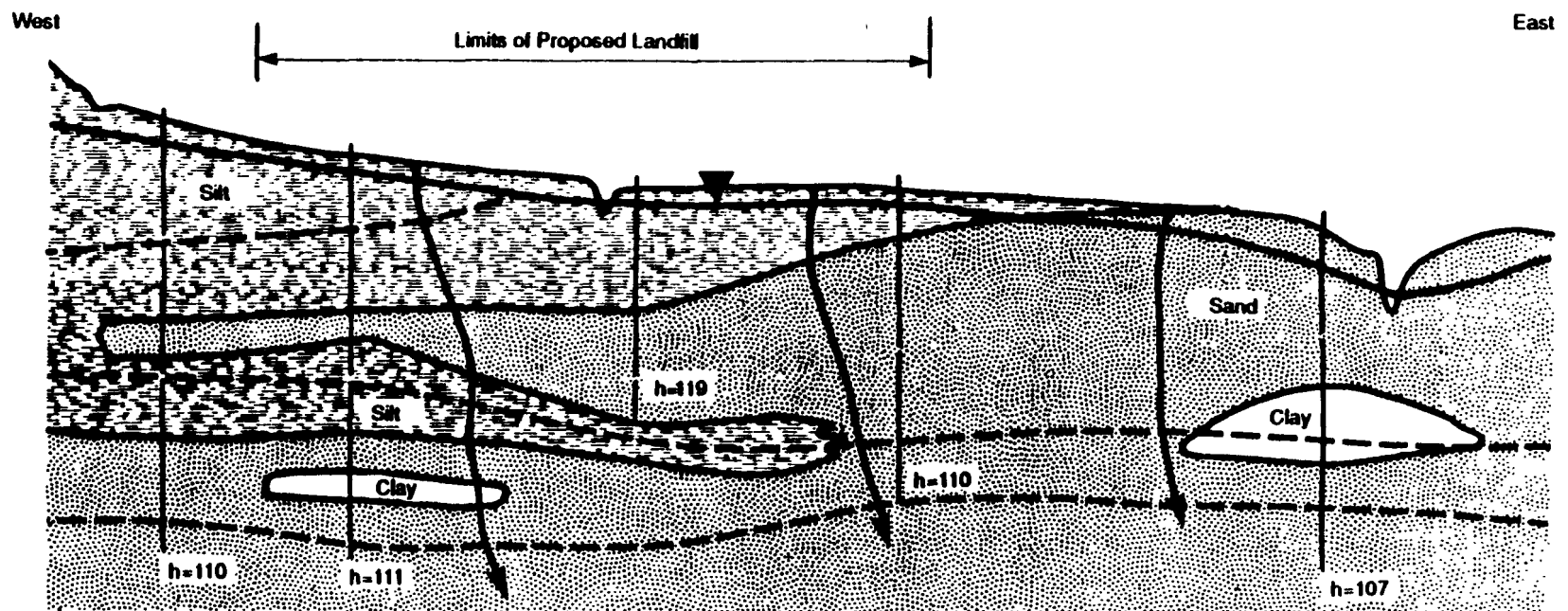
**Figure 10-12. Atlantic and Gulf Coastal Plain**



-  Alluvial Deposits
-  Sand
-  Sandstone
-  Shale
-  Sandy Shale

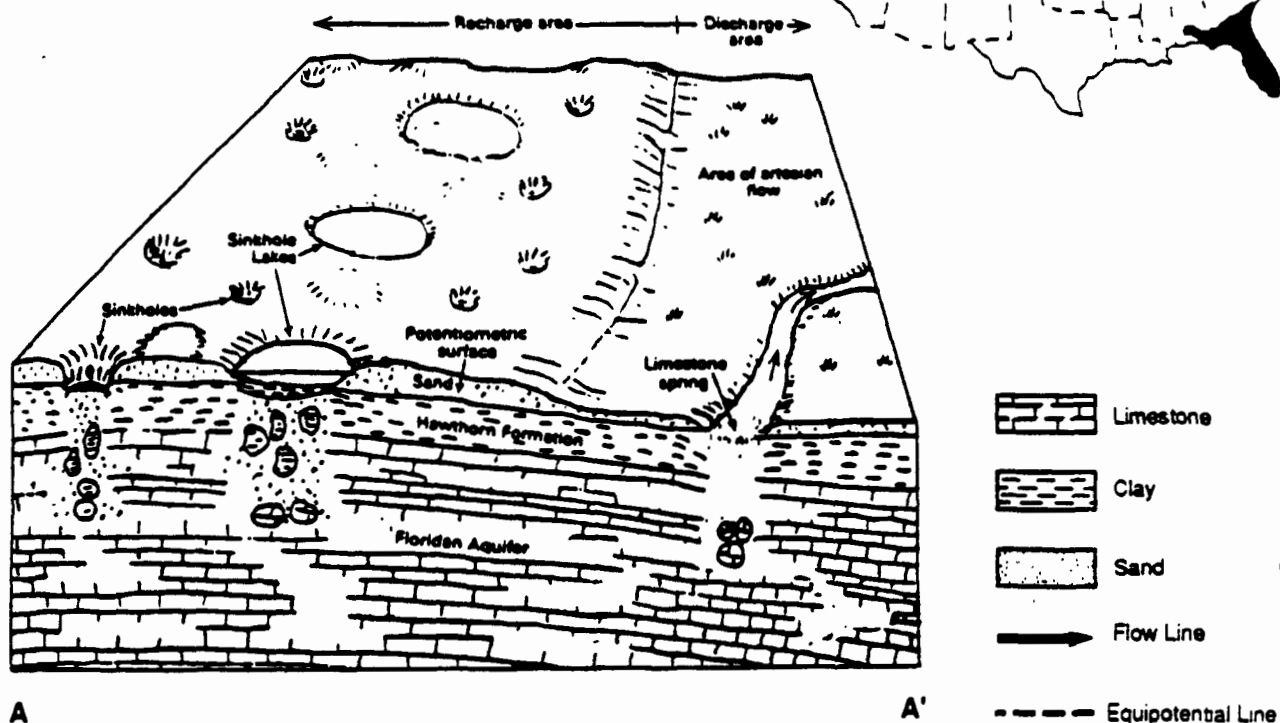
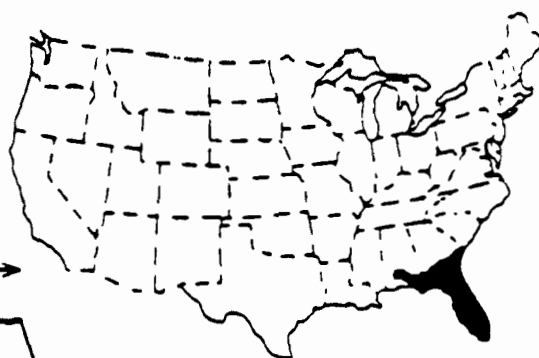
Note: Regional flow based on high recharge in hills which are not shown in this diagram.

Figure 10-12. Atlantic and Gulf Coastal Plain (continued)



# SOUTHEAST COASTAL PLAIN

(Thick layers of sand and clay over semiconsolidated carbonate rocks)



## Solution Limestone

Cross-section with highly generalized flow path lines and equipotential lines. Actual condition in Karst terrain may not be definable due to fractures and solution channel flow.

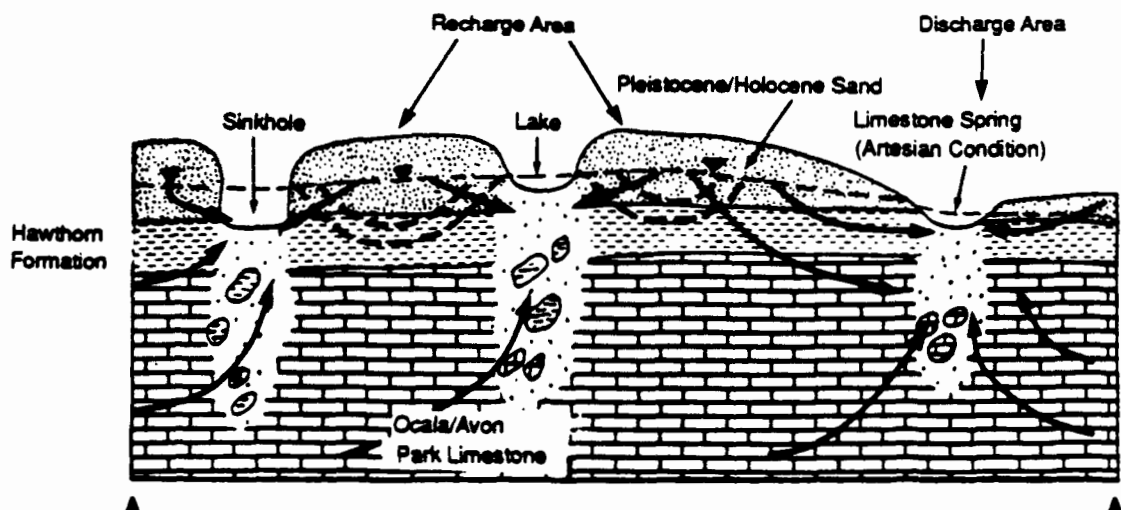
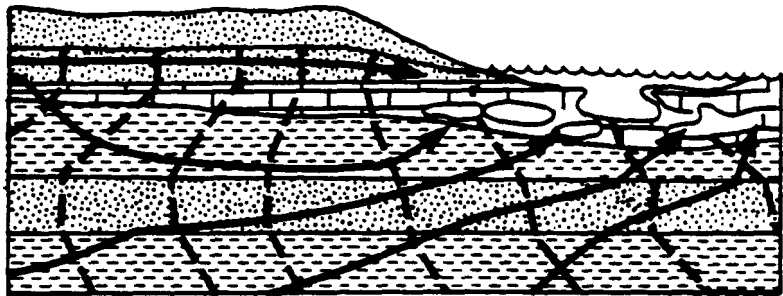


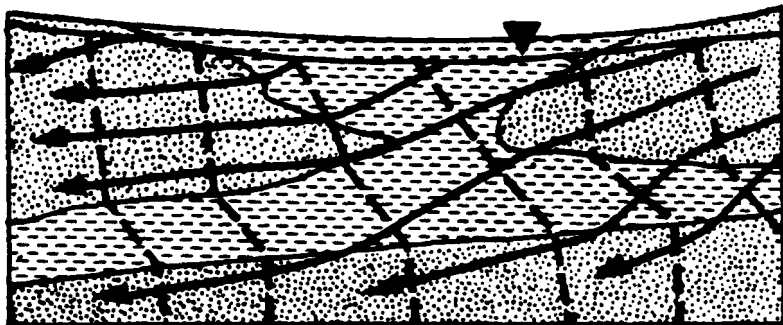
Figure 10-13. Southeast Coastal Plain



**Swamp**



**Beaches and Bars**



- Highly permeable due to water-washed sands.
- Sand deposits serve as a source of recharge to the underlying unconsolidated coastal deposits.

**Figure 10-13. Southeast Coastal Plain (continued)**

## HAWAIIAN ISLANDS

(Lava flows segmented in part by dikes, interbedded with ash deposits, and partly overlain by alluvium)

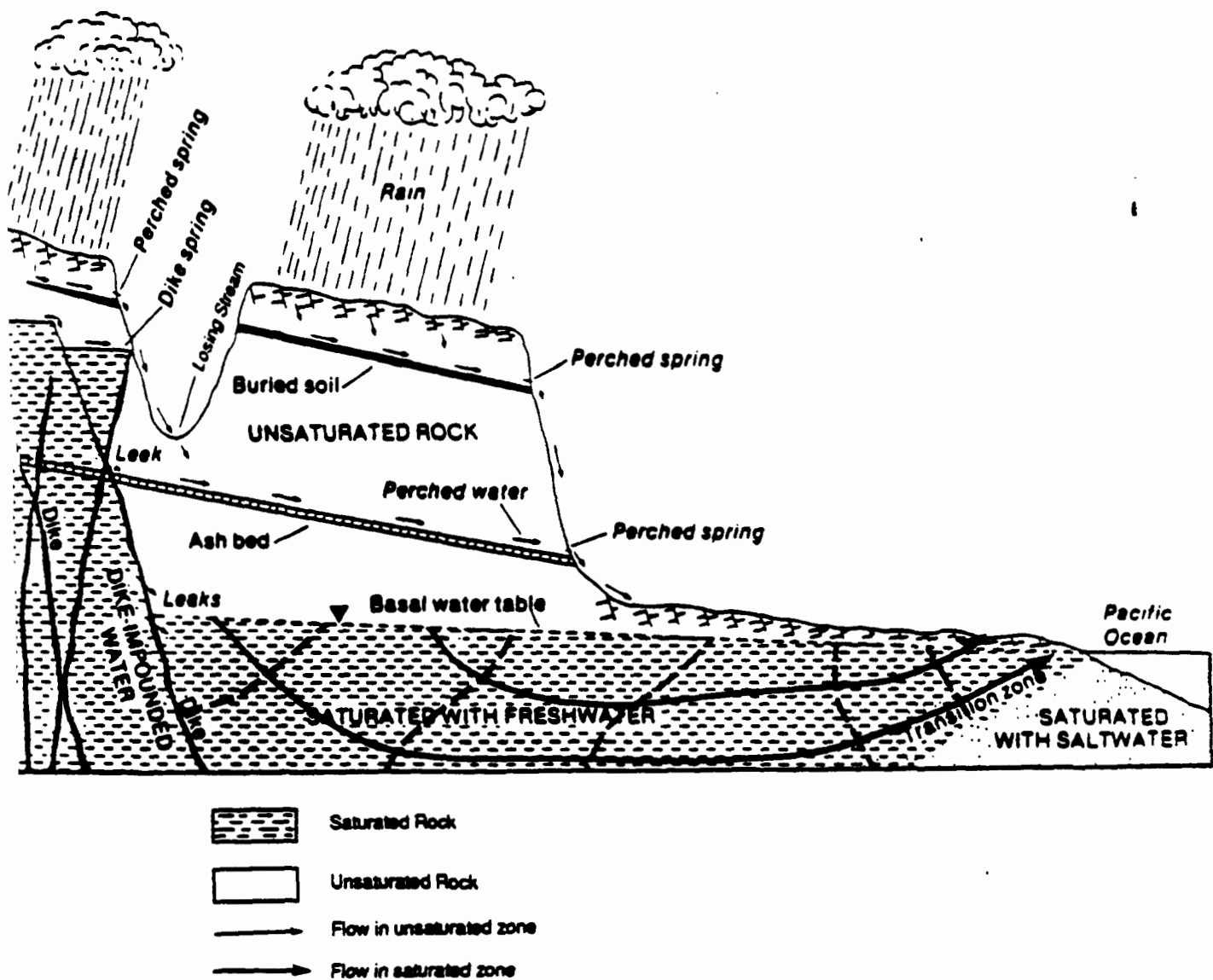
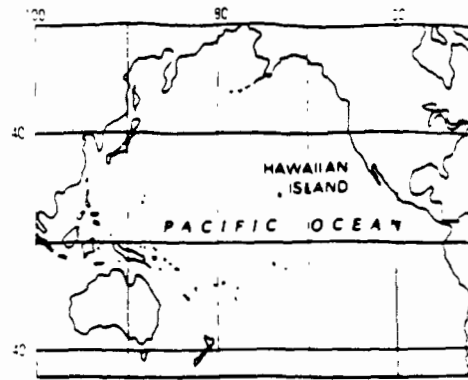
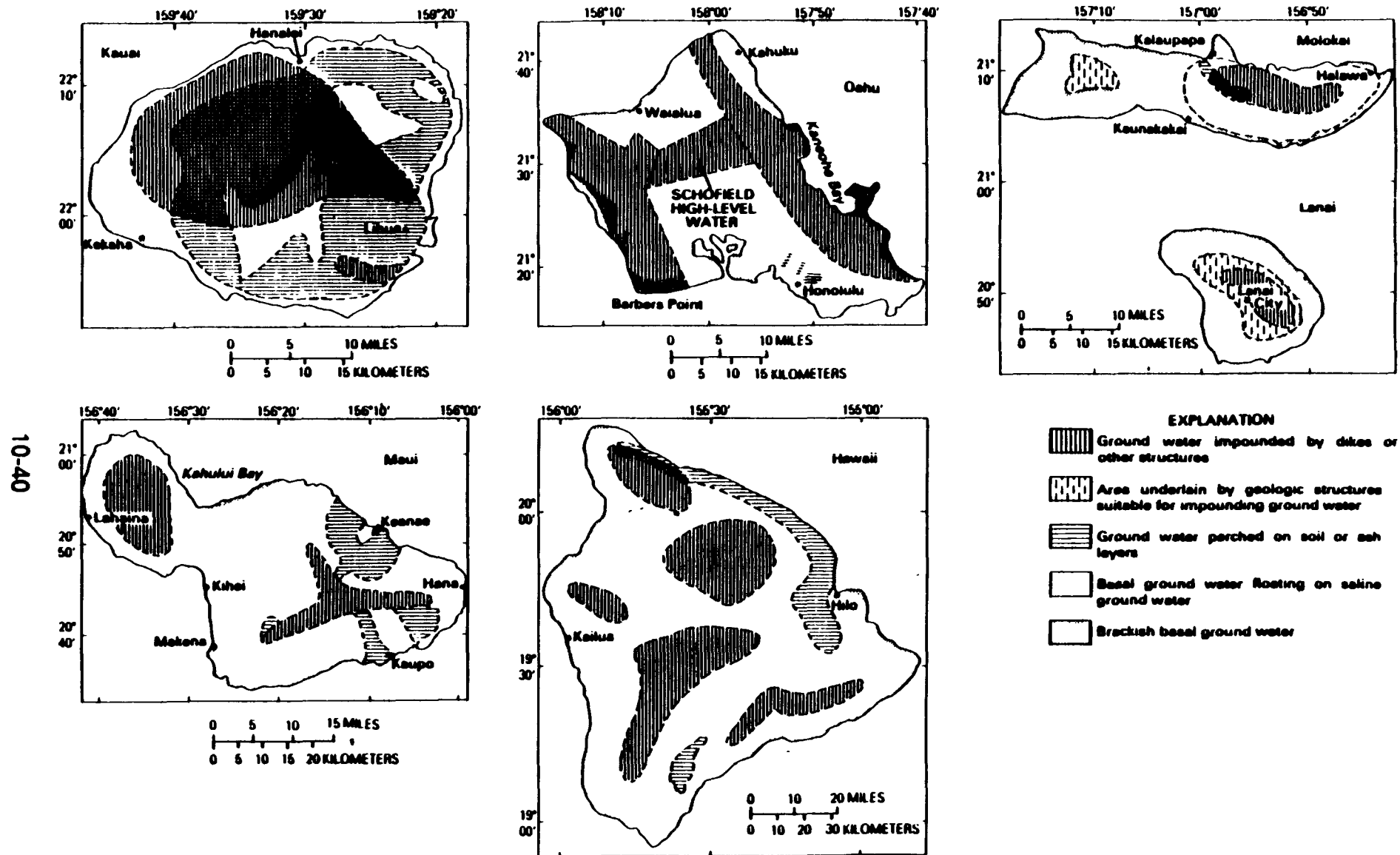


Figure 10-14. Hawaiian Islands



Approximate outline of the different ground-water areas on the principal Hawaiian islands (From Takasaki, 1977)

Figure 10-14. Hawaiian Islands (Continued)

## ALASKA

(Glacial and Alluvial Deposits, Occupied in Part by Permafrost, and Overlying Crystalline, Metamorphic, and Sedimentary Rocks)

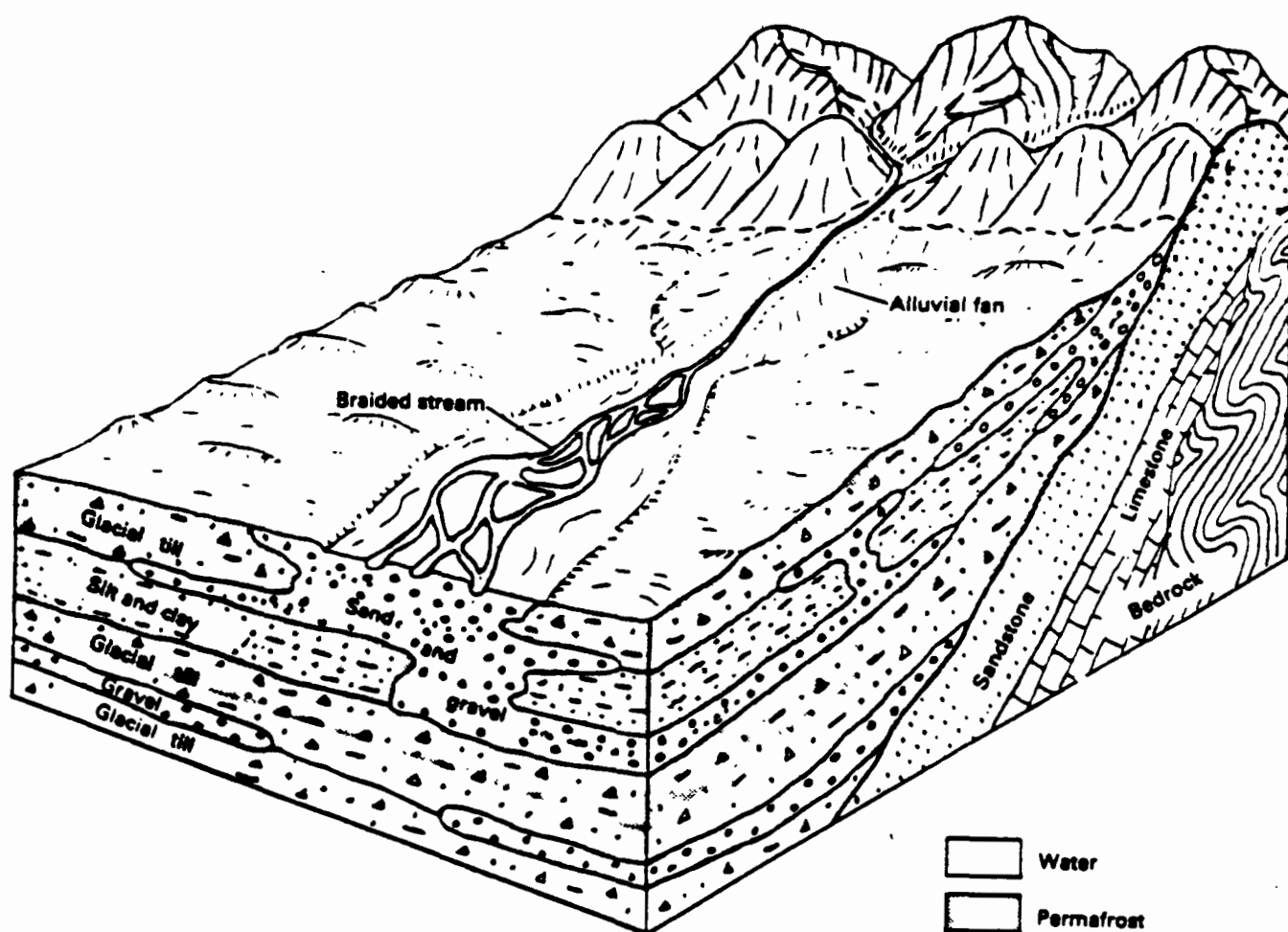


Figure 10-15. Alaska

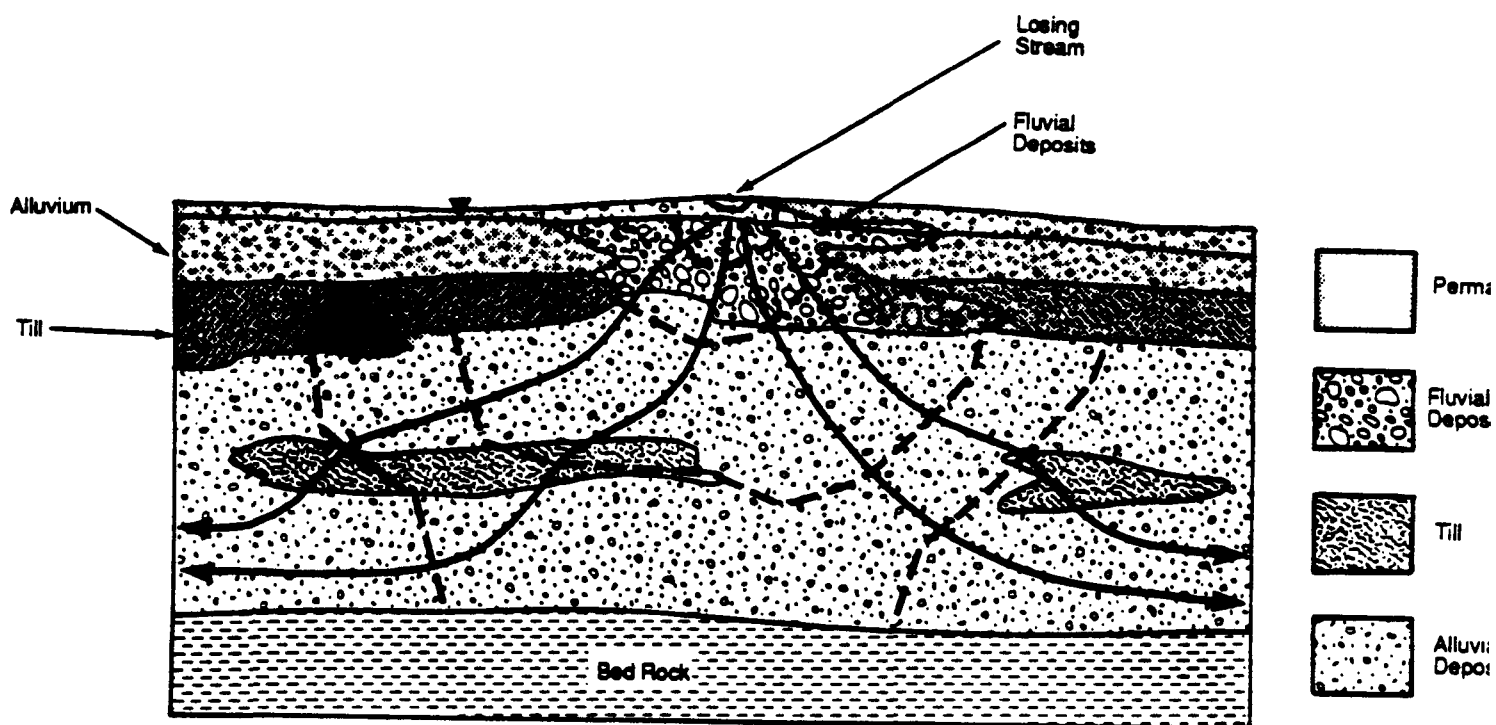
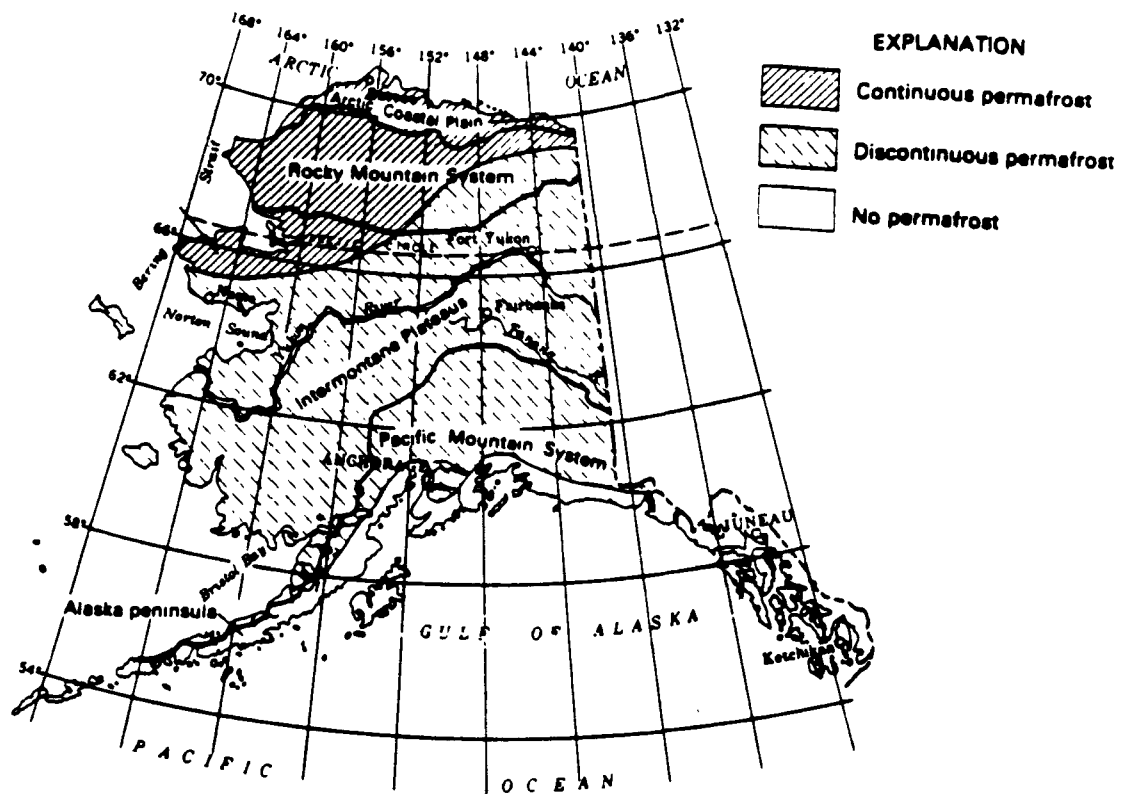


Figure 10-15. Alaska (Continued)

ALLUVIAL VALLEYS  
 (thick sand and gravel deposits beneath floodplains and terraces  
 (streams))

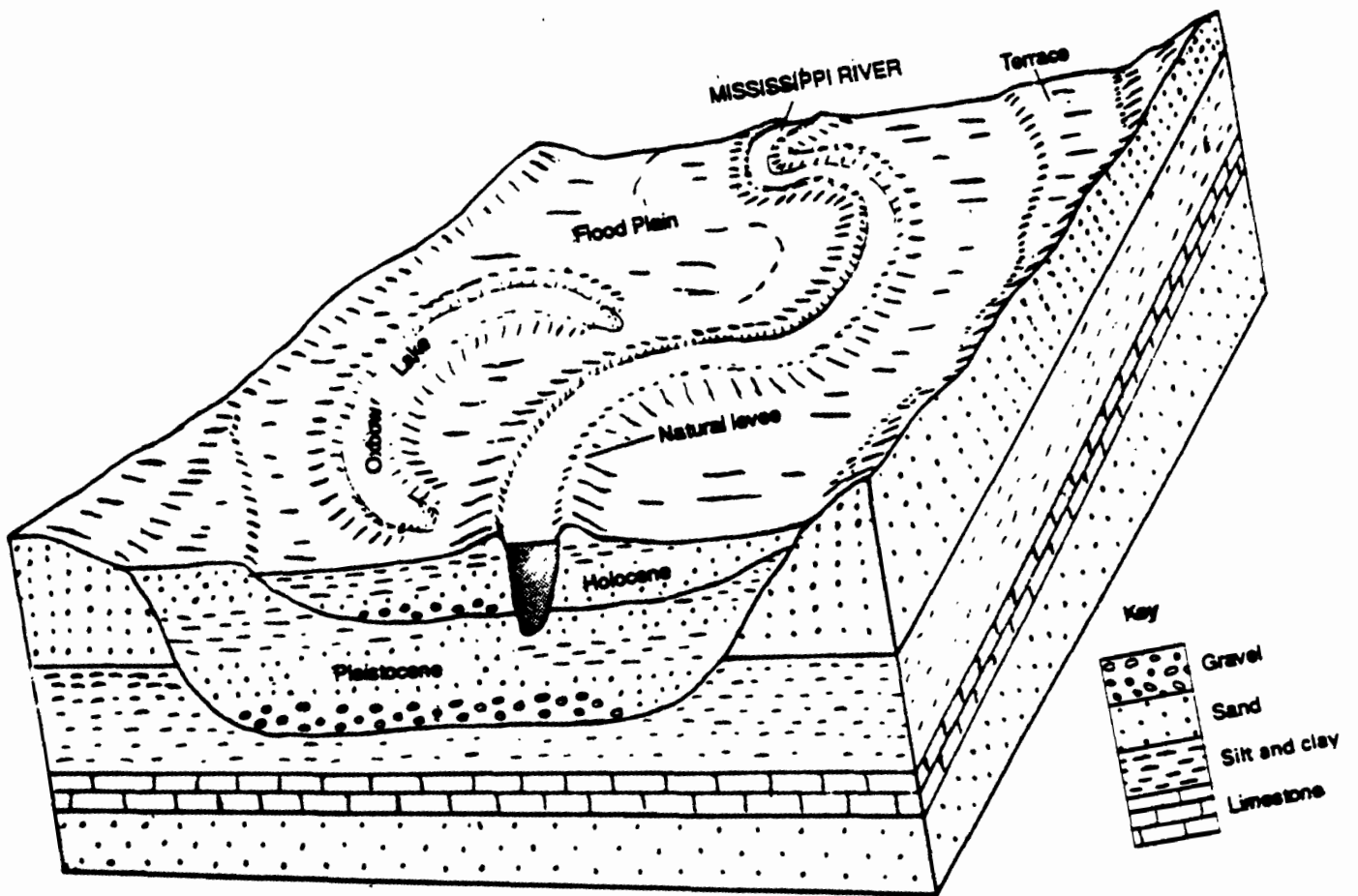
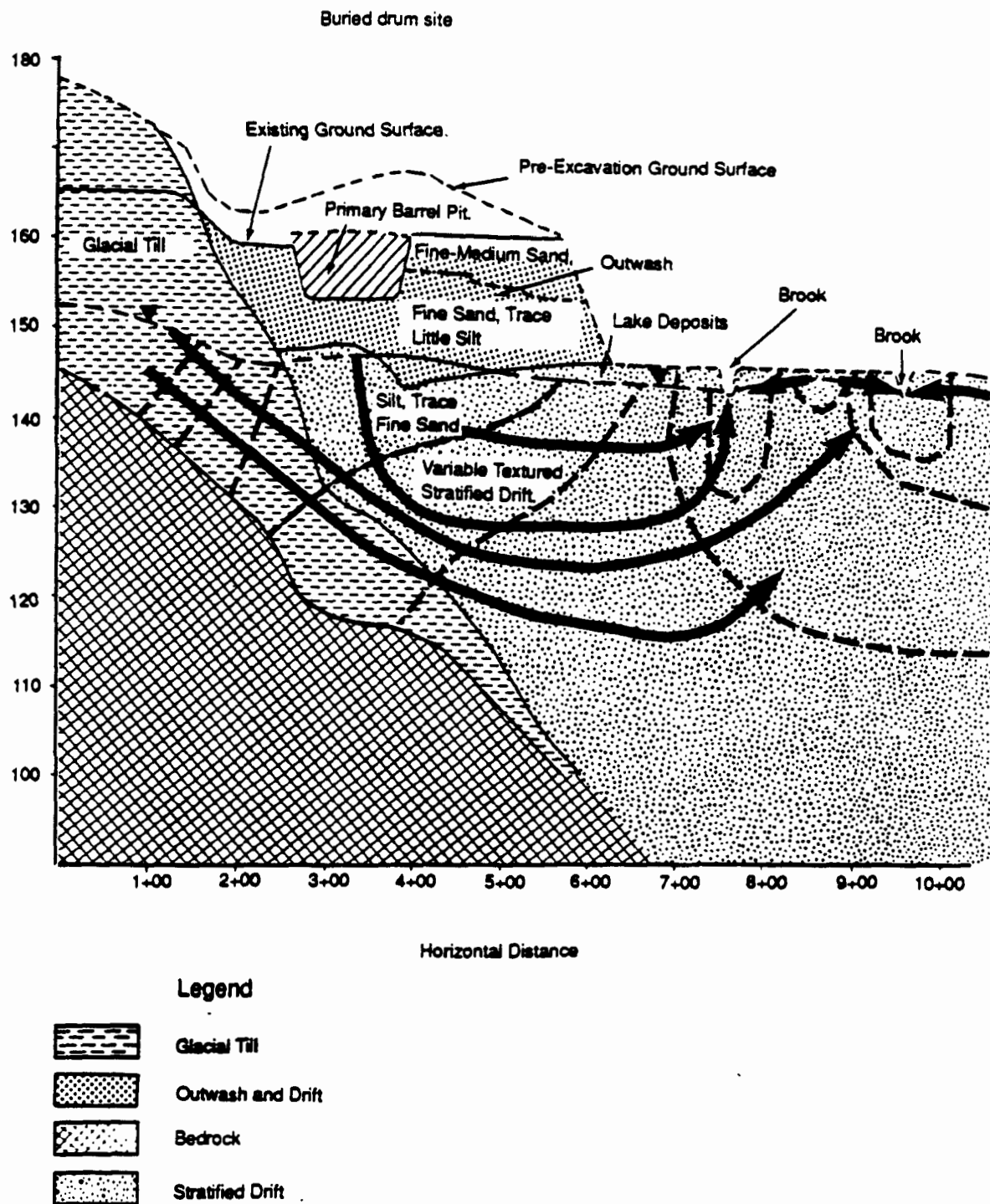


Figure 10-16. Alluvial Valleys



**Figure 10-16. Alluvial Valleys (continued)**

Paper No. 2242). Following are descriptions of each of the major ground-water regions illustrated in the Figures (Figures 10-3 through 10-16).

Ground-water flow in the Western Mountain Ranges region is influenced by melting snow and rainfall at higher altitudes. The thin soils and fractures present in the underlying bedrock have a limited storage capacity and are filled quickly with recharging ground water flowing from higher elevations (see Figure 10-3). The remaining surface water runs overland to streams that eventually may recharge other areas. Streams that recharge ground water are referred to as "losing streams." Figure 10-3 also shows local ground-water flow paths influenced by low permeability bedrock located in intermountain valleys throughout the mountain ranges.

The Alluvial Basins region consists of deep, unconsolidated sediments adjacent to mountain ranges. Precipitation often runs rapidly off the mountains and infiltrates into the alluvium at the valley margins. The water moves through the sand and gravel layers toward the centers of the basins (Figure 10-4). The presence of disjointed masses of bedrock in this region is crucial to the hydrogeological regime. Low permeability igneous bedrock often isolates the ground-water regime into individual basins with minimal exchange of ground water. Where the bedrock is composed of limestone or other highly permeable formations, large regional flow systems can develop, encompassing many basins. Recharge areas in this region are located in upland areas; lowland stream beds only carry water when sufficient runoff from the adjoining mountains occurs.

Basaltic bedrock is the major source of ground water within the Columbia Lava Plateau region. Volcanic bedrock yields water mainly from zones at the contacts of separate basalt flows. The permeability and hydraulic conductivity are much higher in these zones at the edges of the flows than in the center of the flows (see Figure 10-5.) This is caused partially by the rapid cooling and consequent fracturing of the top of each basalt flow.

The Colorado Plateau and Wyoming Basin region is a large plateau consisting principally of sandstones, shales, and limestones. These sedimentary rocks are generally horizontal but have been modified by basins and domes in some areas (see Figure 10-6). Sandstones have significant primary porosity and are the major



water-bearing units in this region. Recharge occurs where the sandstones are exposed. Intermittent losing streams created by sudden summer storms provide some recharge, but most recharge is caused by snowmelt.

Generally, ground water is unconfined in the recharge areas and confined in the lower reaches of the aquifers. The storage coefficients and transmissivities in the confined portions of the aquifers are small, causing extensive drawdown during even minor pumping. Saline ground water is characteristic of this region and is caused by the existence of gypsum and halide in the sedimentary deposits.

The High Plains region is underlain by thick alluvial deposits that comprise a productive and extensively developed aquifer system. The source of recharge to the aquifer system is precipitation, except in Western Texas where recharge is centered at playas (see Figure 10-7). In many areas, well discharges far exceed recharge, and water levels are declining. The dominant features influencing ground-water flow in this region include the Ogallala Aquifer, the Pierre Shale, and the complex interbedding of sand and clay lenses. Figure 10-7 provides generalized flow nets, showing flow patterns through these features.

Thin regolith over fractured sedimentary rocks typifies the nature of the geology in the Nonglaciated Central region (see Figure 10-8). This region extends from the Rocky Mountains to the Appalachian Mountains. Water is transmitted primarily along fractures developed at bedding planes. Interconnected vertical fractures also can store a large portion of the ground water. An example of ground-water flow on a local scale is shown for karst terrain, where ground water moves rapidly through solution cavities and fractures in limestone and where the flow pathways are closely associated with the configuration of fractures. Ground-water flow in the karst regime does not usually follow Darcy's law because most of the flow goes through large channels rather than the pores in the rock. Thus, construction of a flow net may not be appropriate in some cases. An additional example of localized flow in this region is provided, showing a surface impoundment site in Pennsylvania. Notice that ground water discharges to surface water, a phenomenon typical of this region.

The topography of the Glaciated Central region is characterized by rolling hills and mountains in the eastern portion of the region and by flat to gently rolling

terrain in the western portion of the region. Glacial deposits vary in thickness within the region and are underlain by bedrock. Ground water occurs in the glacial deposits in pores between the grains and in the bedrock primarily along fractures. Permeability of glacial deposits ranges from extremely transmissive in gravels to low transmissivity in poorly sorted tills. The presence of buried valleys, till, deltas, kames, and other glacial artifacts highly influences the transmission of ground water within the region. Two examples of localized flow are presented in Figure 10-9. The first example shows a flow regime in an area where till has the highest hydraulic conductivity relative to the other formations. In the second example, the till bed has a much lower hydraulic conductivity than the deltaic outwash deposited above it.

Thick regolith overlies fractured crystalline and metamorphic bedrock in most of the Piedmont and Blue Ridge region. The hydraulic conductivities of regolith and fractured bedrock are similar. However, bedrock wells generally have much larger ground-water yields than regolith wells because, being deeper, they have a much larger available drawdown. Fracture-controlled movement of ground water through bedrock is illustrated by generalized flow paths rather than quantitative flow lines used in a flow net in Figure 10-10, as is ground-water movement through saprolite (weathered bedrock) and river alluvium.

The Northeast and Superior Uplands region is characterized by folded and faulted igneous and metamorphic bedrock overlain by glacial deposits. The primary difference in the ground-water environment between this region and the Piedmont and Blue Ridge region is the presence of glacial material rather than regolith. The different types of glacial material have vastly different storage capacities and hydraulic conductivities. Examples of ground-water flow through till, delta, and kame deposits, as well as a generalized ground-water regime with upward gradients, are illustrated in Figure 10-11.

The Atlantic and Gulf Coastal Plain region is underlain by unconsolidated sediments that consist primarily of sand, silt, and clay. The sediments are often interbedded as a result of deposition on floodplains or deltas and of subsequent reworking by ocean currents. Recharge to the ground-water system occurs in the interstream areas; most streams in this region are gaining streams (see Figure 10-12). Encroachment of salt water into well drawdown areas can be a problem in this

area if high rates of ground-water withdrawal occur. An example of a regional flow net based on high recharge in hills shows how regional flow may differ from localized flow based on local topography. Also shown in Figure 10-12 is a landfill located in a recharge area near the Savannah River in Georgia.

Ground water in the Southeast Coastal Plain region lies primarily within semiconsolidated limestone. Sand, gravel, clay, and shell beds overlie the limestone beds. Recharge in this region occurs by precipitation infiltrating directly into exposed limestone and by seepage through the permeable soils that partially mantle the limestone (see Figure 10-13). Coastal environments, such as beaches and bars, and swamp areas have different ground-water regimes, which are shown in Figure 10-13. Flow through solution channels and large fractures in limestone is often rapid, similar to the situation shown in Figure 10-8.

The Hawaiian Islands region consists of many distinct and separate lava flows that repeatedly issued from several eruption centers forming mountainous islands. Lava extruded below sea level is relatively impermeable; lava extruded above sea level is much more permeable, having interconnected cavities, faults, and joints. Ground-water flow in this region is similar to that of the Columbia Plateau region, with the central parts of thick lava flows being less permeable and the major portion of ground-water flow in these thick beds occurring at the edges and contacts of the different lava flows. Alluvium overlies the lava in the valleys and portions of the coastal plains.

Ground water in this region can be characterized by one of three ground-water flow regimes. The first flow regime consists of ground water impounded in vertical compartments by dikes in the higher elevations near the eruption centers. The second flow regime consists of fresh water floating on salt water in the lava deposits that flank the eruption centers. This ground water is referred to as basal ground water and makes up the major aquifers in the region. In some areas of the coastal plain, basal ground water is confined by overlying alluvium, which may restrain seaward migration of fresh water. The third flow regime is where ground water is perched on soils, ash, or thick impermeable lava flows above the basal ground water. Figure 10-14 illustrates examples of ground-water flow in this region.

The Alaska region comprises several distinct flow regimes that can be categorized by ground-water regions in the lower 48 States. For example, Alaska's Pacific Mountain System is similar to the Western Mountain Range and Alluvial Basin regions described previously. The major variable causing Alaska to be classified as a separate region is its climate and the existence of permafrost over most of the region.

Permafrost has a major effect on the hydraulic conductivity of most geologic deposits. Hydraulic conductivity declines as temperatures drop below 0 °C. This effect can be severe, causing a deposit that would be an aquifer in another area to become a low-permeability aquitard in an area of permafrost. In Alaska, ground-water supplies are drawn from deposits that underlie the permafrost or from areas where the permafrost is not continuous. See Figure 10-15.

Most recharge in this region occurs in large alluvial deposits, such as alluvial fans, which streams cross and discharge to. Although the volume of interstream surface water is large during periods of snow melt, these interstream areas do not act as recharge areas because they are usually frozen during the snow melts.

The Alluvial Valley region consists of valleys underlain by sand and gravel deposited by streams carrying sediment-laden melt water from glaciation that occurred during the Pleistocene. These valleys are considered to be a distinct ground-water terrain. They occur throughout the United States and can supply water to wells at moderate to high rates (see Figure 10-16). These valleys have thick sand and gravel deposits that are in a clearly defined band and are in hydraulic contact with a perennial stream. The sand and gravel deposits generally have a transmissivity of 10 or more times greater than that of the adjacent bedrock. Silt and clay commonly are found both above and below the sand and gravel channels in the Alluvial Valley region as a result of overbank flooding of rivers. Ground-water recharge in this region is predominantly by precipitation on the valleys, by ground water moving from the adjacent and underlying aquifers, by overbank flooding of the streams, and, in some glacial valleys, by infiltration from tributary

streams. An example of a flow net illustrating local ground-water movement beneath a waste disposal site in Connecticut also is shown in Figure 10-16.

In addition to determining the directions of ground-water flow, it is essential to determine the approximate rates of ground-water movement to properly design a monitoring program. Hydraulic conductivity, hydraulic gradient, and effective porosity data are required to estimate the average linear velocity of ground water and, therefore, assist in the determination of the rate of contaminant migration. Hydraulic conductivity data can be determined using single well (slug) test data. Several hydraulic conductivity measurements can be made on materials penetrated by individual wells to provide data on the relative heterogeneity of the materials in question. Measurements made in several wells also provide a comparison to check for effects of poor well construction. Hydraulic conductivity can also be determined from multiple-well (pumping) tests. A multiple-well test provides a hydraulic conductivity value for a larger portion of the aquifer. Hydraulic conductivities determined in the laboratory have been shown to vary by orders of magnitude from values determined by field methods and are, therefore, not recommended for use in the RFI.

Porosity can have an important controlling influence on hydraulic conductivity. Materials with high porosity values generally also have high hydraulic conductivities. An exception is clayey geologic materials which, although possessing high porosities, have low hydraulic conductivity values (resulting in low flow rates) due to their molecular structure. All of the pore spaces within geologic materials are not available for water or solute flow. Dead-end pores and the portion of the total porosity occupied by water held to soil particles by surface tension forces, do not contribute to effective porosity. Therefore, to determine average linear velocities, the effective porosity of the materials should be determined. In the absence of measured values, the values provided in Table 10-4 should be used.

Knowledge of the rates of ground-water flow is essential to determine if the locations of the monitoring wells are within reasonable flow distances of the contaminant sources. Flow rate data can also be used to calculate reasonable sampling frequencies. This is particularly important when attempting to monitor the potential migration of a intermittent contaminant release.

TABLE 10-4. DEFAULT VALUES FOR EFFECTIVE POROSITY

Soil Textural Classes	Effective Porosity of Saturation <sup>a</sup>
<b><u>Unified Soil Classification System</u></b>	
GC, GP, GM, GS	0.20
SW, SP, SM, SC	(20%)
ML, MH	0.15
	(15%)
CL, OL, CH, OH, PT	0.01
	(1%) <sup>b</sup>
<b><u>USDA Soil Textural Classes</u></b>	
Clays, silty clays, sandy clays	0.01
	(1%) <sup>b</sup>
Silts, silt loams, Silty clay loams	0.10
	(10%)
All others	0.20
	(20%)
<b><u>Rock Units (all)</u></b>	
Porous media (nonfractured rocks such as sandstone and some carbonates)	0.15
	(15%)
Fractured rocks (most carbonates, shales, granites, etc.)	0.0001
	(0.01%)

<sup>a</sup> These values are estimates. There may be differences between similar units.

<sup>b</sup> Assumes de minimus secondary porosity. If fractures or soil structure are present, effective porosity should be 0.001 (0.1%).

Geochemical and biological properties of the aquifer matrix should be evaluated in terms of their potential interference with the goals of the monitoring program. For example, chemical reactions or biological transformations of the monitoring constituents of concern may introduce artifacts into the results. Physical and hydrologic conditions will determine whether or not information on chemical or biological interactions can be collected. If the potential for these reactions or transformations exists, consideration should be given to monitoring for likely intermediate transformation or degradation products.

The monitoring system design is influenced in many ways by a site's hydrogeologic setting. Determination of the items noted in the stratigraphy and flow systems discussions will aid in logical monitoring network configurations and sampling activities. For example:

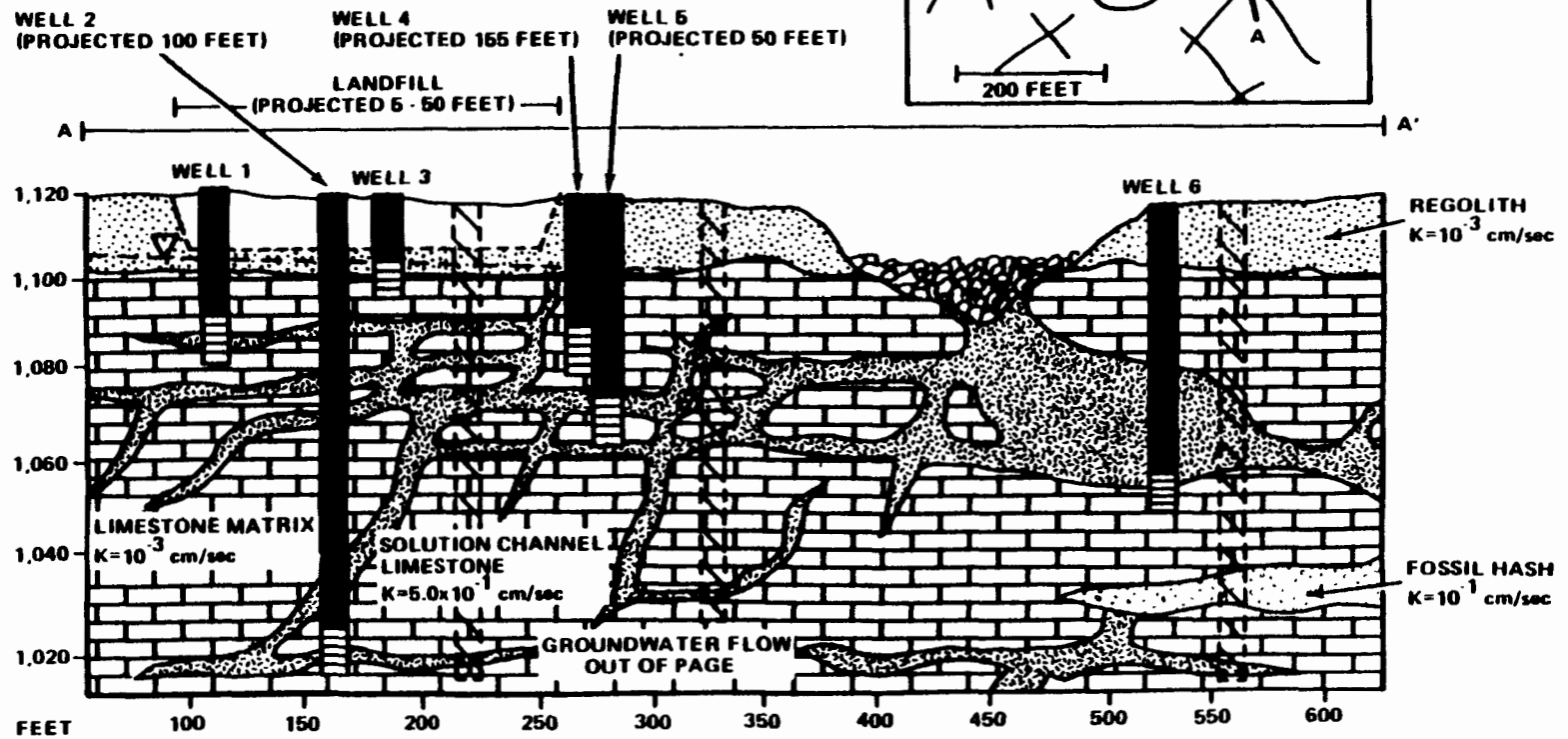
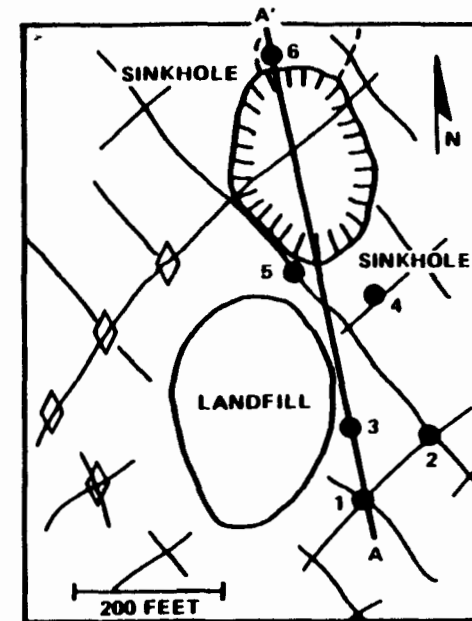
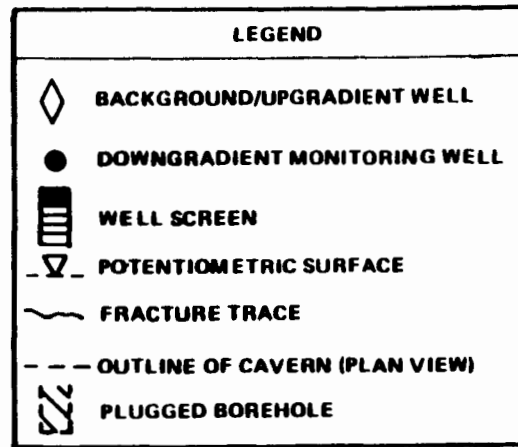
- Background and downgradient wells should be screened in the same stratigraphic horizon(s) to obtain comparable ground-water quality data. Hydraulic conductivities should be determined to evaluate preferential flowpaths (which will require monitoring) and to establish sampling frequencies.
- The distances between and number of wells (well density) should be a function of the spatial heterogeneity of a site's hydrogeology, as is sampling frequency. For example, formations of unconsolidated deposits with numerous interbedded lenses of varying hydraulic conductivity or consolidated rock with numerous fracture traces will generally require a greater number of sampling locations to ensure that contaminant pathways are intercepted.
- The slope of the potentiometric surface and the slope of the aquitard formation strongly influence the migration rates of light and dense immiscible compounds.
- The hydrogeology will strongly influence the applicability of various geophysical methods (Appendix C), and should be used to establish boundary conditions for any modeling to be performed for the site.

- Analyses for contaminants of concern in the ground-water monitoring program can be influenced by the general water quality present. Naturally-occurring cations and anions can affect contaminant reactivity, solubility, and mobility.
- Sites with complex geology will generally require more hydrogeologic information to provide a reasonable assurance that well placements will intercept contaminant migration pathways. For example, Figure 10-17 illustrates a cross-sectional and plan view of a waste landfill located in a mature Karst environment. This setting is characteristic of carbonate environments encountered in various parts of the country, but especially in the southeastern states. An assessment of the geology of the site through the use of borings, geophysical surveys, aerial photography, tracer studies, and other geological investigatory techniques, identified a mature Karst geologic formation characterized by sinkholes, solution channels and extensive vertical and horizontal fracturing in an interbedded limestone/dolomite. Using potentiometric data, ground-water flow was found to be predominantly in an easterly direction.

Solution channels are formed by the flow of water through the fractures. The chemical reaction between the carbonate rock and the ground-water flow in the fractures produces solution channels. Through time, these solution channels are enlarged to the point where the weight of the overlaying rock is too great to support; consequently causing a "roof" collapse and the formation of a sinkhole. The location of these solution channels should guide the placement of monitoring wells. Note that in Figure 10-17 the placement of well No. 2 is offset 50 feet from the perimeter of the landfill. The horizontal placement of well No. 2, although not immediately adjacent to the landfill, is necessary in order to monitor all potential contaminant pathways. The discrete nature of these solution channels dictate that each potential pathway be monitored.

The height of the solution channels ranges from three to six feet directly beneath the sinkhole to one foot under the landfill except for the 40-





foot deep cavern. This limited vertical extent of the cavities allows for full screening of the horizontal solution channels. (Note the change in orientation of solution channels due to the presence of the fossil hash layer).

Chapter I of the RCRA Ground Water Monitoring Technical Enforcement Guidance Document (TEGD) (U.S. EPA, 1986) provides additional guidance in characterization of site hydrogeology. Various sections of the document will be useful to the facility owner or operator in developing monitoring plans for RCRA Facility Investigations.

In order to further characterize a release to ground water, data should be collected to assess subsurface stratigraphy and ground-water flow systems. These are discussed in the following subsections.

#### **10.3.3.1 Subsurface Geology**

In order to adequately characterize the hydrologic setting of a site, an analysis of site geology should first be completed. Geologic site characterization consists of both a characterization of stratigraphy, which includes unconsolidated material analysis, bedrock features such as lithology and structure, and depositional information, which indicates the sequence of events which resulted in the present subsurface configuration.

Information that may be needed to characterize a site's subsurface geology includes:

- Grain size distribution and gradation;
- Hydraulic conductivity;
- Porosity;
- Discontinuities in soil strata; and
- Degree and orientation of subsurface stratification and bedding.

Refer to Section 9 (Soil) for further details.

**Grain size distribution and gradation**--A measurement of the percentage of sand, silt, and clay should be made for each distinct layer of the soil. Particle size can affect contaminant transport through its impact on adsorption and hydraulic conductivity. Sandy soils generally have low sorptive capacity while clays tend to have a high affinity for heavy metals and some organic contaminants. This is due in part to the fact that small clay particles have a greater surface area in relation to their volume than do the larger sand particles. Greater surface areas allow for increased interactions with contaminant molecules. Clays may also bind contaminants due to the chemical structure of the clay. Methods for determination of sand/silt/clay fractions are available from ASTM, Standard Method No. D422-63 (ASTM, 1984).

**Hydraulic conductivity**--This property represents the ease with which fluids can flow through a formation, and is dependent on porosity, and grain size, as well as on the viscosity of the fluid. Hydraulic conductivity can be determined by the use of field tests, as discussed in Section 10.6.

**Porosity**--Soil porosity is the volume percentage of the total volume of the soil not occupied by solid particles (i.e., the volume of the voids). In general, the greater the porosity, the more readily fluids may flow through the soil, with the exception of clays (high porosity), in which fluids are held tightly by capillary forces.

**Discontinuities in geological materials**--Folds are layers of rock or soil that have been naturally bent over geologic time. The size of a fold may vary from several inches wide to several miles wide. In any case, folding usually results in a complex structural configuration of layers (Billings, 1972).

Faults are ruptures in rock or soil formations along which the opposite walls of the formation have moved past each other. Like folds, faults vary in size. The result of faulting is the disruption of the continuity of structural layers.

Folds and faults may act as either barriers to or pathways for ground-water (and contaminant) flow. Consequently, complex hydrogeologic conditions may be exhibited. The existence of folds or faults can usually be determined by examining

geologic maps or surveys. Aerial photographs can also be used to identify the existence of these features. Where more detailed information is needed, field methods (e.g., borings or geophysical methods) may need to be employed.

Joints are relatively smooth fractures found in bedrock. Joints may be as long as several hundred feet (Billings, 1972). Most joints are tight fractures, but because of weathering, joints may be enlarged to open fissures. Joints result in a secondary porosity in the bedrock which may be the major pathway of ground-water flow through the formation (Sowers, 1981).

Interconnected conduits between grains may form during rock formation (Sowers, 1981). The permeability of a bedrock mass is often defined by the degree of jointing. Ground water may travel preferentially along joints, which usually governs the rate of flow through the bedrock. The degree and orientation of joints and interconnected voids is needed to determine if there will be any vertical or horizontal leakage through the formation. In some cases, bedrock acts as an aquitard, limiting the ground-water flow in an aquifer. In other cases, the bedrock may be much more productive than overlying alluvial aquifers.

Geologic maps available from the USGS (see Section 7) may be useful in obtaining information on the degree and orientation of jointing or interconnected void formation. Rock corings may also be used to identify these characteristics.

Degree and orientation of subsurface stratification and bedding--The owner or operator should develop maps of the subsurface structure for the areas of concern. These maps should identify the thickness and depth of formations, soil types and textures, the locations of saturated regions and other hydrogeological features. For example, the existence of an extensive, continuous, relatively horizontal, shallow strata of low permeability can provide a clue to contaminant routing. In such cases, the contaminants may migrate at shallow depths, which are above the regional aquifer. Such contamination could discharge into nearby, low-lying structures (e.g., seepage into residential basements). This "basement seepage" pathway has been demonstrated to be a significant migration channel in many cases. This pathway may result from migration of vapors in the vadose zone or through lateral migration of contaminated ground water. Basement seepage is more likely to occur in locations with shallow ground water. A method for

estimating basement air contaminant concentrations due to volatile components in ground-water seeped into basements appears in Appendix E.

A variety of direct and indirect methods are available to characterize a site geologically with respect to the above geologic characteristics. Direct methods utilize soil borings and rock core samples and subsequent lab analysis to evaluate grain size, texture, uniformity, mineralogy, soil moisture content, bedrock lithology, porosity, and structure. Combined, these data provide the basis for delineating the geologic nature of the site and, in turn, provide the data necessary to evaluate the hydrologic setting.

Indirect methods of geologic investigation, such as geophysical techniques (See Appendix C) and aerial photography (See Appendix A) can be used to supplement data gathered by direct field methods, through extrapolation and correlation of data on surface and subsurface geologic features. Borehole geophysical techniques can be used to extrapolate direct data from soil borings and bedrock cores. Surface geophysical methods can provide indirect information on depth, thickness, lateral extent, and variation of subsurface features that can be used to extrapolate information gained from direct methods. Applicable surface geophysical methods include seismic refraction, electrical resistivity, electromagnetics, magnetics, and ground penetrating radar.

#### **10.3.3.2 Flow Systems**

In addition to characterizing the subsurface geology, the owner or operator should adequately describe the ground-water flow system. To adequately describe the ground-water flow paths, the owner or operator should:

- **Establish the direction of ground-water flow (including horizontal and vertical components of flow);**
- **Establish the seasonal, temporal, and artificially induced (e.g., offsite production well pumping, agricultural use) variations in ground-water flow; and**

- Determine the hydraulic conductivities of the hydrogeologic units underlying the site.

Hydrologic and hydraulic properties and other relevant information needed to fully evaluate the ground-water flow system are listed and discussed below:

- Hydraulic conductivity;
- Hydraulic gradient (vertical and horizontal);
- Direction and rate of flow;
- Aquifer type/identification of aquifer boundaries;
- Specific yield (effective porosity)/storage coefficient;
- Depth to ground water;
- Identify uppermost aquifer;
- Identify recharge and discharge areas;
- Use of aquifer; and
- Aquitard type and location.

Hydraulic conductivity--In addition to defining the direction of ground-water flow in the vertical and horizontal directions, the owner or operator should identify the distribution of hydraulic conductivity within each formation. Variations in the hydraulic conductivity of subsurface materials can affect flow rates and alter directions of ground-water flow paths. Areas of high hydraulic conductivity represent areas of greater ground-water flow and zones of potential migration. Therefore, information on hydraulic conductivities is needed to make decisions regarding well placements. Hydraulic conductivity measurement is described in Section 10.6.

**Hydraulic gradient**--The hydraulic gradient is defined as the change in static head per unit distance in a given direction. The hydraulic gradient defines the direction of flow and may be expressed on maps of water level measurements taken around the site. Ground-water velocity is directly related to hydraulic gradient. Both vertical and horizontal gradients should be characterized.

**Direction and rate of flow**--A thorough understanding of how ground water flows beneath the facility will aid the owner or operator in locating wells to provide suitable background and/or downgradient samples. Of particular importance is the direction of ground-water flow and the impact that external factors (intermittent well pumping, temporal variations in recharge patterns, tidal effects, etc.) may have on ground-water flow patterns. In order to account for these factors, monitoring procedures should include precise water level measurements in piezometers or observation wells. These measurements should be made in a sufficient number of wells and at a frequency sufficient to adequately gauge both seasonal average flow directions and to show any seasonal or temporal fluctuations in flow directions. Horizontal and vertical components of ground-water flow should be assessed. Methods for determining vertical and horizontal components of flow are described in Subsection 10.5.4.

**Identification of aquifer boundaries/aquifer type**--Aquifer boundaries define the flow limits and the degree of confinement of an aquifer. There are two major types of aquifers: unconfined and confined. An unconfined aquifer has a free water surface at which the fluid pressure is the same as atmospheric. A confined aquifer is enclosed by retarding geologic formations and is, therefore, under pressure greater than atmospheric. A confining unit consists of consolidated or unconsolidated earth materials that are substantially less permeable than aquifers. Confining units are called aquitards or aquicludes. Aquifer boundaries can be identified by consulting geologic maps and state geologic surveys. Observation wells and piezometers can be used to determine the degree of confinement of an aquifer through analysis of water level data.

**Specific yield/storativity**--Specific yield and storativity are both terms used to characterize the amount of water an aquifer is capable of yielding. In an unconfined system, the specific yield is the ratio of the drainable volume to the bulk volume of the aquifer medium (some liquid will be retained in pore spaces). The

storativity of a confined aquifer is the volume of water released from a column of unit area and height per unit decline of pressure head. Specific yield or storativity values may be necessary to perform complex ground-water modeling.

Depth to ground water--The depth to ground water is the vertical distance from the land's surface to the top of the saturated zone. A release from a unit not in contact with the water table will first percolate through the unsaturated zone and may, depending upon the nature of the geologic material, disperse horizontally. Thus, a release of this nature may reach a deep water table with limited lateral spreading. Depth to ground water can influence the selection of sampling methods as well as geophysical methods.

A shallow water table can also facilitate releases to other environments via volatilization of some compounds into the unsaturated zone, seepage into basements of buildings in contact with the saturated zone, or the transport of contaminants into wetlands where the water table reaches the level of the ground surface. Sufficient mapping of the water table with particular attention to these features should provide an indication of where these interactions may exist.

Identification of uppermost aquifer--As defined in 40 CFR §260.10, "aquifer" means a geologic formation, group of formations, or part of a formation capable of yielding a significant amount of ground water to wells or springs. "Uppermost aquifer," also defined in 40 CFR §260.10, means the geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility's property boundary. Chapter one of the Technical Enforcement Guidance Document (TEGD) (U.S. EPA, 1986) elaborates on the uppermost aquifer definition. It states that the identification of the confining layer or lower boundary is an essential facet of the definition. There should be very limited interconnection, based on pumping tests, between the uppermost and lower aquifers. If zones of saturation capable of yielding significant amounts of water are interconnected, they all comprise the uppermost aquifer. Identification of formations capable of "significant yield" must be made on a case-by-case basis.

There are saturated zones, such as low permeability clay, that may not yield a significant amount of water, yet may act as pathways for contamination that can



migrate horizontally for some distance before reaching a zone which yields a significant amount of water. In other cases, there may be low yielding saturated zones above the aquifer which can provide a pathway for contaminated ground water to reach basements. If there is reason to believe that a potential exists for contamination to escape along such pathways, the owner or operator should monitor such zones.

For further information on the uppermost aquifer definition, including examples illustrating the determination of hydraulic interconnection in various geologic settings, see Chapter One of the TEGD.

Identification of recharge and discharge areas--Ground-water recharge can be defined as the entry into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table within the saturated zone. Ground-water discharge can be defined as the removal of water from the saturated zone across the water table surface, together with the associated flow toward the water table within the saturated zone (Freeze and Cherry, 1979). Ground-water recharge and discharge areas also represent areas of potential inter-media transport.

Recharge can be derived from the infiltration of precipitation, inter-aquifer leakage, inflow from streams or lakes, or inadvertently by leakage from lagoons, sewer lines, landfills, etc. Discharge occurs where ground water flows to springs, streams, swamps, or lakes, or is removed by evapotranspiration or pumping wells, etc. Information on the source and location of aquifer recharge and discharge areas may be obtained from state water resource publications, geologic surveys, or existing site information. Comparison of aquifer water levels with nearby surface water levels may also provide an indication of the source and location of aquifer recharge and discharge areas.

Flow nets can also be used to determine areas of aquifer recharge and discharge. Section 10.5.2 describes the use of flow nets to determine ground-water flow patterns.

Use of aquifer--The proximity and extent of local ground-water use (e.g., pumping) may dramatically influence the rate and direction of ground-water flow

possibly causing seasonal or episodic variations. These factors should be considered when designing and implementing a ground-water monitoring system. Information on local aquifer use may be available from the USGS, and state and local water authorities. Aquifer use for drinking water or other purposes may also influence the location of ground-water monitoring wells, as it may be appropriate to monitor at locations pertinent to receptors.

Aquitard type and location--Aquitard type refers to the type of geologic formation that serves to bound ground-water flow for a given aquifer. Such boundaries may be rock or may be an unconsolidated unit such as clay, shale, or glacial till. The identification of such formations and their hydraulic characteristics is essential in determining ground-water flow paths. Aquitard locations can be determined by consulting geologic maps and boring log information. Although aquitards are substantially less permeable than aquifers, they are not totally impermeable and can allow significant quantities of water to pass through them over time. The location of an aquitard should be used in determining monitoring well depths.

#### **10.3.4 Sources of Existing Information**

A complete review of relevant existing information on the facility is an essential part of the release characterization. This review can provide valuable knowledge and a basis for developing monitoring procedures. Information that may be available and useful for the investigation includes both site-specific studies and regional surveys available from local, state, and Federal agencies.

Information from the regulatory agency such as the RFA report should be thoroughly reviewed in developing monitoring procedures, and should serve as a primary information source. It may also provide references to other sources of information. In addition, the facility's RCRA Permit Application may contain other relevant information. These reports and all of the facility's RCRA compliance/permit files will provide an understanding of the current level of knowledge about the facility, and will assist in identifying data gaps to be filled during the investigation.

Public information is available from local, state, and Federal governments (see Section 7) concerning the topics discussed below.

#### **10.3.4.1 Geology**

Knowledge of local bedrock types and depths is important to the investigation of a site. Sources of geologic information include United States Geological Survey (USGS) reports, maps, and files; State geological survey records; and local well drilling logs. See also Section 9 (Soils).

#### **10.3.4.2 Climate**

Climate is also an important factor affecting the potential for contaminant migration from a release source. Mean values for precipitation, evaporation, evapotranspiration, and estimated percolation will help determine the potential for onsite and offsite contaminant transport. The investigator should consult monthly or seasonal precipitation and evaporation (or temperature) records. Climate and weather information can be obtained from:

National Climatic Center  
Department of Commerce  
Federal Building  
Asheville, North Carolina 28801  
Tel: (704)258-2850

#### **10.3.4.3 Ground-Water Hydrology**

The owner or operator will need to acquire information on the ground-water hydrology of a site and its surrounding environment. Ground-water use in the area of the site should be thoroughly investigated to find the depths of local wells, and their pumping rates. Sources of such information include the USGS, state geological surveys, local well drillers, and State and local water resources boards. A list of all state and local cooperating offices is available from the USGS, Water Resources Division in Reston, Virginia, 22092. This list has also been distributed to EPA Regional Offices. Water quality data, including surface waters, is available through the USGS via their automated NAWDEX system. For further information, telephone (703)860-6031.

#### **10.3.4.4 Aerial Photographs**

Aerial reconnaissance can be an effective and economical tool for gathering information on waste management facilities. For this application, aerial reconnaissance includes aerial photography and thermal infrared scanning. See Appendix A for a more detailed discussion of the usefulness of aerial photography in release characterization and availability of aerial photographs.

#### **10.3.4.5 Other Sources**

Other sources of information for subsurface and release characterization include:

- U.S. EPA files (e.g., CERCLA-related reports);
- U.S. Geological Survey;
- U.S. Department of Agriculture Soil Conservation Service;
- U.S. Department of Agriculture Agricultural Stabilization and Conservation Service;
- U.S. Department of Interior -Bureau of Reclamation;
- State Environmental Protection or Public Health Agencies;
- State Geological Survey;
- Local Planning Boards;
- County or City Health Departments;
- Local Library;
- Local Well Drillers; and
- Regional Geologic and Hydrologic Publications.

### **10.4 Design of a Monitoring Program to Characterize Releases**

Information on waste, unit and environmental characterization can be used to develop a conceptual model of the release, which can subsequently be used to design a monitoring program to fully characterize the release. The design of a monitoring program is discussed below.

#### **10.4.1 Objectives of the Monitoring Program**

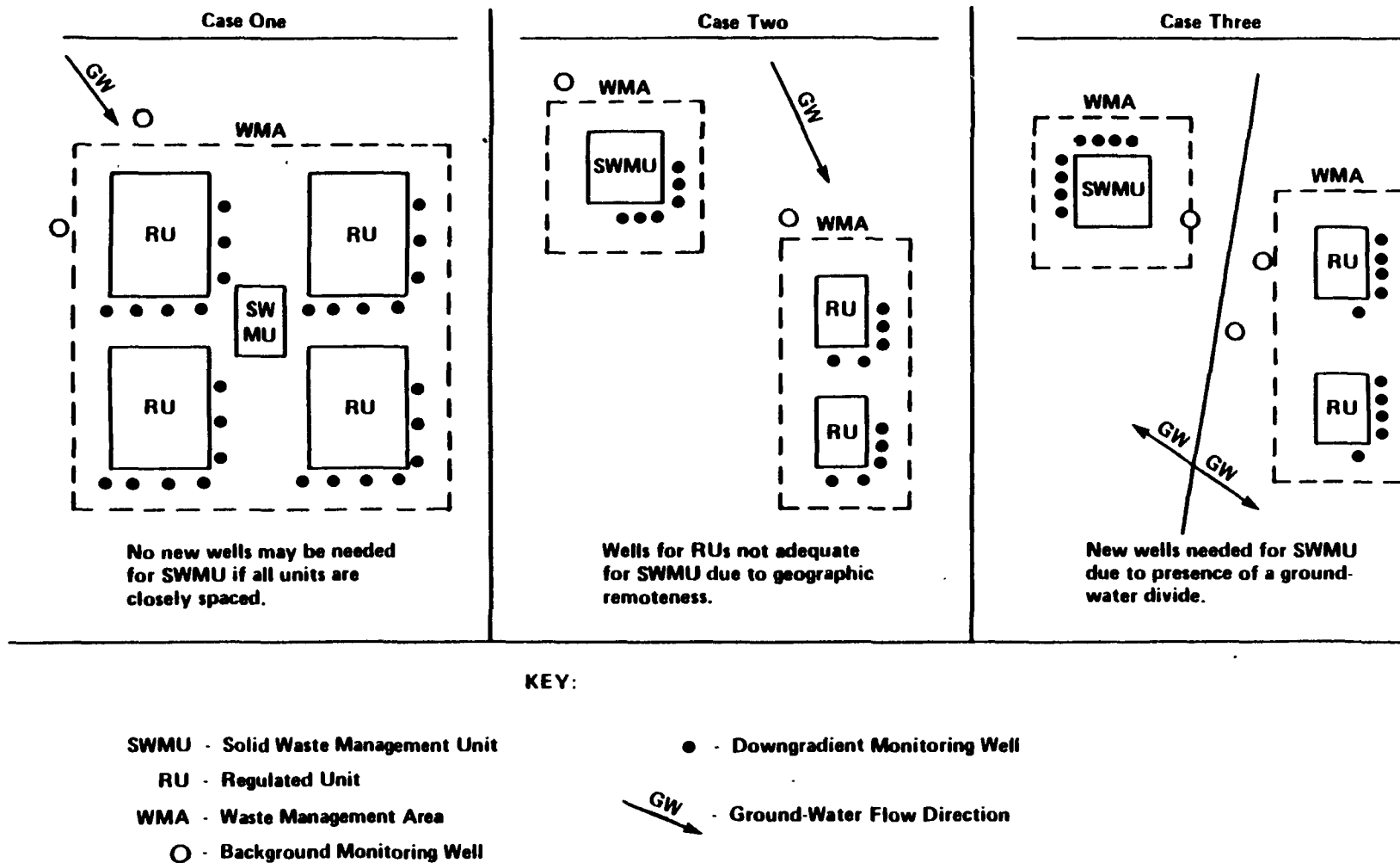
The objective of initial monitoring is to verify or to begin characterizing known or suspected contaminant releases to ground water. To help accomplish this objective, the owner or operator should evaluate any existing monitoring wells to determine if they are capable of providing samples representative of background and downgradient ground-water quality for the unit(s) of concern. Figure 10-18 illustrates three possible cases where existing well systems are evaluated with regard to their horizontal location for use in a ground-water investigation. Adequacy is not only a function of well location but also well construction. Guidance on appropriate well construction materials and methods can be found in the TEGD (EPA, 1986). If the monitoring network is found to be inadequate for all or some of the units of concern, additional monitoring wells should be installed. Further characterization, utilizing both direct and indirect investigative methods, of the site's hydrogeology should be completed to identify appropriate locations for the new monitoring wells.

If initial monitoring verifies a suspected contaminant release, the owner or operator should extend the monitoring program to determine the vertical and horizontal concentrations (i.e., 3-dimensions) of all hazardous constituents in the release. The rate of contaminant migration should also be determined. A variety of investigatory techniques are available for such monitoring programs.

Monitoring procedures should include direct methods of obtaining ground-water quality information (e.g., sampling and analysis of ground water from monitoring wells). Indirect methods of investigation may also be used when appropriate to aid in determining locations for monitoring wells (i.e., through geologic and/or geochemical interpretation of indirect data). For many cases, the use of both direct and indirect methods may be the most efficient approach.

Elements to be addressed in the ground-water monitoring program include:

- Monitoring constituents and indicator parameters;
- Frequency and duration at which samples will be taken;



Note: Drawings not to scale.

**Figure 10-18.**  
**Monitoring well locations**

- Sampling and analysis techniques to be used, including appropriate QA/QC procedures; and
- Monitoring locations.

[Note: Permit application regulations in 40 CFR §270.14(c)(2) require applicants to identify the uppermost aquifer and hydraulically interconnected aquifers beneath the facility property if the facility has any "regulated" units. The application must indicate ground-water flow directions and provide the basis for the aquifer identification (e.g., a report written by a qualified hydrogeologist on the hydrogeologic characteristics of the facility property supported by at least the well drilling logs and available professional literature). However, some RCRA permit applications did not require hydrogeologic characterizations (e.g., storage only facilities) prior to the HSWA Amendments of 1984. Now, such characterizations may be required according to RCRA Section 3004(u) when SWMU releases to ground water are suspected or known. The RCRA Ground Water Monitoring Technical Enforcement Guidance Document (TEGD) (U.S. EPA, 1986), and the Permit Applicant's Guidance Manual for Hazardous Waste Land Treatment, Storage, and Disposal Facilities (U.S. EPA, 1984) should be consulted for further information on regulatory requirements.]

#### **10.4.2 Monitoring Constituents and Indicator Parameters**

Initial monitoring should be focused on rapid, effective release characterization at the downgradient limit of the waste management area. Monitoring constituents should include waste-specific subsets of hazardous constituents from 40 CFR Part 261, Appendix VIII (see Section 3 and the lists provided in Appendix B). Indicator parameters (e.g., TOX, specific conductance) may also be proposed as indicated in Section 3. Such indicators alone may not be sufficient to characterize a release of hazardous constituents, because the natural background variability of indicator constituents can be quite high. Furthermore, indicator concentrations do not precisely represent hazardous constituent concentrations, and the detection limits for indicator analyses are significantly higher than those for specific constituents.

In developing an initial list of monitoring constituents and indicator parameters, the following items should be considered:

- The nature of the wastes managed at the facility should be reviewed to determine which constituents (and any chemical reaction products, if appropriate) are relatively mobile and persistent;
- The effects of the unsaturated zone (if present) beneath the facility on the mobility, stability and persistence of the waste constituents; and
- The concentrations and related variability of the proposed constituents in background ground water.

In the absence of detailed waste characterization information, the owner or operator should review the guidance presented in Section 3, which discusses the use of the monitoring constituent lists in Appendix B. As discussed in Section 3, the use of these lists is contingent upon the level of detail provided by the waste characterization.

The owner or operator should consider monitoring for additional inorganic indicators that characterize the general quality of water at the site (e.g., chloride, iron, manganese, sodium, sulfate, calcium, magnesium, potassium, nitrate, phosphate, silicate, ammonium, alkalinity and pH). Baseline data on such indicators can be used for subsequent monitoring phases and for selecting corrective measures (e.g., in assessing ground-water treatment alternatives). This is also discussed in Section 3 and Appendix B. Information on the major anions and cations that make up the bulk of dissolved solids in water can be used to determine reactivity and solubility of hazardous constituents and therefore predict their mobility under actual site conditions.

### **10.4.3 Monitoring Schedule**

#### **10.4.3.1 Monitoring Frequency**

Monitoring frequency should be based on various factors, including:



- Ground-water flow rate and flow patterns;
- Adequacy of existing monitoring data; and
- Climatological characteristics (e.g., precipitation patterns).

Generally, the greater the rate of ground-water flow, the greater the monitoring frequency needed. For example, monitoring frequency in an intergranular porosity flow aquifer of low permeability materials would likely be less than for a fracture or solution porosity flow aquifer with unpredictable and high flow rates. In the case of a fracture or solution porosity flow aquifer, it is possible that contaminants could migrate past the facility boundary in a matter of days, weeks, or months; thus requiring frequent monitoring.

The adequacy of existing monitoring data can be a factor in determining the monitoring schedule. For example, a facility which has performed adequate monitoring under RCRA interim status requirements may have a good data base which can be helpful in evaluating initial monitoring results. At the other end of the spectrum are facilities lacking hydrogeologic data and monitoring systems. Owners or operators of these facilities will need to design and install an adequate monitoring system for the units of concern. An accelerated monitoring program is recommended at such facilities.

#### 10.4.3.2 Duration of Monitoring

The duration of the initial monitoring phase will vary with facility-specific conditions (e.g., hydrogeology, wastes present) and should be determined through consultation with the regulatory agency. The regulatory agency will evaluate initial monitoring results to determine how long monitoring should continue and to determine the need for adjustments in the monitoring schedule, the list of monitoring constituents, and other aspects of the monitoring effort. If the regulatory agency determines that a release to ground water has not occurred, the investigation process for that release can be terminated at its discretion. If contamination is found during initial monitoring, further monitoring to fully characterize the release will generally be necessary.

#### **10.4.4 Monitoring Locations**

If there is no existing monitoring system or if the system is inadequate to effectively characterize ground-water contamination, the owner or operator should design and install a well system capable of intercepting the suspected contaminant plume(s). The system should also be used for obtaining relevant hydrogeologic data. The monitoring well network configuration should be based on the site's hydrogeology, the layout of the facility and the units of concern, the location of receptors, and should reflect a consideration of any information available on the nature and source of the release. It is important to recognize that the potential pathways of contaminant migration are three dimensional. Consequently, the design of a monitoring network which intercepts these potential pathways requires a three dimensional approach.

- \* In many cases, the initial monitoring system will need to be expanded for subsequent phases. Additional downgradient wells will often be needed to determine the extent of the contaminant plume. A greater number of background wells may also be needed to account for spatial variability in ground-water quality.

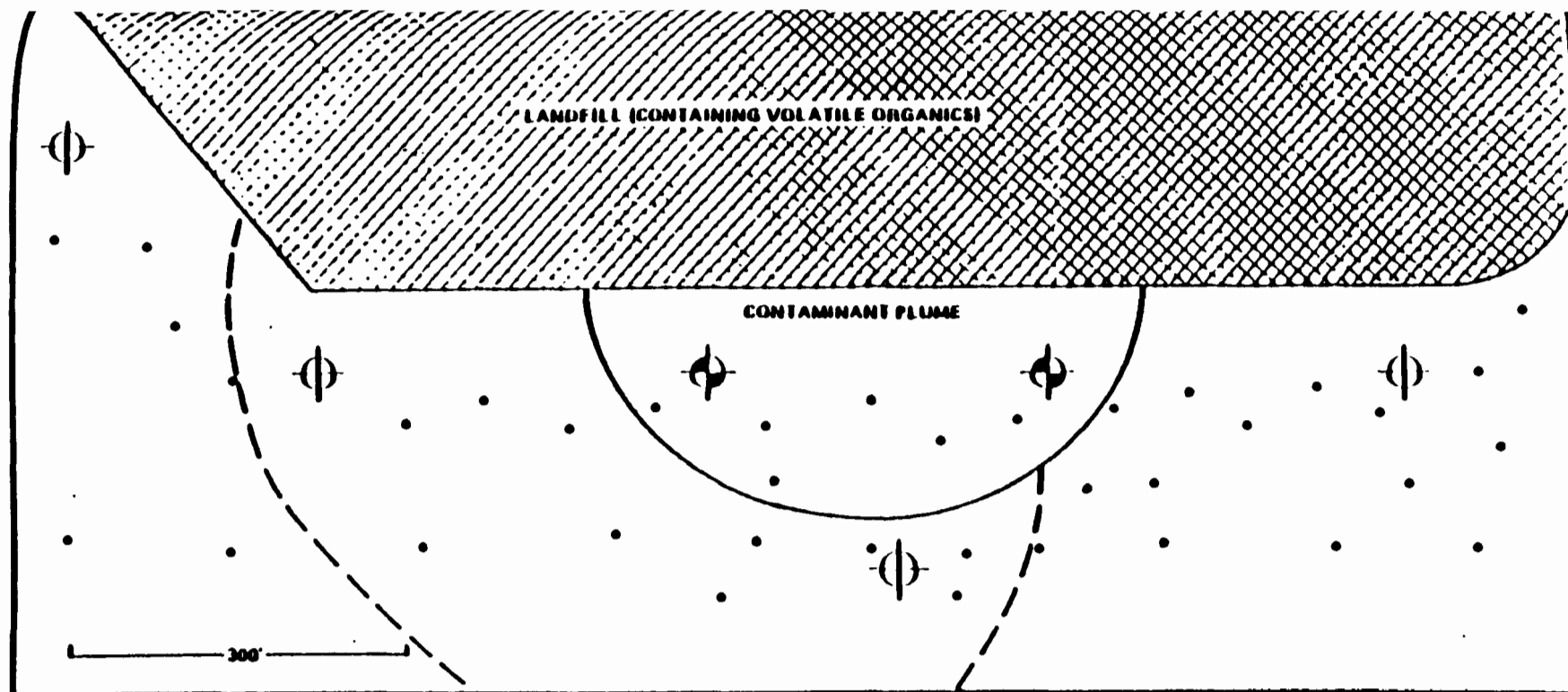
Prior to the installation of additional downgradient monitoring wells, a conceptual model of the release should be made from a review of waste and unit information and current and past site characterization information. Additional hydrogeologic investigations may also be appropriate. For example, piezometer readings surrounding the well(s) showing a release, should be used to determine the current hydraulic gradient(s). These values should be compared to the potentiometric surface map developed for the site hydrogeologic characterization to better describe the direction(s) of release migration. Seasonal (natural or induced) or regional fluctuations should be considered during this comparison. A re-evaluation of the facility's subsurface geologic information should be performed to identify preferential pathways of contaminant migration. In many situations, it may be appropriate to develop ground-water flow nets to show vertical and horizontal components of flow. Guidance on construction of flow nets is provided in Section 10.5.2 and in the Ground Water Flow Net/Flow Line Technical Resource Document, NTIS PB86-224979. (EPA, 1985). The installation of additional piezometers may be necessary to verify the accuracy of the flow nets and assist in

determining whether or not the site hydrogeology has been adequately characterized.

At facilities where it is known or likely that volatile organics have been released to the ground water, organic vapor analysis of soil gas from shallow bore holes may provide an initial indication of the areal extent of the release (Figure 10-19). An organic vapor analyzer (OVA) may be used to measure the volatile organic constituents in shallow hand-augered holes. Alternatively, a sample of soil gas may be extracted from a shallow hole and analyzed in the field using a portable gas chromatograph. These techniques are limited to situations where volatile organics are present. As discussed previously, it is recommended that, where possible, concurrent investigations of more than one contaminated media be conducted. Further, the presence of intervening, saturated, low permeability sediments strongly interferes with the ability to extract a gas sample. Although it is not necessarily a limitation, optimal gas chromatography results are obtained when the analyte is matched with the highest resolution technique, (e.g., electron capture for halogenated species). The effectiveness of this approach should be evaluated by initial OVA sampling in the vicinity of any wells known to be contaminated.

Other direct methods that may be used to define the extent of a release include sampling of seeps and springs. Seeps and springs occur where the local ground-water surface intersects the land surface resulting in ground-water discharge into a stream, lake, or other surface water body. Seeps and springs may be observed near marshes, at road cuts, or near streams. As discharges from seeps and springs reflect the height of the potentiometric surface, they are likely to be most abundant during a wet season.

To minimize the installation of new wells, the use of applicable geophysical and modeling methods may be proposed to describe geologic conditions and contaminant release geometry/characteristics. Such methods can also aid in the placement of new monitoring wells.



(Plan View)

LEGEND	
	Monitoring Well (No Contaminant Detection)
	Soil Gas Analysis Probe Point
	Monitoring Well (Contaminant Detected)
	--- Extent of Contaminated Soil
	— Extent of Ground-Water Contamination Plume

Figure 10-19. Example of using soil gas analysis to define probable location of ground-water release containing volatile organics.

A variety of indirect geophysical methods are currently available to aid in characterizing geologic conditions and ground-water contamination. Geophysical methods do not provide detailed, constituent-specific data; however, they can be useful in investigating geologic conditions and in estimating the general areal extent of a release. This may reduce speculation involved in determining new well locations. Details on the use of geophysical methods are presented in Section 10.6 and in Appendix C.

Mathematical and/or computer modeling results may be used in conjunction with the results of geophysical investigations to assist in well placement decisions. The owner or operator should not, however, depend solely on such models to determine the placement of new monitoring wells. Because models may not accurately account for the high spatial and temporal variability of conditions encountered in the field, modeling results should be limited to estimating the aerial extent of a release, and in determining placement of new monitoring wells.

In order to estimate the potential extent of a release in the direction of ground-water flow, Darcy's law should be applied, if appropriate, to determine the average linear ground-water velocity (see Section 10.5.3). This velocity should then be multiplied by the age of the unit of concern (assuming the unit began releasing immediately) to estimate the potential distance of contaminant migration. This distance should be used as a "yardstick" in determining well locations. More complex modeling (e.g., solute transport), may be proposed by the owner or operator to assist in locating additional monitoring wells. However, modeling results should not be used in lieu of field monitoring data.

The International Ground Water Modeling Center supported largely by the U.S. Environmental Protection Agency, operates a clearing-house for ground-water modeling software, organizes and conducts short courses and seminars, and carries out a research program supporting the Center's technology transfer and educational activities. Two major functions of the Center are the dissemination of information regarding ground-water models and the distribution of modeling software. The Center maintains computerized data bases, including updated computer codes and test files, and descriptions of a large number of ground-water models. By means of a search and retrieval procedure, this information is easily

accessible and readily available. The Center can be contacted at the following address:

International Ground Water Modeling Center  
Holcomb Research Institute  
Butler University  
Indianapolis, Indiana 46208  
Telephone: (317)283-9458

The Center will send, upon request and free of charge, a listing of available publications, and a copy of its Newsletter.

In selecting and applying models, it is important to remember that a model is an artificial representation of a physical system used to characterize a site. A model cannot replace field data, nor can it be more accurate than the available site data. In addition, the use of computer models requires special expertise. Time and experience are needed to select the appropriate code and subsequent calibration. If these resources are not available, modeling should not be attempted. Models are used in conjunction with scientific and engineering judgment; they are an aid to, not a surrogate for, a skilled analyst.

If a model is proposed in the monitoring procedures, the owner or operator should describe all assumptions used in applying the model to the site in question. A sensitivity analysis of the model should be run to determine which input parameters have the most influence on model results, and the model's results should be verified by field sampling. The owner or operator should clear the use of any and all models through the regulatory agency prior to use. Section 3 provides additional information on the use of models.

#### **10.4.4.1 Background and Downgradient Wells**

Background wells (preferably upgradient) may be installed to obtain samples that are not affected by the facility, if the owner or operator believes that other sources are contributing to the releases of concern. These wells should be screened at the same stratigraphic horizon(s) as the downgradient wells. Background wells,

if installed, should be sufficient in number to account for any heterogeneity in background ground-water quality.

Downgradient wells should be located and constructed to provide samples of ground water containing any releases of hazardous constituents from the units of concern. Determination of the appropriate number of wells to be included in an initial monitoring system should be based on various factors, including unit size and the complexity of the hydrogeologic setting (e.g., degree of fracturing and variation in hydraulic conductivity). Downgradient monitoring wells should be located at the limit of the waste management area of the units of concern and at other downgradient locations, as appropriate. For example, "old" releases may show higher constituent concentrations at locations downgradient of the unit. In such cases, flow nets may be useful in determining additional downgradient well locations (See Section 10.5.2).

#### 10.4.4.2 Well Spacing

The horizontal spacing between wells should be a design consideration. Site specific factors as listed in Table 10-5 should be considered when determining the horizontal distances between initial monitoring system wells. These factors cover a variety of physical and operational aspects relating to the facility including hydrogeologic setting, dispersivity, ground-water velocity, facility design, and waste characteristics. In the less common homogeneous geologic setting where simple flow patterns are identified, a more regular well spacing pattern may be appropriate. Further guidance on the consideration of site specific conditions to evaluate well spacing is described in Chapter Two of the TEGD (U.S. EPA, 1986).

Subsequent phase monitoring systems should be capable of identifying the full extent of the contaminant release and establishing the concentration of individual constituents throughout the release. Well installation and monitoring should concentrate on defining those areas that have been affected by the release. A well cluster network should be installed in and around the release to define the horizontal and vertical extent of contamination. Networks of monitoring wells will vary from site to site, depending upon hydrogeological complexity and contaminant characteristics. Surface geophysical techniques and modeling may also

**TABLE 10-5. FACTORS INFLUENCING THE INTERVALS BETWEEN INDIVIDUAL MONITORING WELLS WITHIN A POTENTIAL MIGRATION PATHWAY**

<b>Wells Intervals May Be Closer If the Site:</b>	<b>Wells Intervals May be Wider If the Site:</b>
● <b>Manages or has managed liquid waste</b>	
● <b>Is very small (i.e., the downgradient perimeter of the site is less than 150 feet)</b>	
● <b>Has waste incompatible with liner materials</b>	
● <b>Has fill material near the waste management units (where preferential flow might occur)</b>	
● <b>Has buried pipes, utility trenches, etc., where a point-source leak might occur</b>	
● <b>Has complicated geology</b> - closely spaced fractures - faults - tight folds - solution channels - discontinuous structures	● <b>Has simple geology</b> - no fractures - no faults - no folds - no solution channels - continuous structures
● <b>Has heterogenous conditions</b> - variable hydraulic conductivity - variable lithology	● <b>Has homogeneous conditions</b> - uniform hydraulic conductivity - uniform lithology
● <b>Is located in or near a recharge zone</b>	
● <b>Has a high (steep) or variable hydraulic gradient</b>	● <b>Has a low (flat) and constant hydraulic gradient</b>
● <b>Low dispersivity</b>	● <b>High dispersivity</b>
● <b>High average linear velocity</b>	● <b>Low average linear velocity</b>



be used, where appropriate, to help facilitate release definition. The well density or amount of sampling undertaken to completely identify the extent of migration should be determined by the variability in subsurface geology present at the site. Formations such as unconsolidated deposits with numerous interbedded lenses of varying permeability, or consolidated rock with numerous fracture traces, will generally require more extensive monitoring to ensure that contamination is appropriately characterized.

Monitoring should be performed to characterize the interior portion(s) of a release. This is important because constituents can migrate at differing rates and may have been released at different times. Monitoring only at the periphery of the release may not identify all the constituents in the release, and the concentration of monitoring constituents measured at the periphery of the release may be significantly less than in the interior portion(s). Patterns in concentrations of individual constituents can be established throughout the release by sampling along several lines that perpendicularly transect the release. The number of transects and the spacing between sampling points should be based on the waste characteristics, the size of the release, and variability in geology observed at the site. Sampling locations should also be selected so as to identify those areas of maximum contamination within the release. In addition to the expected hazardous constituents, the release may contain degradation and reaction products, which may also be hazardous.

Results of geophysical methods may be correlated with data from the monitoring well network. The monitoring program should be flexible so that adjustments can be made to reflect release migration and changes in direction.

The spacing between initial downgradient monitoring wells should ensure the measurement of releases near the unit(s) of concern. However, it is possible that the initial spacings between wells will only provide for measurements in the peripheral portion of a release. This might result in water quality measurements that do not reflect the maximum concentration of contaminants in the release. Therefore, additional downgradient wells may be needed adjacent to the units of concern during subsequent monitoring phases.

A similar effect may be observed, even with a closely spaced initial downgradient monitoring network, if a narrow, localized release migrates past the limit of the waste management area. Such a plume may originate from a small leak in a liner and/or from a leak located close to the downgradient limit of the waste management area, thereby limiting the amount of dispersion occurring in the release prior to its passing the monitoring wells. Consequently, if relatively wide spacing exists between wells or there is reason to expect a narrow, localized release, the installation of additional monitoring wells may be necessary in the immediate vicinity of those wells in which a release has been measured. Such an expansion of the monitoring network is recommended when a release has been measured in only one or two monitoring wells, indicating a localized plume.

#### **10.4.4.3 Depth and Screened Intervals**

The depth and screened intervals for initial phase monitoring wells should be based on: (1) geologic factors influencing the potential contaminant pathways of migration to ground water; (2) physical/chemical characteristics of the contaminant controlling its likely movement and distribution in the ground water; and (3) hydrologic factors likely to have an impact on contaminant movement. The consideration of these factors in evaluating the design of monitoring systems is described in the TEGD (U.S. EPA, 1986), including examples of placement in some common geologic environments. Subsection 10.6 provides guidance on borings and monitoring well construction.

In order to establish vertical concentration gradients of hazardous constituents in the release during subsequent monitoring phases, well clusters or multi-depth monitoring wells should be installed. The first well in a cluster (or initial sampling interval in a multi-depth well) should be screened at the horizon in which contamination was initially discovered. Additional wells in a cluster should be screened, where appropriate, above and below the initial well's sampling interval until the margins of the release are established.

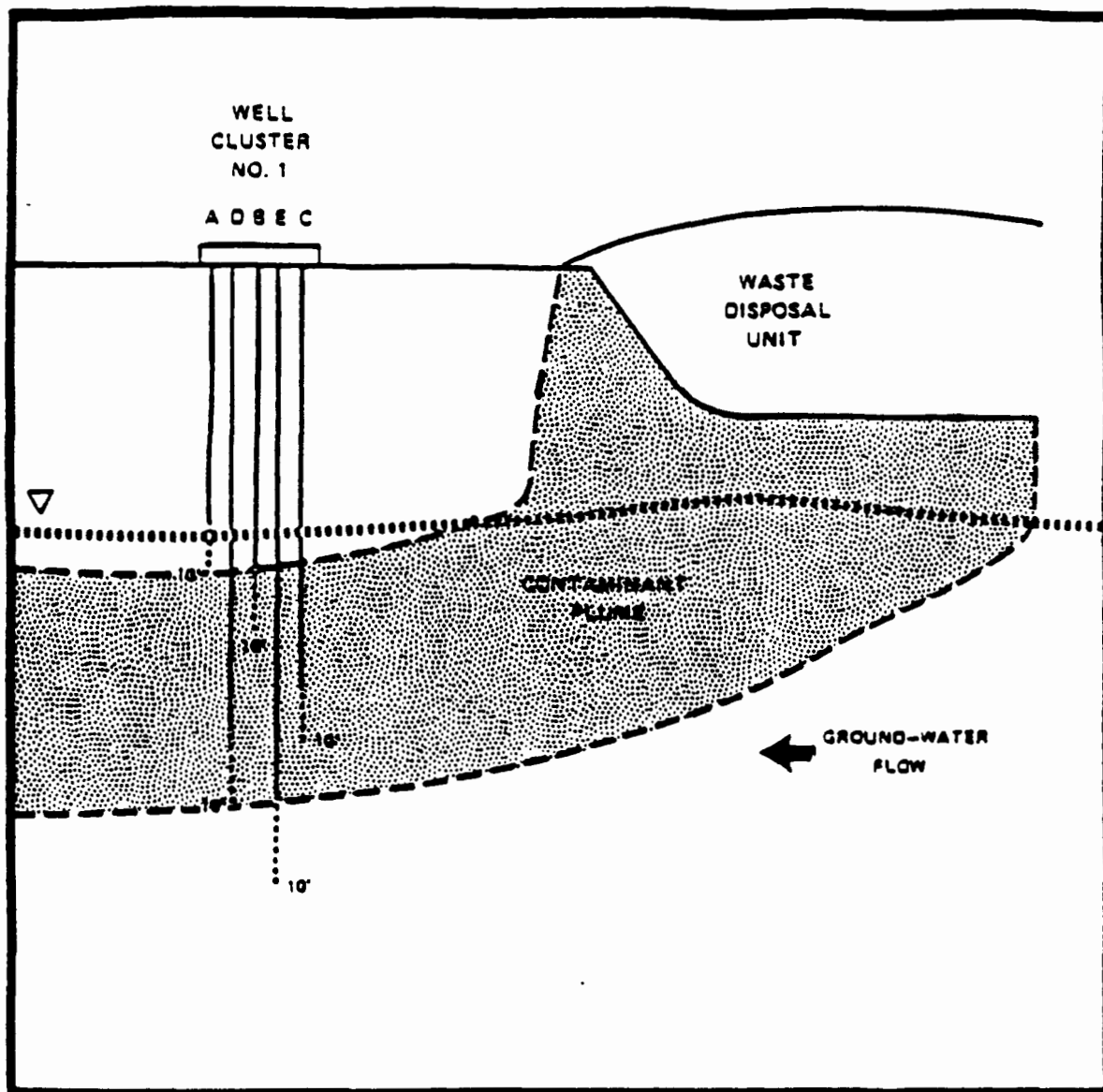
Several wells should be placed at the fringes of the release to define its vertical margins, and several wells should be placed within the release to identify constituents and concentrations. Care must be taken in placing contiguously screened wells close together because one well's drawdown may influence the next

and thus change the horizon from which its samples are drawn. Alternating lower and higher screens should reduce this effect (see Figure 10-20).

The specifications of sampling depths should clearly identify the interval over which each sample will be taken. It is important that these sampling intervals be sufficiently discrete to allow vertical profiling of constituent concentrations in ground water at each sampling location. Sampling will only provide measurements of the average contaminant concentration over the interval from which that sample is taken. Samples taken from wells screened over a large vertical interval may be subject to dilution effects from uncontaminated ground water lying outside the plume limits. The proposed screened interval should reflect the expected vertical concentration gradients within the release.

At those facilities where immiscible contaminants have been released and have migrated as a separate phase (see Figure 10-21), specific techniques will be necessary to evaluate their migration. The detection and sampling of immiscible layers requires specialized equipment that must be used before the well is evacuated for conventional sampling. Chapter 4 of the TEGD (U.S. EPA, 1986) contains a discussion of ground-water monitoring techniques that can be used to sample multi-phased contamination. These sampling techniques vary according to whether the immiscible phase is lighter than water (i.e., floats) or denser than water (i.e., sinks), and is also dependent on the thickness of the layer.

The formation of separate phases of immiscible contaminants in the subsurface is largely controlled by the rate of infiltration of the immiscible contaminant and the solubility of that contaminant in ground water. Immiscible contaminants generally have limited solubility in water. Thus, some amount of the immiscible contaminant released from a unit(s) will dissolve in the ground water and thus *migrate in solution*. However, if the amount of immiscible contaminant reaching ground water exceeds the ability of ground water to dissolve it (i.e., the constituent water solubility), the ground water in the upper portion of the water table aquifer will become saturated and the contaminant will form a separate immiscible phase. Hence, the contaminant will be present in the ground water at a concentration approaching its water solubility, as well as in a separate immiscible phase. If cosolvents are present, the concentration of the contaminant in the ground water can exceed the contaminant's water solubility, whether or not a separate immiscible phase is present.



LEGEND	
! :	WELL AND SCREEN
10'	SCREEN LENGTH
- - - - -	WATER TABLE

Figure 10-20

### Vertical Well Cluster Placement

At this point, the behavior and migration of an immiscible contaminant will be strongly influenced by its density relative to ground water. If the immiscible is less dense than ground water, it will tend to form a separate immiscible layer and migrate on top of the ground water. If the density of the immiscible contaminant is similar to that of ground water, it will tend to mix and flow as a separate phase with the ground water, creating a condition of multiphase flow.

If the density of the immiscible constituent is greater than ground water, it will tend to sink in the aquifer (see Figure 10-21). As the immiscible layer sinks and reaches unaffected ground water in a deeper portion of the aquifer, more of the immiscible contaminant will tend to enter into solution in ground water and begin to migrate as a dissolved constituent. However, if enough of the dense immiscible contaminants are present, some portion of these contaminants will continue to sink as a separate immiscible phase until a geologic formation of reduced permeability is reached. At this point, these dense contaminants will tend to form a layer that migrates along the geologic formation (boundary).

Immiscible phase contaminants may migrate at rates different than that of ground water. In addition, immiscible contaminants may not flow in the same direction as ground water. However, it is important to re-emphasize that some fraction of these contaminants may dissolve in ground water and migrate away from the facility as dissolved constituents.

Light immiscible contaminants tend to migrate downgradient as a floating layer above the saturated zone (see Figure 10-21). The hydraulic gradient is a major factor in the movement of this light immiscible layer. Other important factors involved in the migration rate of a light immiscible phase include the intrinsic permeability of the medium, and the density and viscosity of the contaminants. Oftentimes, an ellipsoidal plume will develop over the saturated zone as depicted in Figure 10-21. While it may be possible to analyze the behavior of a light immiscible layer using analytical or numerical models, the most practical approach for determining the rate and direction of migration of such a layer is to observe its behavior over time with appropriately located monitoring wells.

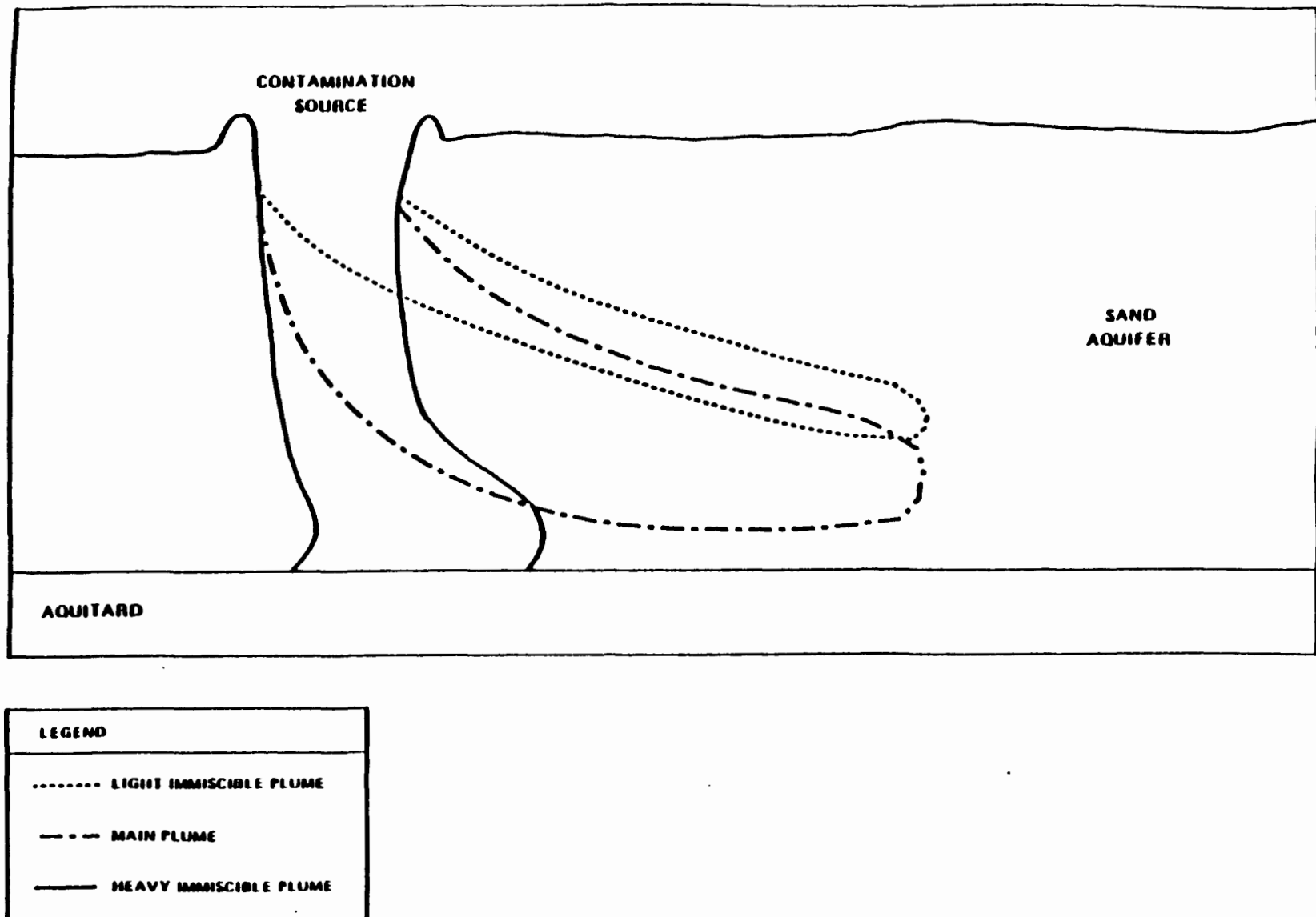


Figure 10-21. General schematic of multiphase contamination in a sand aquifer.

The migration of a layer of dense immiscibles resting on a low permeability geologic formation may be strongly influenced by gravity. Depending on the slope of the retarding formation, the immiscible layer may move with or in a different direction from the flow of the ground water. Consequently, the evaluation of the rate and direction of migration of a dense immiscible layer should include a determination of the configuration of the retarding formation on which the immiscible layer is migrating. The direction of migration and estimates of migration rates of dense immiscibles can then be obtained by including the gravitational forces induced by the slope of the retarding formation in the gradients used to calculate contaminant flow rates. If a dense immiscible layer(s) is expected or known, the monitoring plan should include procedures to verify its direction and rate of flow.

## **10.5 Data Presentation**

Section 5 of this guidance describes data presentation methods with examples. In addition to sorted data tables, the methods described for contaminant isopleth maps, geologic cross-sections, cross-sectional concentration contours, and fence diagrams should be useful for presenting ground-water investigation findings. The following presents specific data presentation methods that may be particularly useful for presenting ground-water investigation data.

### **10.5.1 Waste and Unit Characterization**

Waste and unit characteristics should be presented as:

- **Tables of waste constituents and concentrations;**
- **Tables of relevant physical and chemical properties of waste and constituents;**
- **Narrative description of unit dimensions, operations etc.; and**
- **Topographical map and plan drawings of facility and surrounding areas.**

### **10.5.2 Environmental Setting Characterization**

Environmental characteristics should be presented as follows:

- Tabular summaries of annual and monthly or seasonal relevant climatic information (e.g., temperature, precipitation);
- Narratives and maps of soil and relevant hydrogeological characteristics such as porosity, organic matter content and depth to ground water;
- Maps showing location of natural or man-made engineering barriers and likely migration routes; and
- Maps of geologic material at the site identifying the thickness, depth, and textures of soils, and the presence of saturated regions and other hydrogeological features.

Flow nets should be particularly useful for presenting environmental setting information for the ground-water medium. A flow net provides a graphical technique for obtaining solutions to steady state ground-water flow. A properly constructed flow net can be used to determine the distribution of heads, discharges, areas of high (or low) velocities, and the general flow pattern (McWhorter and Sunada, 1977).

The Ground Water Flow Net/Flow Line Technical Resource Document (TRD), NTIS PB86-224979. (U. S. EPA, 1985), provides detailed discussion and guidance in the construction of flow nets. Although the focus of this document is on the construction of vertical flow nets, the same data requirements and theoretical assumptions apply to horizontal flow nets. The fundamental difference between vertical and horizontal flow nets is in their application. A flow net in the horizontal plane may be used to identify suitable locations for monitoring wells whereas a flow net in the vertical plane would aid in determining the screened interval of a well.



The following excerpts from the Flow Net Document (U.S. EPA, 1985) explain data needs for flow net construction. Several assumptions must be made to construct a flow net:

- Ground-water flow is steady state, which means flow is constant with time;
- The aquifer is completely saturated;
- No consolidation or expansion of the soil or water occurs;
- The same amount of recharge occurs across the system; and
- Flow is laminar and Darcy's law is valid.

Knowledge of the hydrologic parameters of the ground-water system is required to properly construct a flow net. These parameters include:

- Head distribution, both horizontally and vertically;
- Hydraulic conductivity of the saturated zone;
- Saturated zone thickness; and
- Boundary conditions.

The distribution of head can be determined using time equivalent water level measurements obtained from piezometers and/or wells. Plotting the water level elevations on a base map and contouring these data will provide a potentiometric surface. Contour lines representing equal head are called lines of equipotential. Changes in hydraulic head, both horizontally and vertically within an aquifer, must be known for proper flow-net construction. These changes can be delineated with piezometers or monitoring wells installed at varying depths and spatially distributed. The data must be time equivalent because water levels change over time. Ground-water flow directions can be determined by drawing lines

perpendicular to the equipotential lines. Ground water flows from areas of higher hydraulic head to areas of lower hydraulic head.

The hydraulic conductivity of a material depends on the properties of the fluid and the media. Clayey materials generally have low hydraulic conductivities, whereas sands and gravels have high conductivities (U.S. EPA, 1985). Where flow crosses a boundary between different homogeneous media the ground-water flowlines refract and flow velocity changes due to an abrupt change in hydraulic conductivity. The higher permeability formation serves as a conduit to ground-water flow. This is visually apparent in a properly constructed flow net, because flow tubes are narrower in layers with higher conductivity because less area is necessary to conduct the same volume of ground water. In media of lower conductivity, flow tubes will be wider in order to conduct the same volume of flow (Cedergren, 1977). Construction of flow nets for layered geologic settings (heterogeneous, isotropic systems) are discussed in Section 2 of the flow net document (U.S. EPA, 1985).

The boundary conditions of an aquifer must also be known to properly construct a flow net. These boundary conditions will establish the boundaries of the flow net. The three types of boundaries are: 1) impermeable boundaries; 2) constant head boundaries; and 3) water table boundaries (Freeze and Cherry, 1979). Ground water will not flow across an impermeable boundary; it flows parallel to these boundaries. A boundary where the hydraulic head is constant is termed a constant head boundary. Ground-water flow at a constant head boundary is perpendicular to the boundary. Examples of constant head boundaries are lakes, streams, and ponds. The water table boundary is the upper boundary of an unconfined aquifer, and is a line of known and variable head. Flow can be at any angle in relation to the water table due to recharge and the regional ground-water gradient. The boundary conditions of an aquifer can be determined after a review of the geohydrologic data for a site (U.S. EPA, 1985).

Although a complete understanding of the mathematics of ground-water flow is not necessary for proper flow-net construction by graphical methods, a general understanding of the theory of ground-water flow is required. For a brief discussion of ground-water flow theory as applied to flow nets, refer to Section 1 of the flow net document (U.S. EPA, 1985). Detailed guidance on graphical

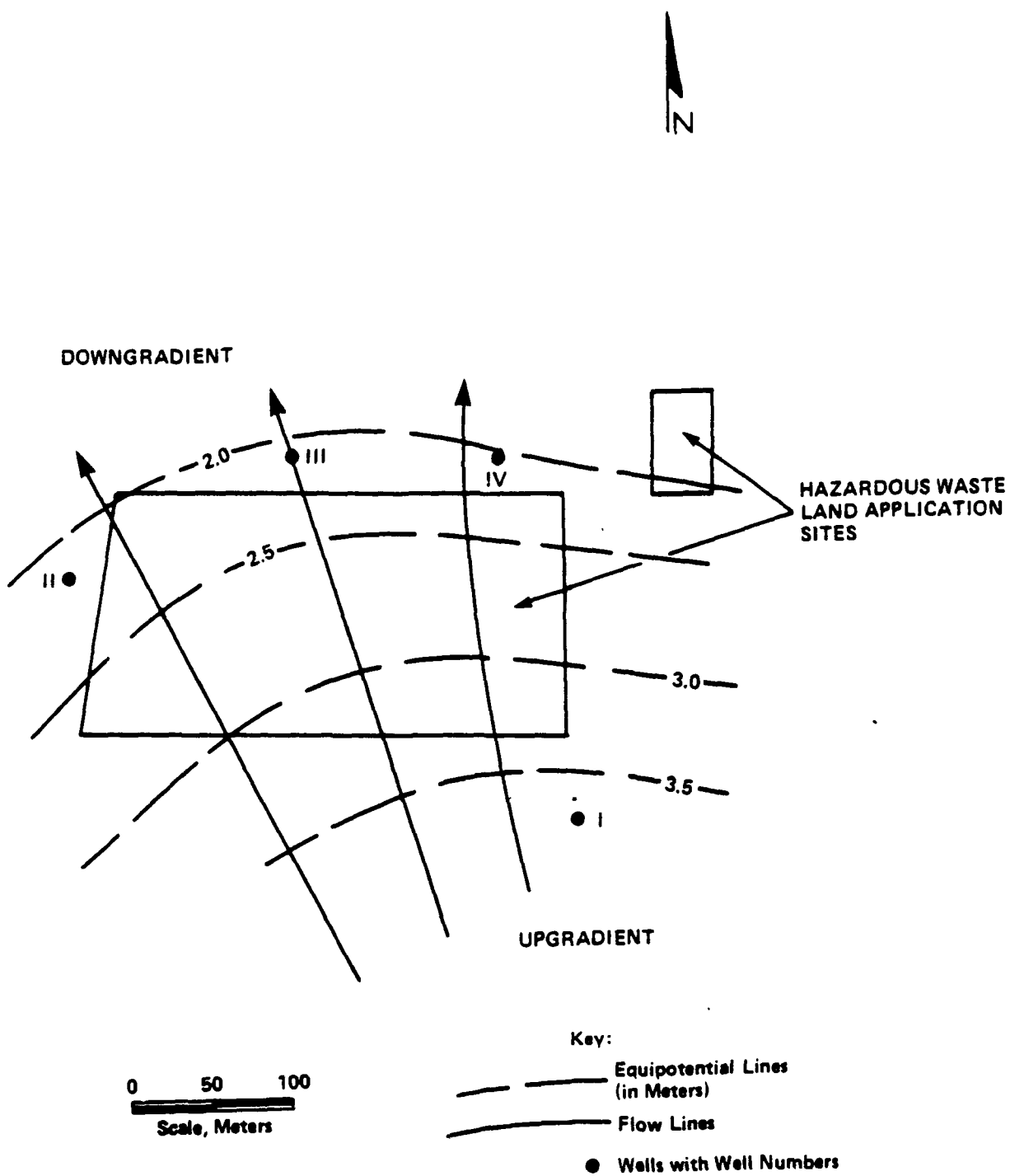
construction of flow nets is given in Section 2 of that document. Mathematical techniques can be used to construct flow nets although graphical techniques are the simplest and most commonly used. It is worth noting that flow nets are dimensionless.

When a flow net has been constructed for a site, it is advisable to test the adequacy of the flow net by installing additional piezometers at selected locations. If the site hydrogeology is adequately characterized by the flow net, the head values in the new piezometer(s) will not vary significantly from those predicted by the flow net.

The number of new piezometers needed to check the adequacy of the flow net would vary depending on a number of factors including size of the site, complexity of the site hydrogeology, amount of data used to construct the flow net, and the level of agreement between the site specific flow net and the regional flow regime. For example, at a site with predominantly horizontal flow and well defined stratigraphy, such as illustrated in Figure 10-22, a single new piezometer could test the flow net. For a site with multiple, interconnected aquifers and a significant vertical component of flow, such as illustrated in Figure 10-23, several nested piezometers might be necessary to test the flow net.

In evaluating flow nets and the results of flow net tests, several factors should be kept in mind. The head measurements in a new piezometer may not exactly match the values predicted by the flow net. Some variation is inherent in this type of measurement. The owner or operator should evaluate whether or not the difference between measured and predicted values is significant in the context of flow direction or flow velocity. A new value which reverses the direction of flow or redirects flow towards potential receptors would obviously be significant. A change in flow velocity as indicated by a revised gradient might be significant if the magnitude of the change is substantial or if an increased velocity suggests that the characterization needs to be extended to a greater distance.

There are several situations in which extreme caution is needed in evaluating a flow net test. In many cases, temporal variations will alter the potentiometric surface between the time the flow net is constructed and a test piezometer is installed. Examples of this situation would include locations with large seasonal



**Figure 10-22. Potentiometric surface showing flow direction**

10-90

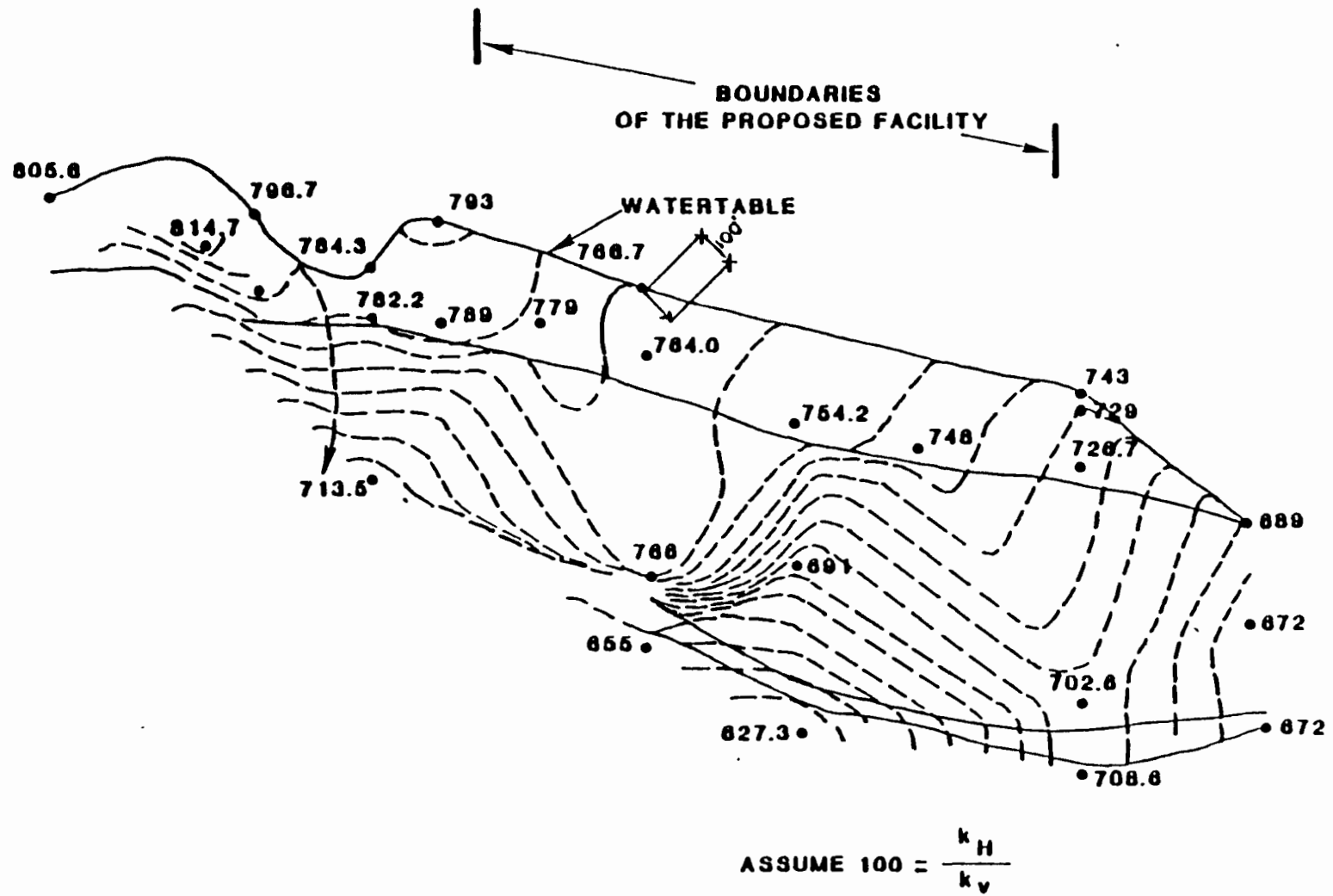


Figure 10-23. Approximate flow net

variations in ground-water levels. Another situation that would introduce problems in interpretation would be a site that is adjacent to tidally influenced surface waters.

Construction of flow nets is not appropriate or valid in certain instances. As discussed in the flow net document (U.S. EPA, 1985), these situations occur when there is a lack of three-dimensional hydrologic data for a ground-water system, and when ground-water flow in a system does not conform to the principles expressed by and assumptions made in Darcy's law. Scaling problems occur when the aquifer and/or geologic layers associated with a particular ground-water system are thin in relation to the length of the flow net. If a flow net is constructed for this situation, the flow net will be made up of squares that are too small to work with unless the scale is exaggerated. For sites where the assumption of steady-state flow is not valid, the construction of flow nets is very difficult. The flow net must be redrawn each time the flow field changes to simulate the transient conditions.

Lack of three-dimensional hydrologic data or hydrologically equivalent data for a ground-water flow system makes proper flow-net construction impossible. Hydrologic testing at various depths within an aquifer and determination of the vertical hydraulic conductivity of an aquifer are essential to provide the necessary data. If these data are not available it will be necessary to obtain them before a flow net can be constructed.

There are three types of ground-water systems in which the principles expressed by Darcy's law do not apply. The first is a system in which the flow is through materials with low hydraulic conductivities under extremely low gradients (Freeze and Cherry, 1979). The second is a system in which a large amount of flow passes through materials with very high hydraulic conductivities. The third is a system in which the porous media assumption is not valid. Darcy's law expresses linear relationships and requires that flow be laminar (flow in which stream lines remain distinct from one another). In a system with high hydraulic conductivity, flow is often turbulent. Turbulent flow is characteristic of karstic limestone and dolomite, cavernous volcanics, and fractured rock systems. Construction of flow nets for areas of turbulent flow would not be valid. The use of Darcy's law also requires the assumption of porous media flow. This assumption may not be valid for many fractured bedrock and karst environments where fractured flow is dominant or large solution features are present.

### 10.5.3 Characterization of the Release

The objective of monitoring is to estimate the nature, rate, and extent (3-dimensional) of the release. Data are, therefore, collected from a set of monitoring wells that will allow characterization of the dimensions and concentrations of constituents in the plume, as well as the rate of flow.

Subsequent monitoring phases may include the measurement of additional constituents in a more extensive well network than initial monitoring. This will necessitate careful data management. Sections 6.8 and 6.9 of the TEGD (U.S. EPA, 1986) provide useful guidance on organizing, evaluating, and presenting monitoring data. Section 4.7 of the TEGD addresses evaluation of the quality of ground-water data. Specific data presentation and evaluation procedures are presented below.

Migration rates can be determined by using the concentration of monitoring constituents over a period of time in wells aligned in the direction of flow. If these wells are located both at the edge of the release and in the interior of the release, subsequent analysis of the monitoring data can then provide an estimate of the rate of migration both of the contaminant front as a whole and of individual constituents within the release. This approach does not necessarily provide a reliable determination of the migration rates that will occur as the contaminant release moves further away from the facility, due to potential changes in geohydrologic conditions or degradation of the contaminants. More importantly, this approach requires the collection of a time series of data of sufficient duration and frequency to gauge the movement of contaminants. Such a delay is normally inappropriate during initial characterization of ground-water contamination because a relatively quick determination of at least an estimate of migration rates is needed to deduce the impact of ground-water contamination and to formulate an appropriate reaction.

Rapid estimates of migration rates should be made from aquifer properties obtained during the hydrogeologic investigation. The average linear velocity ( $v$ ) of the ground water should be calculated using the following form of Darcy's law:

$$\bar{v} = \frac{-K_i}{n_e}$$

where (K) is hydraulic conductivity, (i) is hydraulic gradient, and ( $n_e$ ) is the effective porosity. This assumes that contaminants flow at the same rate as ground water. This equation can be used to roughly estimate the rate of migration, both of the contaminant front as a whole, and of individual dissolved constituents within the release.

Rough estimates of migration rates beyond the facility property boundary can be made based on aquifer properties obtained during the site hydrogeologic characterization and knowledge of the physical and chemical properties of contaminants known to be present. By recognizing the various factors which can affect the transport of monitoring constituents, the owner or operator can determine approximate migration rates. Continued monitoring of the release over time should be conducted to verify the rate(s) of migration. Information on rate(s) of migration should be used in determining any additional monitoring well locations.

More refined estimates of contaminant migration rates should consider potential differential transport rates among various monitoring constituents. Differential transport rates are caused by several factors, including:

- Dispersion due to diffusion and mechanical mixing;
- Retardation due to adsorption and electrostatic interactions; and
- Transformation due to physical, chemical, and/or biological processes.

Dispersion results in the overall dilution of the contaminant; however, chromatographic separation of the contaminant constituents and differential dispersion effects can result in a contaminant arriving at a particular location before the arrival time computed solely on the average linear velocity of ground-water flow. Alternately, retardation processes can delay the arrival of contaminants beyond that calculated using average ground-water flow rate(s). Transformation of waste constituents is a complex process which can be difficult to estimate. While some contaminants, such as radionuclides, decay at a constant rate over time, most degradable chemicals are influenced by a variety of factors and the interactions of



these factors can be extremely difficult to predict. Local geologic variations will also affect constituent migration rates. Relating constituent migration rates to groundwater flow rates is a reasonable and relatively quick way to estimate contaminant flow rates. Where possible, contaminant-specific migration rates should also be determined.

Procedures for the evaluation of monitoring data vary in a site-specific manner, but should all result in determinations of the rate of migration, extent, and composition of hazardous constituents of the release. Where the release is obvious and/or chemically simple, it may be possible to characterize it readily from a descriptive presentation of concentrations found in monitoring wells and through geophysical measurements. Where contamination is less obvious or the release is chemically complex, however, the owner or operator may employ a statistical inference approach. The owner or operator should plan initially to take a descriptive approach to data analysis in order to broadly delineate the extent of contamination. Statistical comparisons of monitoring data among wells and/or over time may be necessary, should the descriptive approach provide no clear determination of the rate of migration, extent, and hazardous constituent composition of the release.

## **10.6 Field Methods**

### **10.6.1 Geophysical Techniques**

During the past decade, extensive development of remote sensing geophysical equipment, portable field instrumentation, field methods, analytical techniques and related computer processing have resulted in an improvement in the capability to characterize hydrogeology and contaminant releases. Some of these geophysical methods offer a means of detecting contaminant plumes and flow directions in both the saturated and unsaturated zones. Others offer a way to obtain detailed information about subsurface soil and rock characteristics. This capability to rapidly analyze subsurface conditions without disturbing the site may provide a better overall understanding of complex site conditions, with relatively low risk to the investigative team.

Various geophysical techniques, including electromagnetic, seismic refraction, electrical resistivity, ground penetrating radar, magnetic, and several borehole methods, can be applicable to RCRA Facility Investigations. Table 10-6 suggests appropriate applications for the various geophysical methods. Appendix C provides additional information.

## **10.6.2 Soil Boring and Monitoring Well Installation**

### **10.6.2.1 Soil Borings**

Soil borings should be sufficient to characterize the subsurface geology below the site. Section 1.2 of TEGD (U.S. EPA, 1986) provides criteria for adequate borings. A summary of these criteria is presented below.

- Installation of initial boreholes at a density based on criteria described in Table 10-7 and sufficient to provide initial information upon which to determine the scope of a more detailed evaluation of geology and potential pathways of contaminant migration.
- Initial boreholes should be drilled into the first confining layer beneath the uppermost aquifer. The portion of the borehole extending into the confining layer should be plugged properly after a sample is taken.
- Additional boreholes should be installed in numbers and locations sufficient to characterize the geology beneath the site. The number and locations of additional boreholes should be based on data from initial borings and indirect investigation.
- Collection of samples of every significant stratigraphic contact and formation, especially the confining layer should be taken. Continuous cores should be taken initially to ascertain the presence and distribution of small and large scale permeable layers. Once stratigraphic control is established, samples taken at regular intervals (e.g., five foot) could be substituted for continuous cores.

**TABLE 10-6. APPLICATIONS OF GEOPHYSICAL METHODS TO  
HAZARDOUS WASTE SITES**

APPLICATION	RADAR	ELECTROMAGNETICS	RESISTIVITY	SEISMIC	METAL DETECTOR	MAGNETOMETER
Mapping of Geohydrologic Features	1	1	1	1	-	-
Mapping of Conductive Leachates and Contaminant Plumes (e.g., Landfills, Acids, Bases)	2	1	1	-	-	-
Locations and Boundary Definition of Buried Trenches with Metal	1	1	2	2	2	2
Location and Boundary Definition of Buried Trenches without Metal	1	1	2	2	-	-
Location and Definition of Buried Metallic Objects (e.g., Drums, Ordinance)	2	2	-	-	1	1

1. Primary method - Indicates the most effective method
2. Secondary method - Indicates an alternate approach

Source: EPA, 1982, Geophysical Techniques for Sensing Buried Waste and Waste Migration

TABLE 10-7. FACTORS INFLUENCING DENSITY OF INITIAL BOREHOLES

Factors That May Substantiate Reduced Density of Boreholes:	Factors That May Substantiate Increased Density of Boreholes:
<ul style="list-style-type: none"> <li>● Simple geology (i.e., horizontal, thick, homogeneous geologic strata that are continuous across site that are unfractured and are substantiated by regional geologic information).</li> </ul>	<ul style="list-style-type: none"> <li>● Fracture zones encountered during drilling.</li> </ul>
<ul style="list-style-type: none"> <li>● Use of geophysical data to correlate well log data.</li> </ul>	<ul style="list-style-type: none"> <li>● Suspected pinchout zones (e.g., discontinuous areas across the site).</li> </ul>
	<ul style="list-style-type: none"> <li>● Geologic formations that are tilted or folded.</li> </ul>
	<ul style="list-style-type: none"> <li>● Suspected zones of high permeability that would not be defined by drilling at 300-foot intervals.</li> </ul>
	<ul style="list-style-type: none"> <li>● Laterally transitional geologic units with irregular permeability (e.g., sedimentary facies changes).</li> </ul>

- Boreholes in which permanent wells are not constructed should be sealed with materials at least an order of magnitude less permeable than the surrounding soil/sediment/rock in order to reduce the number of potential contaminant pathways.
- Samples should be logged in the field by a qualified professional geologist.
- Sufficient laboratory analysis should be performed to provide information concerning petrologic variation, sorting (for unconsolidated sedimentary units), cementation (for consolidated sedimentary units), moisture content, and hydraulic conductivity of each significant geologic unit or soil zone above the confining layer/unit.
- Sufficient laboratory analysis should be performed to describe the mineralogy (X-ray diffraction), degree of compaction, moisture content, and other pertinent characteristics of any clays or other fine-grained sediments held to be the confining unit/layer. Coupled with the examination of clay mineralogy and structural characteristics should be a preliminary analysis of the reactivity of the confining layer in the presence of the wastes present.

ASTM or equivalent methods should be used for soil classification, specifically:

- ASTM Method D422-63 for the particle size analysis of soils, which describes the quantitative determination of the distribution of particle sizes in soils; and
- ASTM Methods D2488-69, for the identification and description of soils based on visual examination and simple manual tests.

An adequate number of geologic cross-sections should be presented by the owner or operator. These cross-sections should adequately depict major geologic or structural trends and reflect geologic/structural features in relation to groundwater flow. Additionally, an owner or operator should provide a surface topo-

graphic map and aerial photograph of the site. Details regarding specific means for the presentation of geologic data are presented in Section 5 and in Section 1.2.3 of the TEGD (U.S. EPA, 1986).

#### **10.6.2.2 Monitoring Well Installation**

The owner or operator is advised to consult Chapter Three of the TEGD (U.S. EPA, 1986) for guidance on monitoring well installation. This chapter provides information on the following topics:

- **Drilling Methods for Installing Wells--Section 3.1 (TEGD)** discusses a variety of well drilling methods and corresponding applicability to the installation of RCRA monitoring wells. The selection of the actual drilling method that an owner or operator should use at a particular site is a function of site-specific geologic conditions. Of utmost importance is that the drilling method the owner or operator uses will minimize the disturbance of subsurface materials and will not cause contamination of the ground water.
- **Monitoring Well Construction Materials--Section 3.2 (TEGD)** discusses the selection of construction materials for RCRA monitoring wells which are durable enough to resist chemical and physical degradation, and do not interfere with the quality of ground-water samples. Specific well components that are of concern include well casings, well screens, filter packs, and annular seals.
- **Design of Well Intakes--Section 3.3 (TEGD)** discusses the design and construction of the intake of monitoring wells so as to: (1) allow sufficient ground-water flow to the well for sampling; (2) minimize the passage of formation materials (turbidity) into the well; and (3) ensure sufficient structural integrity to prevent the collapse of the intake structure.
- **Development of Wells--Section 3.4 (TEGD)** discusses the requirements for proper development of the monitoring wells to ensure turbid-free ground water samples.

- **Documentation of Well Construction Activity--Section 3.5 (TEGD) lists the information required for the design and construction of wells as follows:**
  - date/time of construction;
  - drilling method and drilling fluid used;
  - well location ( $\pm 0.5$  ft);
  - borehole diameter and well casing diameter;
  - well depth ( $\pm 0.1$  ft);
  - drilling and lithologic logs;
  - casing materials;
  - screen materials and design;
  - casing and screen joint type;
  - screen slot size/length;
  - filter pack material/size;
  - filter pack volume calculations;
  - filter pack placement method;
  - sealant materials (percent bentonite);
  - sealant volume (lbs/gallon of cement);
  - sealant placement method;
  - surface seal design/construction;
  - well development procedure;
  - type of protective well cap;
  - ground surface elevation ( $\pm 0.01$  ft);
  - top of casing elevation ( $\pm 0.01$  ft); and
  - detailed drawing of well (including dimensions).
  
- **Specialized Well Design--Section 3.6 (TEGD) discusses two cases which require special monitoring well design: (1) where dedicated pumps are used to draw ground-water samples; and (2) where light and/or dense phase immiscible layers are present.**
  
- **Evaluation of Existing Wells--Section 3.7 (TEGD) discusses how to evaluate the ability of existing wells to produce representative ground-water samples.**

Particular attention should be paid to the discussion in Section 3.2.1 regarding well casing materials (TEGD). It is imperative that well materials are nonreactive to contaminants that may be present in the ground water. In cases where the facility has existing monitoring wells which could potentially be used in the RFI, the owner or operator should evaluate whether these wells are capable of producing representative ground-water samples. A demonstration involving the installation of new well(s) near existing wells and the analysis and comparison of samples for the same monitoring constituents from both wells may be necessary if the existing wells' integrity is in question.

### **10.6.3 Aquifer Characterization**

#### **10.6.3.1 Hydraulic Conductivity Tests**

In addition to defining the direction of ground-water flow in the vertical and horizontal direction, the owner or operator should identify areas of high and low hydraulic conductivity within each formation. Variations in the hydraulic conductivity of subsurface materials can create irregularities in ground-water flow paths. Areas of high hydraulic conductivity represent areas of greater ground-water flow and, if contaminants are present, zones of potential migration. Therefore, information on hydraulic conductivities is generally required before the owner or operator can make reasoned decisions regarding well placements. It may be beneficial to use analogy or laboratory methods to corroborate results of field tests; however, only field methods provide direct information that is adequate to define the hydraulic conductivity.

Hydraulic conductivity can be determined in the field using single well tests, more commonly referred to as slug tests, which are performed by suddenly adding or removing a slug (known volume) of water from a well or piezometer and observing the recovery of the water surface to its original level. Similar results can be achieved by pressurizing the well casing, depressing the water level, and suddenly releasing the pressure to simulate removal of water from the well. Where slug tests are not appropriate (e.g., in fractured flow aquifers), hydraulic conductivity can be determined by multiple well (pumping) tests.



Slug testing is applied by hydrogeologists in many field situations. Interpretation of the results requires some professional judgement. Slug test accuracy is reduced when dealing with extreme values of hydraulic conductivity. Very low values (e.g., less than  $10^{-6}$  cm/sec) are more accurately measured by a resurg head test after bailing or pumping the well dry. High values (e.g., greater than  $10^{-2}$  cm/sec) generally require fast response electronic measurement equipment. High value cases in fractured rock or karst terrain may be misleading if the slug test is measuring the most permeable fractures or solution channels. In such cases, the test results may be misinterpreted to give an artificially high value for the formation as a whole.

When reviewing information obtained from slug tests, several criteria should be considered. First, slug tests are run on one well and, as such, the information obtained from single well tests is limited in scope to the geologic area directly adjacent to the well. Second, the vertical extent of screening will control the part of the geologic formation that is being tested during the slug test. That part of the column above or below the screened interval that has not been tested during the slug test will not have been adequately tested for hydraulic conductivity. Third, the methods used to collect the information obtained from slug tests should be adequate to measure accurately parameters such as changing static water (prior to initiation, during, and following completion of slug test), the amount of water added to, or removed from the well, and the elapsed time of recovery. This is especially important in highly permeable formations where pressure transducers and high speed recording equipment should be used. Lastly, interpretation of the slug test data should be consistent with the existing geologic information (e.g., boring log data). It is, therefore, important that the program of slug testing ensure that enough tests are run to provide representative measures of hydraulic conductivity, and to document lateral and vertical variation of hydraulic conductivity in the geologic materials below the site.

It is important that hydraulic conductivity measurements define hydraulic conductivity both in a vertical and horizontal manner across a site. In assessing hydraulic conductivity measurements, results from the boring program used to characterize the site geology should be considered. Zones of expected high permeability or fractures identified from drilling logs should generally be included in the determination of hydraulic conductivity. Additionally, information from

coring logs can be used to refine the data generated by slug tests (TEGD, Section 1.3.3).

Techniques for determining hydraulic conductivity are specified in Method 9100, Saturated Hydraulic Conductivity, Saturated Leachate Conductivity, and Intrinsic Permeability; from SW-846, Test Methods for Evaluating Solid Waste, 3rd edition, 1986. Method 9100 includes techniques for:

- Laboratory
  - sample collection;
  - constant head methods; and
  - falling head methods.
- Field
  - well construction;
  - well development;
  - single well tests (slug tests); and
  - references for multiple well (pumping) tests.

Cedergren, 1977 also provides an excellent discussion on aquifer tests, including laboratory methods (constant head and falling head), multiple well (pumping) tests (steady-state and nonsteady-state), and single well tests (open-end, packer, and others).

#### 10.6.3.2 Water Level Measurements

Water level measurements are necessary for determining depth to the water table and mapping ground-water contours to determine hydraulic gradients and flow rates. Depths to water are normally measured with respect to the top of the casing as in well depth determinations. Several methods are available, including the electric sounder and the chalked steel tape.

The electric sounder, although not the most accurate method, is recommended for initial site work because of the minimal potential for equipment

contamination and simplicity of use. Sounders usually consist of a conductivity cell at the end of a graduated wire, and a battery powered buzzer. When the cell contacts the water the increased conductivity completes the circuit and allows current to flow to the alarm buzzer. The depth to water can then be read from the graduations on the wire or the wire can be measured directly. This device may not be suitable for use if a potentially flammable or explosive layer (e.g., due to methane gas) is present in the well, unless it is an intrinsically safe device.

The chalked steel tape is a more accurate device for measuring static water levels. The lower 0.5 to 1.0 meters of a steel measuring tape is coated on either side with either carpenter's chalk or any of the various indicating pastes. A weight is attached to the lower end to keep the tape taut and it is lowered into the center of the well (condensate on the casing wall may prematurely wet the tape). A hollow "plopping" sound occurs when the weight reaches water, then the tape is lowered very slowly for at least another 15 cm, preferably to an even increment on the measuring tape. Next, the tape is carefully withdrawn from the well; water depth is determined by subtracting the wetted length of tape from the total length of tape in the well. In small diameter wells, the volume of the weight may cause the water to rise by displacement. In general, the use of indicating paste or chalk should be discouraged although they may not present a significant problem if water samples are not collected. As with all depth measurement devices, the wetted section of the tape and the weight must be thoroughly cleaned before reuse to avoid cross contamination.

The following sections of the TEGD (U.S. EPA, 1986) should be consulted for water level measurement requirements, and information on data interpretation:

- Ground-water level measurement (1.3.1.1);
- Interpretation of ground-water level measurements (1.3.1.2);
- Establishing vertical components of ground-water flow (1.3.1.3); and
- Interpretation of flow direction (1.3.1.4).

### 10.6.3.3 Dye Tracing

Dye tracing is a field method which can be used to measure the velocity of ground water for highly permeable strata (such as karst terrain and highly fractured rock media). When the velocity of flowing water and the hydraulic gradient at a common point are known, the permeability can be estimated. The hydraulic gradient ( $i$ ) of an existing water table can be estimated from wells in the area. If not, observation wells must be installed (Cedergren, 1977).

The procedure used in dye tracing involves the insertion of a dye, such as fluorescein sodium into a test hole and observation of the time it takes to emerge in a nearby test pit or on a bank from which seepage is emerging. The average linear velocity,  $v$ , is determined by dividing the distance traveled,  $L$ , by the time of travel,  $t$ . The effective porosity,  $n_e$ , is determined from test data for the in-place soil; if no tests are available, it is determined using the values in Table 10-4. The hydraulic conductivity is calculated from the equation:

$$K = \frac{\bar{v} n_e}{i}$$

It should be noted that the time required for tracers to move even short distances can be very long unless the formations contain highly permeable strata (Cedergren, 1977). As a result of the limitations of tracer techniques, this type of study is applied only in highly specialized locations. Uncertainties associated with the flow path make interpretation of the results difficult. This technique has been used effectively in conjunction with modeling in complex terrain with the tracer study serving to calibrate the model.

### 10.6.4 Ground-Water Sample Collection Techniques

The procedure for collecting a ground water sample involves the following steps presented in Chapter 4 of TEGD (U.S. EPA, 1986):

- Measurement of static water level elevation (4.2.1);

- Monitoring of immiscible layers (4.2.2);
- Well evacuation (4.2.3);
- Sample withdrawal (4.2.4);
- In situ or field analyses (4.2.5);
- Sample preservation and handling (4.3); and
- Chain-of-custody procedures (4.4).

Collection of static water level elevations on a continuing basis is important to determine if horizontal and vertical flow gradients have changed since initial site characterization, which could necessitate modification of the ground-water monitoring system. Steps should be taken to monitor for the presence and/or extent of light and/or dense phase immiscible organic layers before the well is evacuated for conventional sampling if wastes of this type are present at the facility.

The water standing in the well prior to sampling may not be representative of in situ ground-water quality. Therefore, the owner or operator should remove the standing water in the well so that water which is representative of the formation can replace the standing water. Purged water should be collected and screened with photoionization or organic vapor analyzers, pH, temperature, and conductivity meters. If these parameters and facility background data suggest that the water may be hazardous, it should be drummed and disposed of properly.

The technique used to withdraw a ground-water sample from a well should be selected based on a consideration of the parameters which will be analyzed in the sample. To ensure the ground-water sample is representative of the formation, it is important to avoid physically altering or chemically contaminating the sample during the withdrawal process. In order to minimize the possibility of sample contamination, the owner or operator should:

- (1) Use only polytetrafluoroethylene (PTFE) or stainless steel sampling devices; and
- (2) Use dedicated samplers for each well. (If a dedicated sampler is not available for each well, the sampler should be thoroughly cleaned between sampling events, and blanks should be taken and analyzed to ensure that cross contamination has not occurred.)

Section 4.2.4 of TEGD (U.S. EPA, 1986) includes specific factors to take into consideration regarding sample withdrawal.

Some parameters are physically or chemically unstable and must be tested either in the borehole using a probe (in situ) or immediately after collection using a field test kit. Examples of several unstable parameters include pH, redox potential, chlorine, dissolved oxygen, and temperature. Although specific conductivity (analogous to electrical resistance) is relatively stable, it is recommended that this characteristic also be determined in the field. Most conductivity instruments require temperature compensation; therefore, temperatures of the samples should be measured at the time conductivity is determined.

Many of the constituents and parameters that are included in ground-water monitoring programs are not stable and, therefore, sample preservation may be required. Refer to methods from EPA's Test Methods for Evaluating Solid Waste - Physical/Chemical Methods, 1986 (EPA/SW-846 GPO No. 955-001-00000-1) for sample preservation procedures and sample container requirements.

Improper sample handling may lead to sample contamination. Samples should be transferred into their containers in such a way as to minimize any contamination. Handling methods are analyte dependent. Special handling considerations for various analyte types are discussed in Section 4.3.3 of the TEGD (U.S. EPA, 1986).

An adequate chain-of-custody program will allow for the tracing of possession and handling of individual samples from the time of field collection through laboratory analysis. An owner or operator's chain-of-custody program requirements are detailed in Section 4 (Quality Assurance and Quality Control).

Chapter Four of the TEGD (U.S. EPA, 1986) may also be consulted for sample collection techniques as well as for analytical procedures, field and laboratory QA/QC requirements, and suggestions for reporting of ground-water data. Section 4 of this guidance presents a general discussion of QA/QC. In addition, the owner or operator may also find the following publication useful for sampling information:

- U.S. EPA. September, 1987. Practical Guide for Ground Water Sampling. EPA/600/2-85/104. NTIS PB86-137304. Washington, D.C. 20460.

## 10.7 Site Remediation

Although the RFI Guidance is not intended to provide detailed guidance on site remediation, it should be recognized that certain data collection activities that may be necessary for a Corrective Measures Study may be collected during the RFI. EPA has developed a practical guide for assessing and remediating contaminated sites that directs users toward technical support, potential data requirements and technologies that may be applicable to EPA programs such as RCRA and CERCLA. The reference for this guide is provided below.

U.S. EPA. 1988. Practical Guide for Assessing and Remediating Contaminated Sites. Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

This guide is designed to address releases to ground water as well as soil, surface water and air. A short description of the guide is provided in Section 1.2 (Overall RCRA Corrective Action Process), under the discussion of Corrective Measures Study.

In addition to the above described reference, several ground-water computer modeling programs are available to assist in designing ground-water remediation systems, such as the one referenced below. Application of such models should be based on site-specific considerations, as most models are not applicable to all situations.

U.S. EPA. 1987. Zone of Capture for Ground Water Corrective Action. IBM Compatible Computer Program and Users Guide. Federal Computer Products

## 10.8 Checklist

### RFI CHECKLIST- GROUND WATER

Site Name/Location \_\_\_\_\_

Type of Unit \_\_\_\_\_

1. Does waste characterization include the following information? (Y/N)

- Constituents of concern/supporting indicator parameters \_\_\_\_\_
- Concentrations of constituents \_\_\_\_\_
- Physical form of waste \_\_\_\_\_
- Chemical properties of waste (organic, inorganic, acid, base) and constituents \_\_\_\_\_
- pH \_\_\_\_\_
- pKa \_\_\_\_\_
- Viscosity \_\_\_\_\_
- Water solubility \_\_\_\_\_
- Density \_\_\_\_\_
- $K_{ow}$  \_\_\_\_\_
- Henry's Law Constant \_\_\_\_\_
- Physical and chemical degradation (e.g., hydrolysis) \_\_\_\_\_

2. Does unit characterization include the following information? (Y/N)

- Age of unit \_\_\_\_\_
- Construction integrity \_\_\_\_\_
- Presence of liner (natural or synthetic) \_\_\_\_\_
- Location relative to ground-water table or bedrock or other confining barriers \_\_\_\_\_
- Unit operation data \_\_\_\_\_
- Presence of cover \_\_\_\_\_
- Presence of on/offsite buildings \_\_\_\_\_
- Depth and dimensions of unit \_\_\_\_\_
- Inspection records \_\_\_\_\_
- Operation logs \_\_\_\_\_



## RFI CHECKLIST- GROUND WATER (Continued)

- Past fire, explosion, or other complaint reports \_\_\_\_\_
- Existing ground-water monitoring data \_\_\_\_\_
- Presence of natural or engineered barriers near unit \_\_\_\_\_

3. Does environmental setting information include the following information? (Y/N)

### Site Soil Characteristics

- Grain size distribution and gradation \_\_\_\_\_
- Hydraulic Conductivity \_\_\_\_\_
- Porosity \_\_\_\_\_
- Discontinuities in soil strata (e.g., faults) \_\_\_\_\_
- Degree and orientation of subsurface stratification and bedding \_\_\_\_\_

### Ground-Water Flow System Characterization

(Y/N)

- Use of aquifer \_\_\_\_\_
- Regional flow cells and flow nets \_\_\_\_\_
- Depth to water table \_\_\_\_\_
- Direction of flow \_\_\_\_\_
- Rate of flow \_\_\_\_\_
- Hydraulic conductivity \_\_\_\_\_
- Storativity/specific yield (effective porosity) \_\_\_\_\_
- Aquifer type (confined or unconfined) \_\_\_\_\_
- Aquifer characteristics (e.g., homogeneous, isotropic, leaky) \_\_\_\_\_
- Hydraulic gradient \_\_\_\_\_
- Identification of recharge and discharge areas \_\_\_\_\_
- Identification of aquifer boundaries (i.e., areal extent) \_\_\_\_\_
- Aquitard characteristics (depth, permeability degree of jointing, continuity) \_\_\_\_\_

## RFI CHECKLIST- GROUND WATER (Continued)

<u>Ground-Water Quality Characteristics</u>		(Y/N)
●	Presence of minerals and organics	_____
●	Background water quality	_____
●	Monitoring constituents and indicator parameters	_____
4.	Have the following data on the initial phase of the release characterization been collected?	(Y/N)
●	Extent	_____
●	Location	_____
●	Shape	_____
●	Hydraulic gradient across plume	_____
●	Depth to plume	_____
●	Chemistry and concentration	_____
●	Velocity	_____
●	Potential receptors	_____
5.	Have the following data on the subsequent phase(s) of the release characterization been collected?	(Y/N)
●	Extent	_____
●	Location	_____
●	Shape	_____
●	Hydraulic gradient across plume	_____
●	Depth to plume	_____
●	Chemistry and concentration	_____
●	Velocity	_____
●	Potential receptors	_____

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## **SECTION 11**

### **SUBSURFACE GAS**

#### **11.1 Overview**

This section applies to units with subsurface gas releases, primarily landfills, leaking underground tanks, and units containing putrescible organic matter, but may include other units.

The objective of an investigation of a subsurface gas release is to verify, if necessary, that subsurface gas migration has occurred and to characterize the nature, extent, and rate of migration of the release of gaseous material or constituents through the soil. Methane gas should be monitored because it poses a hazard due to its explosive properties when it reaches high concentrations, and also because it can serve as an indicator (i.e., carrier gas) for the migration of hazardous constituents. Other gases (e.g., carbon dioxide and sulfur dioxide) may also serve as indicators. This section provides:

- An example strategy for characterizing subsurface gas releases, which includes characterization of the source and the environmental setting of the release, and conducting monitoring to characterize the release itself;
- Formats for data organization and presentation;
- Field methods which may be used in the investigation; and
- A checklist of information that may be needed for release characterization.

The exact type and amount of information required for sufficient release characterization will be site-specific and should be determined through interactions between the regulatory agency and the facility owner or operator during the RFI process. This guidance does not define the specific data required in all instances;

however, it identifies possible information which may be necessary to perform release characterizations and methods for obtaining this information. The RFI Checklist, presented at the end of this section, provides a tool for planning and tracking information for subsurface gas release characterizations. This list is not meant to serve as a list of requirements for all subsurface gas releases to soil. Some releases will involve the collection of only a subset of the items listed.

As indicated in the following sections, subsurface gas migrates along the path of least resistance, and can accumulate in structures (primarily basements) on or off the facility property. If this occurs, it is possible that an immediate hazard may exist (especially if the structures are used or inhabited by people) and that interim corrective measures may be appropriate. Where conditions warrant, the owner or operator should immediately contact the regulatory agency and consider immediate measures (e.g., evacuation of a structure).

Case Study Numbers 23 and 24 in Volume IV (Case Study Examples) provide examples of subsurface gas investigations.

## **11.2 Approach for Characterizing Subsurface Gas Releases**

### **11.2.1 General Approach**

The collection and review of existing information for characterization of the contaminant source and the environmental setting will be the primary basis for development of a conceptual model of the release and subsequent development of monitoring procedures to characterize the release. A conceptual model of the release should be formulated using all available information on the waste, unit characteristics, environmental setting, and any existing monitoring data. This model (not a computer or numerical simulation model) should provide a working hypothesis of the release mechanism, transport pathway/mechanism, and exposure route (if any). The model should be testable/verifiable and flexible enough to be modified as new data become available.



The conceptual model for subsurface gas should consider the ability of the waste to generate gaseous constituents, the conditions which would favor subsurface migration of the gaseous release, and the likelihood of such a release to reach and accumulate within structures (e.g., residential basements) at explosive or toxic concentrations.

Additional data collection to characterize the contaminant source and environmental setting may be necessary prior to implementing the monitoring procedures. The subsurface pathway data collection effort should be coordinated, as appropriate, with similar efforts for other media investigations.

Characterization of subsurface gas releases can be accomplished through a phased monitoring approach. An example of a strategy for characterizing subsurface gas releases is shown in Table 11-1.

Development of monitoring procedures should include determining the specific set of subsurface gas indicators and constituents for monitoring. Methane, carbon dioxide, and site-specific volatile organics (e.g., vinyl chloride), can be used to identify the presence of subsurface gas during initial monitoring. Subsequent monitoring will generally involve these gases, but may also involve various other constituents. Development of the monitoring procedures should also include selection of the appropriate field and analytical methods. Selection of these methods will be dependent on site and unit specific conditions.

An initial monitoring phase should be implemented using screening techniques and appropriate monitoring constituent(s). A subsurface gas migration model can be used, as applicable, as an aid in selection of monitoring locations. Subsequent monitoring will generally be necessary if subsurface gas migration is detected during the initial survey. This additional monitoring may include a wider range of constituents.

Characterization of a subsurface gas release can involve a number of tasks to be completed throughout the course of the investigation. These tasks are listed in Table 11-2 with associated techniques and data outputs.

**TABLE 11-1**

**EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES OF SUBSURFACE GAS<sup>1</sup>**

**INITIAL PHASE**

- 1. Collect and review existing information on:**
  - Waste
  - Unit
  - Environmental setting
  - Contaminant releases, including inter-media transport
- 2. Identify any additional information necessary to fully characterize release:**
  - Waste
  - Unit
  - Environmental setting
  - Contaminant releases, including inter-media transport
- 3. Develop monitoring procedures:**
  - Formulate conceptual model of release
  - Determine monitoring program objectives
  - Determine monitoring constituents and indicator parameters
  - Sampling approach selection
  - Sampling schedule
  - Monitoring locations
  - Analytical methods
  - QA/QC procedures
- 4. Conduct Initial Monitoring:**
  - Use subsurface gas migration model to estimate release dimensions (plot 1.0 and 0.25 lower explosion limit isopleths for methane)
  - Monitor ambient air and shallow boreholes around the site using portable survey instruments to detect methane and other indicator parameters
  - Use results of above two steps to refine conceptual model and determine sampling locations and depths; conduct limited well installation program. Monitor well gas and shallow soil boreholes for indicators and constituents
  - Monitor surrounding structures (e.g., buildings and engineered conduits) for other indicator parameters and constituents
- 5. Collect, evaluate and report results:**
  - Compare methane results with lower explosion limit (LEL) and 0.25 LEL and report results immediately to regulatory agency if these values are exceeded

**TABLE 11-1 (Continued)**

**EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES OF SUBSURFACE GAS<sup>1</sup>**

- Summarize and present data in appropriate format
- Determine if monitoring program objectives were met
- Determine if data are adequate to describe nature, rate and extent of release
- Report results to regulatory agency

**SUBSEQUENT PHASES (If Necessary)**

1. Identify additional information necessary to characterize release:
  - Modify conceptual model and identify additional information needs
  - Selection of monitoring constituents for subsequent phase
  - Spatial extent of subsurface gas migration
  - Concentration levels of methane and other indicators and additional monitoring constituents
  - Evaluate potential role of inter-media transport
2. Expand initial monitoring as necessary:
  - Expand subsurface gas well monitoring network
  - Add or delete constituents and parameters
  - Expand number of structures subject to monitoring
  - Increase or decrease monitoring frequency
3. Conduct subsequent monitoring:
  - Perform expanded monitoring of area for methane and other indicator parameters and specific monitoring constituents
  - Further monitoring of surrounding structures if warranted
4. Collect, evaluate and report results/identify additional information necessary to characterize release:
  - Compare monitoring results to health and environmental criteria and identify/respond to emergency situations and identify priority situations that warrant interim corrective measures - notify regulatory agency immediately
  - Summarize and present data in appropriate format
  - Determine if monitoring program objectives were met
  - Determine if data are adequate to describe nature, rate, and extent of release
  - Identify additional information needs
  - Determine need to expand monitoring system
  - Evaluate potential role of inter-media transport
  - Report results to regulatory agency

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<sup>1</sup> The possibility for inter-media transport of contamination should be anticipated throughout the investigation.

**TABLE 11-2  
RELEASE CHARACTERIZATION TASKS FOR SUBSURFACE GAS**

Investigatory Tasks	Investigatory Techniques	Data Presentation Formats/Outputs
<b>1. Waste/Unit Characterization</b> <ul style="list-style-type: none"> <li>- Identification of waste constituents of concern</li> <li>- Identification of unit characteristics which promote a subsurface gas release</li> </ul>	<ul style="list-style-type: none"> <li>- See Sections 3, 7 and Appendix B</li> <li>- See Section 7</li> </ul>	<ul style="list-style-type: none"> <li>- Listing of potential monitoring constituents</li> <li>- Description of the unit, if active, and operational conditions concurrent with subsurface gas sampling</li> </ul>
<b>2. Environmental Setting Characterization</b> <ul style="list-style-type: none"> <li>- Definition of climate</li> <li>- Definition of site-specific meteorological conditions</li> <li>- Definition of soil conditions</li> <li>- Definition of site-specific terrain</li> <li>- Identification of subsurface gas migration pathways</li> <li>- Identification and location of engineered conduits</li> <li>- Identification and location of surrounding structures</li> </ul>	<ul style="list-style-type: none"> <li>- Climate summaries for regional National Weather Service stations</li> <li>- Meteorological data from regional National Weather Service stations</li> <li>- See Section 9 (e.g., porosity, moisture content, organic carbon content, etc.)</li> <li>- See Sections 7, 9 and Appendix A</li> <li>- Review of unit design and environmental setting</li> <li>- Review of water level measurements</li> <li>- Examination of maps, engineering diagrams, etc.</li> <li>- Ground penetrating radar (See Appendix C)</li> <li>- Survey of surrounding area</li> </ul>	<ul style="list-style-type: none"> <li>- Tabular summaries for parameters of interest</li> <li>- Tabular listing for parameters of interest concurrent with subsurface gas sampling</li> <li>- Soil physical properties</li> <li>- Topographic map of site area</li> <li>- Identification of possible migration pathways</li> <li>- Depth to water table</li> <li>- Description of the examination</li> <li>- Results of study</li> <li>- Map with structures identified</li> </ul>
<b>3. Release Characterization</b> <ul style="list-style-type: none"> <li>- Model extent of release</li> <li>- Screening evaluation of subsurface gas release</li> <li>- Measurement for specific constituents</li> </ul>	<ul style="list-style-type: none"> <li>- Gas migration model (See Appendix D)</li> <li>- Shallow borehole monitoring and monitoring in surrounding buildings for indicators and specific constituent(s)</li> <li>- Selected gas well installation and monitoring</li> <li>- Monitoring in surrounding buildings</li> </ul>	<ul style="list-style-type: none"> <li>- Estimated methane concentration isopleths for LEL and 0.25 LEL</li> <li>- Listing of concentrations levels</li> <li>- Tables of concentrations</li> <li>- Detailed assessment of extent and magnitude of releases</li> <li>- Tables of concentrations</li> </ul>

As monitoring data become available, both within and at the conclusion of discrete investigation phases, it should be reported to the regulatory agency as directed. The regulatory agency will compare the monitoring data to applicable health and environmental criteria to determine the need for (1) interim corrective measures; and/or (2) a Corrective Measures Study. In addition, the regulatory agency will evaluate the monitoring data with respect to adequacy and completeness to determine the need for any additional monitoring efforts. The health and environmental criteria and a general discussion of how the regulatory agency will apply them are supplied in Section 8. A flow diagram illustrating RFI decision points is provided in Section 3 (See Figure 3-2).

Notwithstanding the above process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For these situations, the owner or operator is directed to obtain and follow the RCRA Contingency Plan requirements under 40 CFR Part 264, Subpart D.

#### **11.2.2 Inter-media Transport**

Contaminated ground water and contaminated soil can result in releases of gaseous constituents via subsurface migration, primarily due to volatilization of organic constituents. Information collected from ground-water and soil investigations may provide useful input data for the subsurface gas pathway characterization. It may also be more efficient to jointly conduct monitoring programs for such related media (e.g., concurrent ground water and subsurface gas migration monitoring programs).

Subsurface gas migration also has the potential for inter-media transport (e.g., transfer of contamination from subsurface gas to the soil and air media). Therefore, information from the subsurface gas migration investigation will also provide useful input for assessing soil contamination and potential air emissions.

#### **11.3 Characterization of the Contaminant Source and the Environmental Setting**

The type of waste managed in the unit will determine the conditions under which the gas can be generated, and the type of unit and characteristics of the

surrounding environment (e.g., soil type and organic content) establishes potential migration pathways. Units which may be of particular concern for subsurface gas releases contain putrescible organic material and generally include below grade landfills, units closed as landfills (e.g., surface impoundments), and underground tanks. These types of units may have waste deposited or stored at such depths as to allow for subsurface gas generation by volatilization or decomposition of organic wastes and subsequent migration (see Figures 11-1 and 11-2).

The nature and extent of contamination are affected by environmental processes such as dispersion, diffusion, and degradation, that can occur before and after the release occurred. Factors that should be considered include soil physical and chemical properties, subsurface geology and hydrology, and in some cases, climatic or meteorologic patterns.

The principle components of "landfill gas" are generally methane and carbon dioxide produced by the anaerobic decomposition of organic materials in wastes. Methane is of particular concern due to its explosive/flammable properties, although other gases of concern could be present. The presence of these other gases in a unit is primarily dependent upon the types of wastes managed, the volatilities of the waste constituents, temperature, and possible chemical interactions within the waste. Previous studies (e.g., Hazardous Pollutants in Class II Landfills, 1986, South Coast Air Quality Management District, El Monte, California and U.S. EPA. 1985. Technical Guidance for Corrective Measures - Subsurface Gas. Washington, D.C. 20460) have indicated that the predominant components of landfill gas are methane and carbon dioxide. Methane is generally of greater concentration, however, carbon dioxide levels are generally also high, especially during the early stages of the methane generation process. Concentrations of subsurface gas constituents which may accompany methane/carbon dioxide are generally several orders of magnitude less than methane. In some cases (e.g., associated with acidic refinery wastes) sulfur dioxide may be the primary subsurface gas.

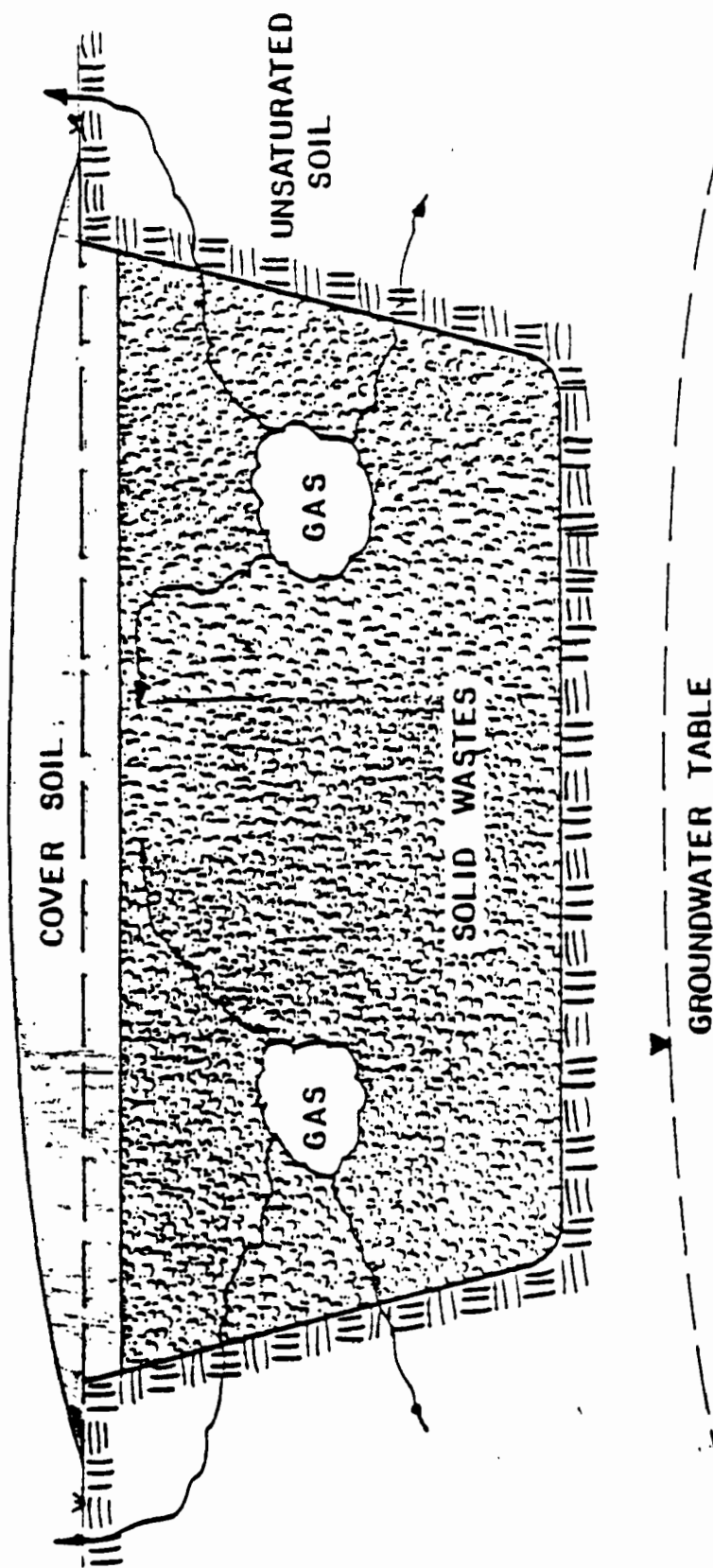
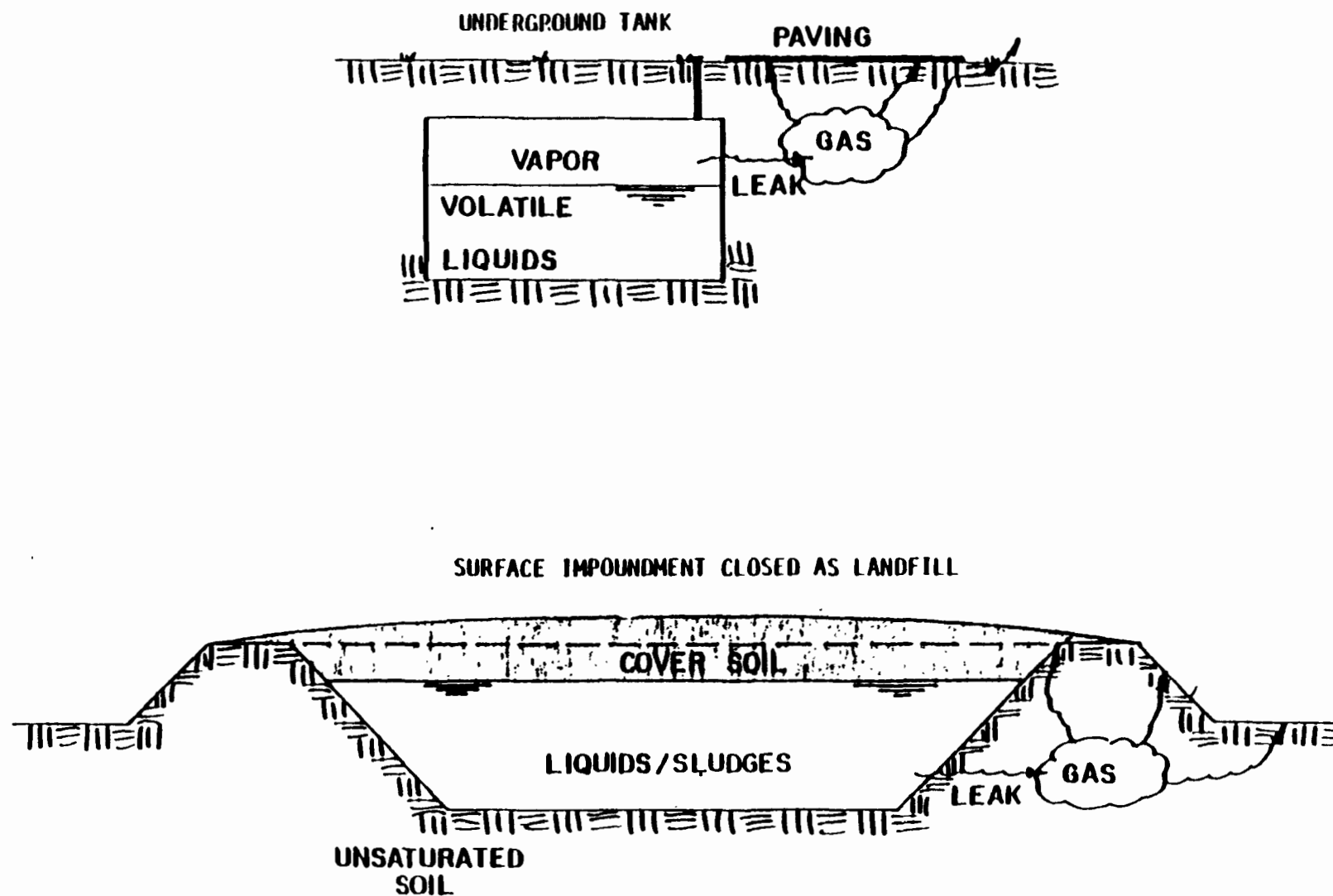


Figure 11-1. Subsurface Gas Generation/Migration in a Landfill  
 (Note: Gas may also migrate slowly through cover soil.)



**Figure 11-2.** Subsurface Gas Generation/Migration from Tanks and Units Closed as Landfills (Note: Gas may also migrate slowly through cover soil.)



### **11.3.1 Waste Characterization**

#### **11.3.1.1 Decomposition Processes**

Subsurface gas generation occurs by biological, chemical, and physical decomposition of disposed or stored wastes. Waste characteristics usually affect the rate of decomposition. The owner or operator should review unit-specific information (waste receipts, waste composition surveys, and any other records of wastes managed) to determine waste type, quantities, location, dates of disposal, waste moisture content, organic content, etc.

The three decomposition processes known to occur in the production of subsurface gases are biological decomposition, chemical decomposition, and physical decomposition. These are discussed below:

##### **11.3.1.1.1 Biological Decomposition**

The extent of biological decomposition and subsequent gas generation from a given waste is related to the type of unit. Biological decomposition, due primarily to anaerobic microbial degradation, is significant in most landfills and units closed as landfills which contain organic wastes. Generally, the amount of gas generated in a landfill is directly related to the amount of organic matter present.

Organic wastes such as food, sewage sludges, and garden wastes decompose rapidly, resulting in gas generation shortly after burial, with high initial yields. Much slower decomposing organic wastes include paper, cardboard, wood, leather, some textiles and several other organic components. Inorganic and inert materials such as plastics, man-made textiles, glass, ceramics, metals, ash, and rock do not contribute to biological gas production. At units closed as landfills, waste types that undergo biological decomposition might include bulk organic wastes, food processing sludges, treatment plant sludges, and composting waste.

Waste characteristics can increase or decrease the rate of biological decomposition. Factors that enhance anaerobic decomposition include high moisture content, adequate buffer capacity and neutral pH, sufficient nutrients (nitrogen and phosphorus), and moderate temperatures. Characteristics that

generally decrease biological decomposition include the presence of acidic or basic pH, sulfur, soluble metals and other microbial toxicants. The owner or operator should review the waste characteristic information to document if biological decomposition and subsequent gas generation may be occurring.

Under anaerobic conditions, organic wastes are primarily converted by microbial action into carbon dioxide and methane. Trace amounts of hydrogen, ammonia, aromatic hydrocarbons, halogenated organics, and hydrogen sulfide may also be present. With regard to subsurface migration, the primary gases of concern are methane (because of its explosive properties) and constituents that may be present in amounts hazardous to human health or the environment.

#### 11.3.1.1.2 Chemical Decomposition

Gas production by chemical reaction can result from the disposal or storage of incompatible wastes. Reactive or ignitable wastes can produce explosive or heat-producing reactions, resulting in rapid production of gases, and increased pressures and temperatures. Under acidic conditions, a strong oxidizing agent can react with organic wastes to produce carbon dioxide and ammonia which can migrate from the unit, possibly providing a transport mechanism for other gaseous components.

Under typical conditions, gas production from chemical reactions is not expected to occur at landfills or units closed as landfills. However, volatile liquids stored in underground tanks may have a significant potential to create a release by chemical reaction. Good waste management practices, particularly the proper design and operation (e.g., pressure-relief valves and leak detection systems) of underground tanks can minimize the potential for gas release.

#### 11.3.1.1.3 Physical Decomposition

Physical decomposition phenomena include volatilization and combustion. Volatilization can result in subsurface gas generation in underground tanks if there is a leak or puncture. The greater a compound's vapor pressure, the greater will be its potential to volatilize. Maintenance of underground tanks (e.g., pressure-relief valves and leak detection systems) can minimize volatilization.

Combustion processes (e.g., underground fires) sometimes occur at active landfills and result in subsurface gas release. Combustion can convert wastes to byproducts such as carbon dioxide, carbon monoxide, and trace toxic components. Combustion processes can also accelerate chemical reaction rates and biological decomposition, creating greater potential for future subsurface gas generation and subsequent release. The owner or operator should review facility records to determine if combustion has occurred and when.

#### 11.3.1.2 Presence of Constituents

Subsurface gas generation and migration of methane is of concern because of its explosive properties. In addition, methane and other decomposition gases can facilitate the migration of volatile organic constituents that may be of concern because of potential toxic effects. Subsurface gas migration due to leaks from subsurface tanks may also be associated with a variety of volatile organic constituents.

In determining the nature of a release, it may be necessary to determine the specific waste constituents in the unit. Two means of obtaining these data are:

- (1) Review of facility records. Review of facility records may not provide adequate information (e.g., constituent concentrations) for RFI purposes. For example, facility records of waste handled in the unit may only indicate generic waste information. Knowledge of individual constituents and concentrations is generally needed for purposes of the RFI.
- (2) Conducting waste sampling and analysis. When facility records do not indicate the specific constituents of the waste which are likely to be released and may migrate as subsurface gas, direct waste characterization may be necessary. This effort, aimed at providing compound specific data on the waste, can be focused in terms of the constituents for which analysis should be performed through review of the waste types in the unit. In some cases, however, the generic waste description (e.g., flammable liquids) will not give an indication of the

specific constituents present, and analysis for all of the constituents of concern as gaseous releases (See Appendix B, List 2) may be required.

Additional guidance on identification of monitoring constituents is presented in Section 3.6. Section 7 provides guidance on waste characterization.

#### 11.3.1.3 Concentration

Determination of concentrations of the constituents of concern in the waste may indicate those constituents which are of prime concern for monitoring. The concentration of a constituent in a waste (in conjunction with its physical/chemical properties and total quantity) provides an indication of the gross quantity of material that may be released in the gaseous form.

#### 11.3.1.4 Other Factors

In addition to the factors described above, determination of the potential for volatilization of the waste constituents will help determine if they may be released. The parameters most important when assessing the potential for volatilization of a constituent include the following:

- Water solubility. The solubility in water indicates the maximum concentration at which a constituent can dissolve in water at a given temperature. This value can be used to estimate the distribution of a constituent between the dissolved aqueous phase in the unit and the undissolved solid or immiscible liquid phase. Considered in combination with the constituent's vapor pressure, it can provide a relative assessment of the potential for volatilization.
- Vapor pressure. Vapor pressure refers to the pressure of vapor in equilibrium with a pure liquid. It is best used in a relative sense; constituents with high vapor pressures are more likely to be released in the gaseous form than those with low vapor pressures, depending on other factors such as relative solubility and concentration (i.e., at high concentrations releases can occur even though a constituent's vapor pressure is relatively low).

- Octanol/water partition coefficient. The octanol/water partition coefficient indicates the tendency of an organic constituent to sorb to organic components of the soil or waste matrices of a unit. Constituents with high octanol/water partition coefficients will adsorb readily to organic carbon, rather than volatilizing to the atmosphere. This is particularly important in landfills and land treatment units, where high organic carbon contents in soils or cover material can significantly reduce the release potential of vapor phase constituents.
- Partial pressure. For constituents in a mixture, particularly in a solid matrix, the partial pressure of a constituent will be more significant than the pure vapor pressure. In general, the greater the partial pressure, the greater the potential for release. Partial pressures will be difficult to obtain. However, when waste characterization data is available, partial pressures can be estimated using methods commonly found in engineering and environmental science handbooks.
- Henry's Law constant. Henry's law constant is the ratio of the vapor pressure of a constituent and its aqueous solubility (at equilibrium). It can be used to assess the relative ease with which the compound may be removed from the aqueous phase via vaporization. It is accurate only when used in evaluating low concentration wastes in aqueous solution. Thus it will be most useful when the unit being assessed is a surface impoundment or tank containing dilute wastewaters. As the value increases, the potential for significant vaporization increases, and when it is greater than 0.001, rapid volatilization will generally occur.
- Raoult's Law. Raoult's Law can be used to predict releases from concentrated aqueous solutions (i.e., solutions over 10% solute). This will be most useful when the unit contains concentrated waste streams.

### 11.3.2 Unit Characterization

Unit design (e.g., waste depth, unit configuration, and cover materials) also affects gas generation. Generally, the amount of gas generated increases with

landfill volume and often with landfill depth. Deeper landfills have a proportionally larger anaerobic zone, greater insulation and compaction, and are more likely to confine gas production. Deeper landfills, such as trench fills or canyon fills, can trap gases along confining sidewalls and bottom bedrock or ground water. Daily, interim, and final cover soils can confine gases within the landfill. This is particularly true for low permeability cover soils (e.g., clays) which impede vertical gas migration. Conversely, mounds or shallow landfills have large surface areas through which gases can vent more easily.

Unit operations, such as methods and procedures used to segregate and isolate inert wastes, to prevent moisture infiltration, to compact and increase the density of the waste, and to minimize or prevent mixing of waste types, can affect resultant releases of subsurface gases. Daily covering of the unit may inhibit decomposition and thus gas generation and subsequent migration.

Certain units have a high potential for allowing the movement of subsurface gas. These units are those that receive and/or store large volumes of decomposable wastes, volatile organic liquids, or highly reactive materials. Subsurface gas migration may occur especially when major portions of a land-based unit are below grade. Gas generated by these units can migrate vertically and laterally from the unit, following the path of least resistance.

Some units are operated above grade or in relatively shallow soils (e.g., surface impoundments, land treatment units). The potential for subsurface gas migration from such units is usually low. Gases generated by such units will generally be vented to the atmosphere unless prevented by a natural barrier (e.g., frozen ground) or an engineered barrier (e.g., soil cover).

Information on unit operations will therefore be important in assessing the potential for subsurface gas migration. Unit operational data may also be required concurrent with any subsurface gas sampling activities. It is particularly important to obtain operational data on any gas collection system in use at the time of sampling. These gas collection systems can significantly affect subsurface gas migration rates, patterns and constituent concentration levels.

Generally, the units that pose the greatest potential for subsurface gas migration include landfills, sites closed as landfills, and underground storage tanks. These are discussed below.

#### **11.3.2.1 Landfills**

Gas generated in landfills can vent vertically to the atmosphere and/or migrate horizontally through permeable soil, as shown in Figure 11-1. Closure of the landfill or periodic covering of cells or lifts with impermeable caps may impede the vertical movement of the gases, forcing them to migrate laterally from the unit. Gas migration laterally through the subsurface (e.g., through underground utility line channels or sand lenses) may accumulate in structures on or off the facility property.

#### **11.3.2.2 Units Closed as Landfills**

Gas generation and subsequent migration is likely to occur at units closed as landfills containing organic wastes, as previously discussed. Although surface impoundments and waste piles may be closed as landfills, they tend to produce less gas than landfills because they generally contain smaller quantities of decomposable and volatile wastes and are generally at shallow depths. Closure of such units with an impermeable cover will, however, increase the potential for lateral gas movement and accumulation in onsite and offsite structures (see Figure 11-2).

#### **11.3.2.3 Underground Tanks**

Subsurface gas release and subsequent migration may occur if an underground tank is leaking. Underground tanks frequently contain volatile liquids that could enter the unsaturated zone should a leak occur (see Figure 11-2).

### **11.3.3 Characterization of the Environmental Setting**

#### **11.3.3.1 Natural and Engineered Barriers**

Subsurface conditions at the site should be evaluated to determine likely gas migration routes. Due to the inherent mobility of gases, special attention must be

paid to zones of high permeability created by man-made, biological, and physical weathering action. These zones include backfill around pipes, animal burrows, solution channels, sand and/or gravel lenses, desiccation cracks, and jointing in bedrock. The presence of dead rodents, snakes and other burrowing animals is usually a good indication of a potential subsurface gas pathway.

Natural and engineered barriers can also affect gas migration, generally by inhibiting migration pathways. Natural barriers to gas migration include surface water, ground water, and geologic formations. Engineered barriers include walls, onsite structures, underground structures, caps, liners, and other design features. On the other hand, preferred pathways for subsurface gas migration may result from previous underground construction (e.g., underground utility lines) that can facilitate gas flow. Natural and engineered barriers are discussed in more detail below.

#### 11.3.3.1.1 Natural Barriers

Surface water, ground water, and saturated soils can slow down or control the direction of subsurface gas migration. Gases encountering these barriers will follow the pathway of least resistance, usually through unsaturated porous soil.

Geologic barriers can also impede or control the route of subsurface gas migration. For example, soil type is an important factor in gas migration. Gravels and sands allow gas to migrate readily, particularly sand/gravel lenses, while clayey gravels and sandy and organic clays tend to impede gas movement. Underground utility trenches, backfill with granular materials, filled-in mine shafts, and tunnels or natural caverns can also serve to channel subsurface gas flow. Climatic conditions such as precipitation or freezing can reduce the porosity of surface soils, thereby impeding upward gas movement. Information regarding characterization of soils is provided in Section 9 (Soils).

#### 11.3.3.1.2 Engineered Barriers

Landfills and units closed as landfills may use caps and liners to prevent moisture infiltration and leachate percolation to ground water. Caps can contribute to horizontal gas movement when upward migration to the surface is



restricted (as shown in Figure 11-1). Liners tend to impede lateral migration into the surrounding unsaturated soils. The owner or operator should evaluate cap/liner systems (type, age, location, etc.) to determine potential gas migration pathways. Similar to liners, slurry walls used to border landfill units can retard lateral gas movement. With respect to underground tanks, caps and liners are not typically used. Tanks are often placed into soils with sand or gravel backfill during installation, followed by paving on the surface. Thus, any escaping gases from a leaking underground tank may migrate laterally along the path of least resistance adjacent to the units. The owner or operator should evaluate tank construction, and age, integrity, and location.

#### **11.3.3.2 Climate and Meteorological Conditions**

The climate of the site should be defined to provide background information for assessing the potential for subsurface gas migration, identifying migration pathways, and designing the subsurface gas migration monitoring system. Climatic information, on an annual and monthly or seasonal basis, should be collected for the following parameters:

- Temperature means/extremes and frost season (which indicates the potential for impeding the upward migration of the subsurface gas, thus confining the gas within the ground);
- Precipitation means and snowfall (which indicates the potential for "trapping" as well as an indication of soil moisture conditions which affect subsurface gas migration); and
- Atmospheric pressure means (which indicates the potential for gaseous releases to ambient air from a unit of concern).

The primary source of climate information for the United States is the National Climatic Data Center (Asheville, NC). The National Climatic Data Center can provide climate summaries for the National Weather Service station nearest to the site of interest. Standard references for climatic information also include the following:

Local Climatological Data - Annual Summaries with Comparative Data, published annually by the National Climatic Data Center;

Climates of the States, National Climatic Data Center; and

Weather Atlas of the United States, National Climatic Data Center.

Meteorological data for the above parameters should also be obtained concurrently with subsurface gas sampling activities. As previously discussed, these meteorological conditions can influence subsurface gas migration rates, patterns and concentration levels. Therefore, these data are necessary to properly interpret subsurface gas sampling data. Concurrent meteorological data for the sampling period can be obtained from the National Climatic Data Center for National Weather Service stations representative of the site area. In some cases, onsite meteorological data will also be available from an existing monitoring program or associated with an RFI characterization of the air media (See Section 12).

#### 11.3.3.3 Receptors

Receptor information needed to assess potential subsurface gas exposures includes the identification and location of surrounding buildings and potential sensitive receptors (e.g., residences, nursing homes, hospitals, schools, etc.). This information should also be considered in developing the monitoring procedures. Additional discussion of potential receptors is provided in Section 2.

### 11.4 Design of a Monitoring Program to Characterize Releases

Existing data should help to indicate which units have the potential to generate methane or other gases or constituents of concern. Such information can be found in construction or design documents, permit and inspection reports, records of waste disposal, unit design and operation records, and documentation of past releases.

Units of concern should be identified on the facility's topographic map. The location and areal extent of these units can be determined from historical records, aerial photographs, or field surveys. The depths and dimensions of underground

structures, locations of surrounding buildings, and waste-related information should be identified. Waste management records may provide information on waste types, quantities managed, location of waste units, and dates of waste disposal. Waste receipts, waste composition surveys, and records of waste types (e.g., municipal refuse, bulk liquids, sludges, contaminated soils, industrial process wastes or inert materials) should be reviewed. For underground tanks, liquid waste compositions, quantities, and physical properties should be determined.

Review of unit design and operation records may provide background information on units of concern. These records may include engineering design plans, inspection records, operations logs, damage or nuisance litigation, and routine monitoring data. Also, for landfills and units closed as landfills, data may include the presence and thickness of a liner, ground-water elevations, waste moisture contents, type and amount of daily cover, records of subsurface fires, and in-place leachate and/or gas collection systems. Historical information on underground tank integrity may be contained in construction and monitoring records. Records of past releases may provide information on problems, corrective measures, and controls initiated.

The owner or operator should review records of subsurface conditions to determine potential migration pathways. Aerial photographs or field observations should identify surface water locations. Infrared aerial photography or geological surveys from the USGS can be used as preliminary aids to identify subsurface geologic features and ground-water location. In addition to obtaining and reviewing existing information, a field investigation may be necessary to confirm the location of natural barriers. The local soil conservation service will often have information describing soil characteristics (e.g., soil type, permeability, particle size) or a site specific investigation may need to be conducted. (Soil information sources are discussed in Section 9). Climatic summaries (e.g., temperature, rainfall, snowfall) can be obtained from the National Climatic Data Center for the National Weather Service station nearest to the site of interest (Specific climatic data references are cited in Section 12). Historical records of the site (prior use, construction, etc.) should also be reviewed to identify any factors affecting gas migration routes. The monitoring program should also address any engineered structures affecting the migration pathway.

In addition to the above, the owner or operator should examine the units and surrounding area for signs of settlement, erosion, cracking of covers, stressed or dead vegetation, dead rodents, snakes and other burrowing animals, contamination of surface waters, odors, elevated temperatures in any existing monitoring wells, and for venting of smoke or gases. The condition of any existing gas monitoring systems and containment or collection systems should also be examined, as well as any structural defects in tanks or liners. Any overflow/alarm shut off systems, subsurface leak detection systems, secondary containment structures (e.g., concrete pads, dikes or curbs) or other safety systems for early detection of potential gas releases should be checked.

By reviewing all existing information, the owner or operator should be able to develop a conceptual model of the release and design a monitoring program to characterize the release.

#### **11.4.1 Objectives of the Monitoring Program**

Characterization of subsurface gas releases can be accomplished through a phased monitoring approach. The objective of initial monitoring should be to verify suspected releases, if necessary, or to begin characterizing known releases. Monitoring should include methane and other indicators such as carbon dioxide, as well as individual constituents if appropriate. If initial monitoring verifies a suspected release, the owner or operator should expand the monitoring program to determine the vertical and horizontal extent of the release, as well as the concentrations of all constituents of concern in the release.

The full extent of the release can be determined through additional shallow borehole and gas monitoring well locations. The goal of this further characterization will be to identify the boundary of gas migration, including the leading edge of the migration.

A great deal of the effort conducted during any subsequent phase may involve investigating anomalous areas where subsurface conditions are non-uniform. In these situations, the gas migration characteristics may differ from surrounding areas. Consequently, non-random sampling techniques are generally most appropriate to monitor these areas. The location of additional gas wells and

shallow boreholes at the sites of subsurface anomalies will provide information regarding the migration pattern around these anomalous areas. Also, because gas well installation may be conducted only to a limited extent under the initial monitoring phase, additional wells may need to be installed.

The monitoring program should also address the selection of constituents of concern, sampling frequency and duration, and the monitoring system design.

#### **11.4.2 Monitoring Constituents and Indicator Parameters**

As discussed above, the number and identity of potential subsurface gas constituents will vary on a site-specific basis. Constituents to be included for monitoring depends primarily on the type of wastes received. For example, if an underground storage tank contains specific constituents, they should be considered during subsurface gas monitoring activities. The guidance provided in Section 3 and the lists provided in Appendix B should be used to determine a select set of constituents and indicator parameters for subsurface gas monitoring.

Methane should be used as the primary indicator of subsurface gas migration during the initial and any subsequent monitoring phases. Supplemental indicators (e.g., carbon dioxide and sulfur dioxide) may also be used as appropriate. Field screening equipment should be used to detect the presence of methane in terms of the lower explosive limit (LEL). The LEL for methane is 5 percent by volume, which is equivalent to 50,000 ppm. Individual constituents should also be monitored. In addition, oxygen detectors and nitrogen analyses can be used to confirm the representativeness of all subsurface gas well samples obtained. (The presence of oxygen and nitrogen in well samples indicates the intrusion of ambient air into the well during monitoring. Samples containing ambient air would result in an underestimate of methane and other indicators as well as specific monitoring constituents.)

Methane concentrations observed during the initial monitoring phase which exceed the LEL at the property boundary or 0.25 the LEL within surrounding structures, would warrant initiation of subsequent monitoring phases and, possibly, consideration of interim corrective measures. Similarly, the presence of individual constituents would also trigger the need for subsequent monitoring phases.

Regardless of the degree to which monitoring constituents can be limited by site-specific data, analyses for all constituents identified as applicable in Appendix B (List 2) will generally be necessary for the subsurface gas medium at selected monitoring locations.

#### **11.4.3            Monitoring Schedule**

A monitoring schedule should be established and described in the RFI Work Plan. This schedule should describe the sampling frequency, the duration of the sampling effort, and the conditions under which sampling should occur.

During initial monitoring, bar punch probe (See Section 11-6) monitoring for methane and appropriate constituents should be conducted at least twice over the course of one week. Monitoring the wells for methane and constituents should be conducted at least once a week for one month. (Subsurface gas wells should not be monitored for at least 24 hours after installation to allow time for equilibration.) Surrounding buildings should be monitored at least once a week for one month.

During any subsequent monitoring phases, more extensive sampling may be needed to adequately characterize the nature and extent of the release. Monitoring of wells and buildings for methane and constituents should be conducted every other day for a two week period to account for daily fluctuations in gas concentrations.

Conditions for sampling should also be defined. Sampling should generally not be performed if conditions conducive to decreasing gas concentrations are present (e.g., subsurface gas pressure at less than atmospheric pressure). In these cases, sampling should be delayed until such conditions pass. Subsurface gas pressures have a diurnal cycle and are generally at a maximum during the afternoon.

## **11.4.4 Monitoring Locations**

### **11.4.4.1 Shallow Borehole Monitoring**

Areas identified for subsurface gas monitoring as a result of characterization of the contaminant source and the environmental setting should be investigated for concentrations of methane and constituents during the initial monitoring phase. Shallow borehole monitoring using a bar punch probe method or equivalent (See Section 11.6) is recommended. The bar punch is simply a steel or metal bar which is hand-driven or hammered to depths of 6 feet. Once this hole is made it is covered with a stopper or seal to confine the headspace in the hole. The hole should be allowed to equilibrate for up to an hour prior to sampling to provide sufficient time for subsurface gas to replace the air in the hole. The ease of installation of bar punch holes and the ability to obtain real-time direct measurements from field survey instruments combine to make this task a relatively simple operation. It should be recognized, however, that shallow borehole monitoring is a rapid screening method and therefore has its limitations. Two major limitations are that negative findings cannot assure the absence of a release at a greater depth and that air intrusions can dilute the sampling readings. See also Sections 9 (Soil) and 10 (Ground Water) for additional information.

The number of locations to monitor will vary from site to site. However, due to the ease of this operation, it is recommended that many locations be surveyed during the initial monitoring phase. Selection of locations along the perimeter of the unit of concern and at intervals of approximately 100 feet is an adequate initial approach. Individual site conditions and anomalies should be considered to determine whether the number of sampling locations should be increased or decreased. A large site with homogeneous subsurface conditions could require fewer sampling locations by increasing the distance between sampling points. A site with many subsurface anomalies, such as engineered barriers or varying soil strata, would require a greater number of sampling locations. In general, sampling locations should be established where conditions are conducive to gas migration, such as in sands, gravels and porous soils, and near engineered conduits (e.g., underground utility lines). The appropriate precautions should be taken when sampling near engineered conduits so as not to damage such property and to assure the safety of the investigative team and others.

The distance from the unit at which to sample can best be determined through consideration of site-specific characteristics (e.g., soil conditions), and can be aided by the use of the gas concentration contour map generated by the predictive model described in Appendix D. The shallow borehole survey should be fairly extensive, ranging from sampling locations very near the unit to locations at the property boundary and beyond.

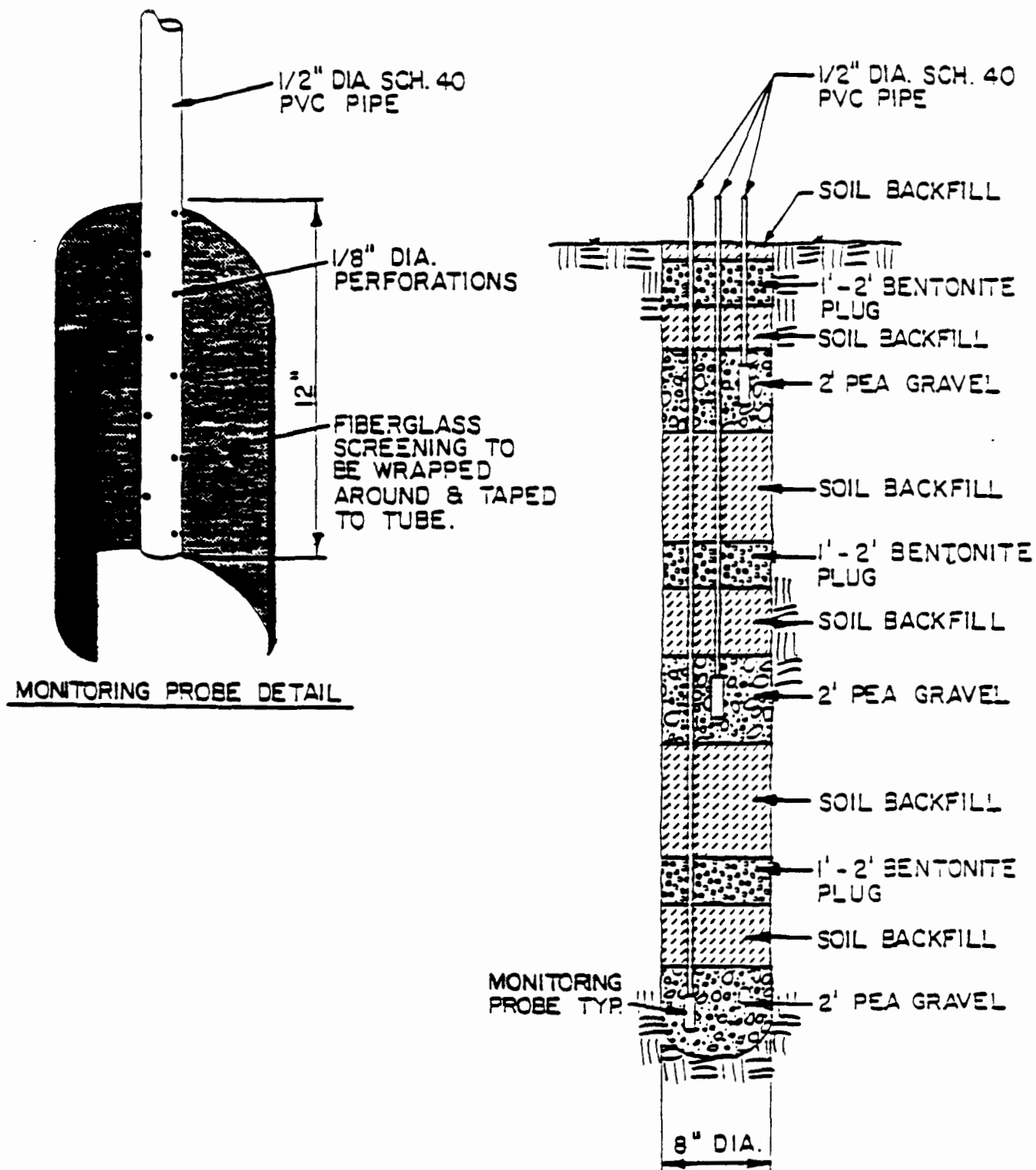
#### 11.4.4.2 Gas Monitoring Wells

Gas monitoring wells (See Section 11.6) should be installed to obtain data on subsurface gas concentrations at depths greater than the depth accessible with a bar punch probe. Wells should be installed to a depth equal to that of the unit. Multiple probe depths may be installed at a single location as illustrated in Figure 11-3. Where buried material is fairly shallow (e.g., <10-feet), single depth gas monitoring probes may be sufficient. When buried material exceeds this depth below ground, multiple depth probes should be installed.

The location and depth of gas monitoring wells should be based on the presence of highly permeable zones (e.g., dry sand or gravel), alignment with offsite structures, proximity of the waste deposit, areas where there is dead or unhealthy vegetation (that may be due to gas migration), and any engineered channels which would promote the migration of a subsurface gas release (e.g., utility lines). This information should be gathered during a review of subsurface conditions, as discussed previously. At a minimum, a monitoring well should be installed at the location(s) of expected maximum concentration(s), as determined or estimated during the initial monitoring phase.

Gas monitoring well installation usually requires the use of a drilling rig or power auger. Once a borehole has been drilled to the desired depth, the gas monitoring probes can be installed as illustrated in Figure 11-3. Additional information concerning the installation of subsurface gas monitoring wells is provided in Section 10 (Ground Water) and in Guidance Manual for the Classification of Solid Waste Disposal Facilities NTIS PB81-218505 (U.S. EPA, 1981).





**Figure 11-3. Schematic of a Deep Subsurface Gas Monitoring Well**

Equilibration times of at least 24 hours should be allowed prior to collection of subsurface gas samples for analysis after well installation and between subsequent collection periods. Individual site characteristics or anomalies which can create significantly different subsurface conditions will require an increased number of wells to sufficiently determine the presence of gas migration. For example, if the predominant soil strata along one side of a unit changes from sandy clay to gravel, a well should be installed in both of these areas. Also, if the amount of gas producing waste buried at the site varies greatly from one area to another, gas monitoring wells should be installed near each area of concern.

Subsurface gas monitoring may be done concurrently with ground-water investigations (Section 10), because results of subsurface gas monitoring may provide useful information for identifying the overall extent of any ground-water contamination.

#### 11.4.4.3 Monitoring in Buildings

Monitoring should also be conducted in surrounding structures near the areas of concern, since methane and other subsurface gas constituents migrating through the soil can accumulate in confined areas. Use of an explosimeter for methane is the recommended monitoring technique (See Section 11.6).

Sampling should be conducted at times when the dilution of the indoor air is minimized and the concentration of soil gas is expected to be at its highest concentration. Optimal sampling conditions would be after the building has been closed for the weekend or overnight and when the soil surface outside the building and over the unit of concern has been wet or frozen for several days. These conditions will maximize the potential for lateral migration of gas into buildings rather than vertically into the ambient air. Recommended sampling locations within the building include basements, crawl spaces, and around subsurface utility lines such as sewer or electrical connections. Access conduits such as manholes or meter boxes are good sampling locations for water, sewer, or gas main connections. Methane and, if appropriate, individual constituents should be monitored for.

The threat of explosion from accumulation of methane within a building makes this monitoring activity important as well as dangerous. The monitoring of

gas concentrations within buildings is a simple process involving a walk through inspection of areas with portable field instruments (e.g., explosimeter). Such measurements should begin during the initial monitoring phase. The importance of identifying potential releases to buildings warrants a complete inspection of all suspect areas. The inherent danger during these investigations warrants adequate health and safety procedures (See Section 6).

If significant concentrations of methane or constituents are measured in surrounding structures during initial monitoring, subsequent monitoring may need to be expanded to include buildings at greater distances from the unit(s) of concern and to include additional constituents of concern. In addition, interim corrective measures should be considered.

Background indoor air quality levels may be accounted for during the collection and evaluation of the in-building sampling data. Background levels can be accounted for by identifying potential indoor air emission sources (e.g., use of natural gas as a fuel or wood paneling which has the potential for formaldehyde emissions). Further guidance on this subject is presented in the following reference:

U.S. EPA. 1983. Guidelines for Monitoring Indoor Air Quality. EPA- 600/1-4 83-046. NTIS PB83-264465. Office of Research and Development. Washington, D.C. 20460.

#### 11.4.4.4 Use of Predictive Models

In addition to monitoring potential gas releases using portable survey instruments, the owner or operator should consider the use of predictive models to estimate the configuration and concentration of gas releases. A subsurface gas predictive model has been developed by EPA to estimate methane gas migration from sanitary landfills. This model is based on site soil conditions, waste-related data, and other environmental factors.

As part of the initial monitoring phase, the model provided in Appendix D (or another appropriate predictive model after consultation with the regulatory agency), should be used to estimate the extent of subsurface gas migration. Results from this model can be used in determining appropriate monitoring locations. The

methane gas migration model presented in Appendix D yields a methane concentration isopleth map of a release. The LEL and 0.25 LEL isopleths for methane should be mapped for the RFI when appropriate. Because predictive models may not be sensitive to relevant site conditions, however, model results should be used cautiously for the monitoring program design and to supplement actual field data.

## **11.5 Data Presentation**

Subsurface gas data collected during the RFI should be presented in formats that clearly define the composition and extent of the release. The use of tables and graphs is highly recommended. Section 5.2 provides a detailed discussion of data presentation methods.

### **11.5.1 Waste and Unit Characterization**

Waste and unit characteristics should be presented as:

- Tables of waste constituents and concentrations;
- Tables of relevant physical and chemical properties of waste and potential contaminants;
- Narrative description of unit dimensions, operations, etc.; and
- Topographical map and plan drawings of facility and surrounding areas.

### **11.5.2 Environmental Setting Characterization**

Environmental characteristics should be presented as follows:

- Tabular summaries of annual and monthly or seasonal relevant climatic information (e.g., temperature, precipitation);
- Narratives and maps of soil and relevant hydrogeological characteristics such as porosity, organic matter content, and depth to ground water;

- Maps showing location of natural or man-made engineering barriers and likely migration routes; and
- Maps of geologic material at the site identifying the thickness, depth, and textures of soils, and the presence of saturated regions and other hydrogeological features.

### **11.5.3 Characterization of the Release**

In general, release data should be initially presented in tabular form. To facilitate interpretation, graphs of concentrations of individual constituents plotted against distance from the unit should be used to identify migration pathways and areas of elevated concentrations. Concentration isopleth maps can also be drawn to identify the direction, depths, and distances of gas migration, and concentrations of constituents of concern. Specific examples of these and other data presentation methods are provided in Section 5. Methane concentrations should be presented in terms of the LEL and 0.25 LEL isopleths. Specific monitoring constituent concentrations should also be presented.

## **11.6 Field Methods**

Field methods for subsurface gas investigations involve sample collection and analysis. Sample collection methods are discussed to summarize the monitoring techniques described above. Because subsurface gas monitoring is similar to air monitoring, the available methods for the collection and analysis of subsurface gas samples are presented here only in tabular format with further discussion in the air section of this document (Section 12). Tables 11-3 through 11-5 summarize various methodologies available to collect and analyze air samples. These methodologies range from real-time analyzers (e.g., methane explosimeters) to the collection of organic vapors on sorbents or whole air samples with subsequent laboratory analysis.

A portable gas chromatograph with a flame ionization detector (calibrated with reference to methane) can be used to measure methane concentrations in the field. Methane explosimeters (based on the principle of thermal conductivity) are

**TABLE 11-3**  
**SUMMARY OF SELECTED ONSITE ORGANIC SCREENING METHODOLOGIES**

Instrument or detector	Measurable parameters	Low range of detection	Comments
Century Series 100 or AID Model 500 (survey mode)	Volatile organic species	Low ppm	Uses Flame Ionization Detector (FID)
GfG Gas Etechronics (Methanometer)	Methane explosion potential	Low ppm	Sensitive to methane
National Mine Service Company	Methane explosion potential	Low ppm	Sensitive to methane
Mine Safety Appliances, Inc.	Methane explosion potential	Low ppm	Sensitive to methane

TABLE 11-4

## SUMMARY OF CANDIDATE METHODOLOGIES FOR QUANTIFICATION OF VAPOR PHASE ORGANICS

Collection Techniques	Analytical Technique	Applicability <sup>a</sup>	Positive Aspects	Negative Aspects
1. Sorption onto Tenax-GC or carbon molecular sieve packed cartridges using low-volume pump	Thermal Desorption into GC or GC/MS	I	<ul style="list-style-type: none"> <li>adequate QA/QC data base</li> <li>widely used on investigations around uncontrolled waste sites</li> <li>wide range of applicability</li> <li><math>\mu\text{g}/\text{m}^3</math> detection limits</li> <li>practicality for field use</li> </ul>	<ul style="list-style-type: none"> <li>possibility of contamination</li> <li>artifact formation problems</li> <li>rigorous cleanup needed</li> <li>no possibility of multiple analysis</li> <li>low breakthrough volumes for some compounds</li> </ul>
2. Sorption onto charcoal packed cartridges using low-volume pump	Desorption with solvent-analysis by GC or GC/MS	II	<ul style="list-style-type: none"> <li>large data base for various compounds</li> <li>wide use in industrial applications</li> <li>practical for field use</li> </ul>	<ul style="list-style-type: none"> <li>problems with irreversible adsorption of some compounds</li> <li>high (<math>\text{mg}/\text{m}^3</math>) detection limits</li> <li>artifact formation problems</li> <li>high humidity reduces retention efficiency</li> </ul>
3. Sorption onto polyurethane foam (PUF) using low-volume or high-volume pump	Solvent extraction of PUF; analysis by GC/MS	I, II, III	<ul style="list-style-type: none"> <li>wide range of applicability</li> <li>easy to preclean and extract</li> <li>very low blanks</li> <li>excellent collection and retention efficiencies</li> <li>reusable up to 10 times</li> </ul>	<ul style="list-style-type: none"> <li>possibility of contamination</li> <li>losses of more volatile compounds may occur during storage</li> </ul>

TABLE 11-4 (continued)

## SUMMARY OF CANDIDATE METHODOLOGIES FOR QUANTIFICATION OF VAPOR PHASE ORGANICS

Collection Techniques	Analytical Technique	Applicability <sup>a</sup>	Positive Aspects	Negative Aspects
4. Sorption on passive dosimeters using Tenax or charcoal as adsorbing medium	Analysis by chemical or thermal desorption followed by GC or GC/MS	I or II	<ul style="list-style-type: none"> <li>• Samplers are small, portable, require no pumps</li> <li>• makes use of analytical procedures of known precision and accuracy for a broad range of compounds</li> <li>• <math>\mu\text{g}/\text{m}^3</math> detection limits</li> </ul>	<ul style="list-style-type: none"> <li>• problems associated with sampling using sorbents (see #I and II) are present</li> <li>• uncertainty in volume of air sampled makes concentration calculations difficult</li> <li>• requires minimum external air flow rate</li> </ul>
5. Cryogenic trapping of analytes in the field	Desorption into GC	II, III	<ul style="list-style-type: none"> <li>• applicable to a wide range of compounds</li> <li>• artifact formation minimized</li> <li>• low blanks</li> </ul>	<ul style="list-style-type: none"> <li>• requires field use of liquid nitrogen or oxygen</li> <li>• sample is totally used in one analysis-no reanalysis possible</li> <li>• samplers easily clogged with water vapor</li> <li>• no large data base on precision or recoveries</li> </ul>
6. Whole air sample taken in glass or stainless steel bottles	Cryogenic trapping or direct injection into GC or GC/MS (onsite or laboratory)	II, III	<ul style="list-style-type: none"> <li>• useful for grab sampling</li> <li>• large data base</li> <li>• excellent long-term storage</li> <li>• wide applicability</li> <li>• allows multiple analyses</li> </ul>	<ul style="list-style-type: none"> <li>• difficult to obtain integrated samples</li> <li>• low sensitivity if preconcentration is not used</li> </ul>
7. Whole air sample taken in Tedlar® Bag	Cryogenic trapping or direct injection into GC or GC/MS (onsite or laboratory)	II, III	<ul style="list-style-type: none"> <li>• grab or integrated sampling</li> <li>• wide applicability</li> <li>• allows multiple analyses</li> </ul>	<ul style="list-style-type: none"> <li>• long-term stability uncertain</li> <li>• low sensitivity if preconcentration is not used</li> <li>• adequate cleaning of containers between samples may be difficult</li> </ul>



TABLE 11-4 (continued)

## SUMMARY OF CANDIDATE METHODOLOGIES FOR QUANTIFICATION OF VAPOR PHASE ORGANICS

Collection Techniques	Analytical Technique	Applicability <sup>a</sup>	Positive Aspects	Negative Aspects
8. Dinitrophenylhydrazine liquid Impinger sampling using low-volume pump	HPLC/UV analysis	IV	<ul style="list-style-type: none"> <li>• specific to aldehydes and ketones</li> <li>• good stability for derivatized compounds</li> <li>• low detection limits</li> </ul>	<ul style="list-style-type: none"> <li>• fragile equipment</li> <li>• sensitivity limited by reagent impurities</li> <li>• problems with solvent evaporation when long-term sampling is performed</li> </ul>
9. Direct introduction by probe	Mobile MS/MS	I, II, III, IV	<ul style="list-style-type: none"> <li>• immediate results</li> <li>• field identification of air contaminants</li> <li>• allows "real-time" monitoring</li> <li>• widest applicability of any analytical method</li> </ul>	<ul style="list-style-type: none"> <li>• high instrument cost</li> <li>• requires highly trained operators</li> <li>• grab samples only</li> <li>• no large data base on precision or accuracy</li> </ul>

## a Applicability Code

- I Volatile, nonpolar organics (e.g., aromatic hydrocarbons, chlorinated hydrocarbons) having boiling points in the range of 80 to 200° C.
- II Highly volatile, nonpolar organics (e.g., vinyl chloride, vinylidene chloride, benzene, toluene) having boiling points in the range of -15 to +120° C.
- III Semivolatile organic chemicals (e.g., organochlorine pesticides and PCBs).
- IV Aldehydes and ketones.

**TABLE 11-5  
TYPICAL COMMERCIALLY AVAILABLE SCREENING TECHNIQUES FOR ORGANICS IN AIR**

Techniques	Manufacturer	Compounds Detected	Approximate Detection Limit	Comment
Gas Detection Tubes	Draeger Matheson (Kitagawa)	Various organics and inorganics	0.1 to 1 ppmv	Sensitivity and selectivity highly dependent on components of interest.
Continuous Flow Colorimeter	CEA Instruments, Inc.	Acrylonitrile, formaldehyde, phosgene	0.05 to 0.5 ppmv	Sensitivity and selectivity similar to detector tubes.
Colorimetric Tape Monitor	MDA Scientific	Toluene, diisocyanate, dinitro-toluene, phosgene, and various inorganics	0.05-0.5 ppmv	Sensitivity and selectivity similar to detector tubes.
Infrared Analysis	Foxboro/Wilkes	Most organics	1-10 ppmv	Some inorganic gases (H <sub>2</sub> , CO) will be detected and therefore are potential interferences.
FID (Total Hydrocarbon Analyzer)	Beckman MSA, Inc. AID, Inc.	Most organics	0.5 ppmv	Responds uniformly to most organic compounds on a carbon basis.
GC/FID (portable)	Foxboro/Century AID, Inc.	Same as above except that polar compounds may not elute from the column	0.5 ppmv	Qualitative as well as quantitative information obtained.
PID and GC/PID (portable)	HNU, Inc. AID, Inc. Photovac, Inc.	Most organic compounds can be detected with the exception of methane	0.1 to 100 ppbv	Selectivity can be adjusted by selections of lamp energy. Aromatics most readily detected.
GC/ECD (portable)	AID, Inc.	Halogenated and nitro substituted compounds	0.1 to 100 ppbv	Response varies widely from compound to compound.
GC/FPD (portable)	AID, Inc.	Sulfur or phosphorus-containing compounds	10-100 ppbv	Both inorganic and organic sulfur or phosphorus compounds will be detected.
Chemiluminescent Nitrogen Detector	Antek, Inc.	Nitrogen-containing compounds	0.1 ppmv (as N)	Inorganic nitrogen compounds will interfere.

also available and provide direct readings of LEL levels and/or percent methane present by volume.

Table 11-3 provides a list of organic screening methodologies suited for detection of methane. Commercial monitoring equipment (direct reading) suitable for screening application are also available specifically for carbon dioxide, and sulfur dioxide. Similar field screening equipment are available for oxygen in order to check for the potential for intrusion of ambient air into the subsurface gas monitoring well. These screening monitors are available from most major industrial hygiene equipment vendors. Direct reading gas detection (e.g., draeger) tubes are also available for methane and other subsurface gas indicators for screening applications.

It is important that all monitoring procedures be fully documented and supported with adequate QA/QC procedures. Information should include: locations and depths of sampling points, methods used (including sketches and photographs), survey instruments used, date and time, atmospheric/soil temperature, analytical methods, and laboratory used, if any. Also see Section 4 (Quality Assurance and Quality Control).

The three basic monitoring techniques available for sampling subsurface gas; above ground air monitoring, shallow borehole monitoring, and gas well monitoring are summarized below.

#### **11.6.1 Above Ground Monitoring**

This technique consists of the collection of samples of the subsurface gas after it has migrated out of the soil or into engineered structures (e.g., within buildings or along under-ground utility lines.). Basically, there is no difference in the apparatus from that described for ambient air monitoring (Section 12). The locations at which sampling is conducted, however, are selected to focus on areas where gases might accumulate. Sampling methods can utilize various types and brands of portable direct-reading survey instruments (see Table 11-5). However, because methane gas is frequently the major component of the soil gas, those which are most sensitive to methane, such as explosimeters and FID organic vapor

analyzers, are the preferred instruments. More selective air sampling methods are used, however, for constituent analyses (see Section 12 - Air Methods).

### **11.6.2 Shallow Borehole Monitoring**

Shallow borehole monitoring involves subsurface gas monitoring to depths of up to 6 feet below the ground surface. Bar punches or metal rods which can be hand-driven or hammered into the ground are used to make boreholes from which gas samples are removed. Table 11-6 provides the basic procedure for shallow and deep subsurface monitoring techniques. Sample collection should follow the same methods employed during above ground monitoring.

Shallow borehole monitoring, as previously discussed, is a rapid screening method and, therefore, has its limitations. Two major limitations are that negative findings cannot assure the absence of a release at a greater depth and that air intrusion can dilute the measured concentration levels of the sample. Misleading results can also be obtained if the surface soil layer is contaminated (e.g., due to a spill).

### **11.6.3 Gas Well Monitoring**

Monitoring gas within wells will involve either the lowering of a sampling probe (made of a nonsparking material) through a sealed cap on the top of the well to designated depths, or the use of fixed-depth monitoring probes (see Figure 11-3 and Table 11-6). The probe outlet is usually connected to the desired gas monitoring instrument. More information on gas well monitoring is provided in Sections 9 (Soil) and 10 (Ground Water).

## **11.7 Site Remediation**

Although the RFI Guidance is not intended to provide detailed guidance on sites remediation, it should be recognized that certain data collection activities that may be necessary for a Corrective Measures Study may be collected during the RFI. EPA has developed a practical guide for assessing and remediating contaminated site that directs users toward technical support, potential data requirements and

**TABLE 11-6**  
**SUBSURFACE SAMPLING TECHNIQUES**

---

**SHALLOW (Up to 6 ft deep)**

- Select sampling locations based on soil data and existing monitoring data.
- Penetrate soil to desired depth. A steel rod 1/2 to 3/4 inch diameter and a heavy hammer are sufficient. A bar punch equipped with insulated handles is better for numerous holes. It is a small, hand operated pile driver with a sliding weight on the top. Hand augers may also be used.
- Insert inert (e.g., Teflon) tubing to bottom of hole. Tubing may be weighted or attached to a small diameter stick to assure that it gets to the bottom of the hole. Tubing should be perforated along bottom few inches to assure gas flow.
- Close top of hole around tubing using a gas impervious seal.
- Before sampling record well head pressure.
- Readings may be taken immediately after making the barhole.
- Attach meter or sampling pump and evacuate hole of air-diluted gases before recording gas concentrations or taking samples.
- When using a portable meter, begin with the most sensitive range (0-100 percent by volume of the lower explosive limit (LEL) for methane). If meter is pegged, change to the next least sensitive range to determine actual gas concentration.
- Tubing shall be marked, sealed, and protected if sampling will be done later.

**TABLE 11-6 (Continued)**  
**SUBSURFACE SAMPLING TECHNIQUES**

- 
- If results are erratic the hole should be plugged and further readings taken a few minutes later.
  - Monitoring should be repeated a day or two after probe installation to verify readings.

**DEEP (More Than 6 ft deep)**

- Same general procedures as above.
- Use portable power augers or truck-mounted augers.
- For permanent monitoring points, use rigid tubing (e.g., Teflon) and the general construction techniques shown in Figure 11-4.

**CAUTION**

- When using hand powered equipment, stop if any unusually high resistance is met. This resistance could be from a gas pipe or an electrical cable.
  - Before using powered equipment, confirm that there are no underground utilities in the location(s) selected (see Appendix C - Geophysical Techniques).
  - Use non-sparking equipment and procedures and monitor for methane explosive limits.
-

technologies that may be applicable to EPA programs such as RCRA and CERCLA. The reference for this guide is provided below.

U.S. EPA. 1988. Practical Guide for Assessing and Remediating Contaminated Sites. Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

The guide is designed to address releases to ground water as well as soil, surface water and air. A short description of the guide is provided in Section 1.2 (Overall RCRA Corrective Action Process), under the discussion of Corrective Measures Study.

## 11.8 Checklist

### RFI CHECKLIST - SUBSURFACE GAS

Site Name/Location \_\_\_\_\_

Type of Unit \_\_\_\_\_

- |    |  |       |
|----|--|-------|
| 1. | Does waste characterization include the following information?                   | (Y/N) |
|    | ● Physical form of waste   | _____ |
|    | ● Chemical composition and concentrations  | _____ |
|    | ● Presence of biodegradable waste components                                     | _____ |
|    | ● Quantities managed and dates of receipt  | _____ |
|    | ● Location of wastes in unit   | _____ |
|    | ● Waste material moisture content and temperature                                | _____ |
|    | ● Chemical and physical properties of constituents of concern                    | _____ |
| 2. | Does unit characterization include the following information?                    | (Y/N) |
|    | ● Age of unit  | _____ |
|    | ● Construction integrity   | _____ |
|    | ● Presence of liner (natural or synthetic)                                       | _____ |
|    | ● Location relative to ground-water table or bedrock or other confining barriers | _____ |
|    | ● Unit operation data  | _____ |
|    | ● Presence of cover or other surface covering to impede vertical gas migration   | _____ |
|    | ● Presence of gas collection system  | _____ |
|    | ● Presence of surrounding structures such as buildings and utility conduits      | _____ |
|    | ● Depth and dimensions of unit   | _____ |
|    | ● Inspection records   | _____ |
|    | ● Operation logs   | _____ |
|    | ● Past fire, explosion, odor complaint reports                                   | _____ |



## RFI CHECKLIST - SUBSURFACE GAS (Continued)

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- Existing gas/ground-water monitoring data \_\_\_\_\_
  - Presence of natural or engineered barriers near unit \_\_\_\_\_
  - Evidence of vegetative stress \_\_\_\_\_
3. Does environmental setting information include the following information? (Y/N)
- Definition of regional climate \_\_\_\_\_
  - Definition of site-specific meteorological conditions \_\_\_\_\_
  - Definition of soil conditions \_\_\_\_\_
  - Definition of site specific terrain \_\_\_\_\_
  - Identification of subsurface gas migration routes \_\_\_\_\_
  - Identification and location of engineered conduits \_\_\_\_\_
  - Identification of surrounding structures \_\_\_\_\_
4. Have the following data on the initial phase of the release characterization been collected? (Y/N)
- Extent and configuration of gas plume \_\_\_\_\_
  - Measured methane and gaseous constituent concentration levels in subsurface soil and surrounding structures \_\_\_\_\_
  - Sampling locations and schedule \_\_\_\_\_
5. Have the following data on the subsequent phase(s) of the release characterization been collected? (Y/N)
- Extent and configuration of gas plume \_\_\_\_\_
  - Measured methane and gaseous constituent concentration levels in subsurface soil and surrounding structures \_\_\_\_\_
  - Sampling locations and schedule \_\_\_\_\_

## 11.9 References

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**APPENDIX C**

**GEOPHYSICAL TECHNIQUES**

## APPENDIX C

### GEOPHYSICAL TECHNIQUES

The methods presented in this Appendix have been drawn primarily from two sources. The first, Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982) was written specifically for application at hazardous waste sites, and for an audience with limited technical background. All of the surface geophysical methods discussed below can be found in this document. The second, Geophysical Explorations (U.S. Army Corps of Engineers, Engineering Manual 1110-1-1802, 1979) is a more generic application-oriented manual which contains the borehole methods described in this section.

Caution should be exercised in the use of geophysical methods involving the introduction or generation of an electrical current, particularly when contaminants are known or suspected to be present which have ignitable or explosive properties. The borehole methods are of particular concern due to the possible build up of large amounts of explosive or ignitable gases (e.g., methane).

### ELECTROMAGNETIC SURVEYS

The electromagnetic (EM)\* method provides a means of measuring the electrical conductivity of subsurface soil, rock, and ground water. Electrical conductivity is a function of the type of soil and rock, its porosity, permeability, and the fluids which fill the pore space. In most cases the conductivity (specific conductance) of the pore fluids will dominate the measurement. Accordingly, the EM method is applicable both to assessment of natural geohydrologic conditions and to mapping of many types of contaminant plumes. Additionally, trench

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\*The term "electromagnetic" has been used in contemporary literature as a descriptive term for other geophysical methods, including ground penetrating radar and metal detectors which are based on electromagnetic principles. However, this document will use electromagnetic (EM) to specifically imply the measurement of subsurface conductivities by low frequency electromagnetic induction. This is in keeping with the traditional use of the term in the geophysical industry from which the EM methods originated.

boundaries, buried wastes and drums, as well as metallic utility lines can be located with EM techniques.

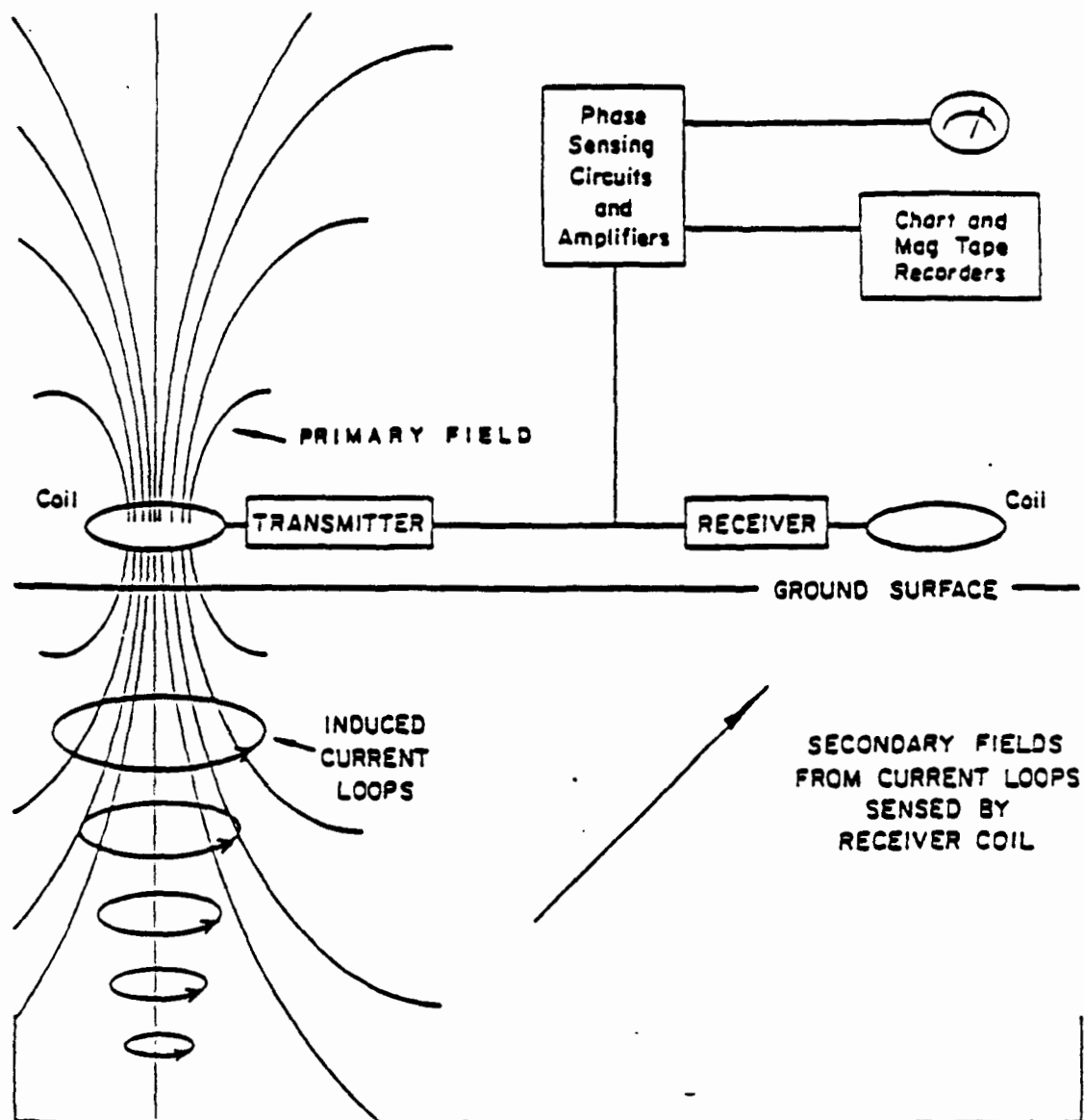
Natural variations in subsurface conductivity may be caused by changes in soil moisture content, ground-water specific conductance, depth of soil cover over rock, and thickness of soil and rock layers. Changes in basic soil or rock types, and structural features such as fractures or voids may also produce changes in conductivity. Localized deposits of natural organics, clay, sand, gravel, or salt- rich zones will also affect subsurface conductivity.

Many contaminants will produce an increase in free ion concentration when introduced into the soil or ground water systems. This increase over background conductivity enables detection and mapping of contaminated soil and ground water at hazardous waste sites. Large amounts of organic fluids such as diesel fuel can displace the normal soil moisture, causing a decrease in conductivity which may also be mapped, although this is not commonly done. The mapping of a plume will usually define the local flow direction of contaminants. Contaminant migration rates can be estimated by comparing measurements taken at different times.

The absolute values of conductivity for geologic materials (and contaminants) are not necessarily diagnostic in themselves, but the variations in conductivity, laterally and with depth, are significant. It is these variations which enable the investigator to rapidly find anomalous conditions (See Figure C-1).

At hazardous waste sites, applications of EM can provide:

- **Assessment of natural geohydrologic conditions;**
- **Locating and mapping of burial trenches and pits containing drums and/or bulk wastes;**
- **Locating and mapping of plume boundaries;**
- **Determination of flow direction in both unsaturated and saturated zones;**



**Figure C-1. Block diagram showing EM principle of operations.**

- Rate of plume movement by comparing measurements taken at different times; and
- Locating and mapping of utility pipes and cables which may affect other geophysical measurements, or whose trench may provide a pathway for contaminant flow.

Chapter V of Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982) should be consulted for further detail regarding use, capabilities, and limitations of electromagnetic surveys.

## SEISMIC REFRACTION SURVEYS

Seismic refraction techniques are used to determine the thickness and depth of geologic layers and the travel time or velocity of seismic waves within the layers. Seismic refraction methods are often used to map depths to specific horizons such as bedrock, clay layers, and the water table. In addition to mapping natural features, other secondary applications of the seismic method include the locations and definition of burial pits and trenches.

Seismic waves transmitted into the subsurface travel at different velocities in various types of soil and rock, and are refracted (or bent) at the interfaces between layers. This refraction affects their path of travel. An array of geophones (transducers that respond to the motion of the ground) on the surface measures the travel time of the seismic waves from the source to the geophones at a number of spacings. The time required for the wave to complete this path is measured, permitting a determination to be made of the number of layers, the thicknesses of the layers and their depths, as well as the seismic velocity of each layer. The wave velocity in each layer is directly related to its material properties such as density and hardness. Figure C-2 depicts the seismic refraction technique.

Seismic refraction can be used to define natural geohydrologic conditions, including thickness and depth of soil and rock layers, their composition and physical properties, and depth to bedrock or the water table. It can also be used for the detection and location of anomalous features, such as pits and trenches and for evaluation of the depth of burial sites or landfills.

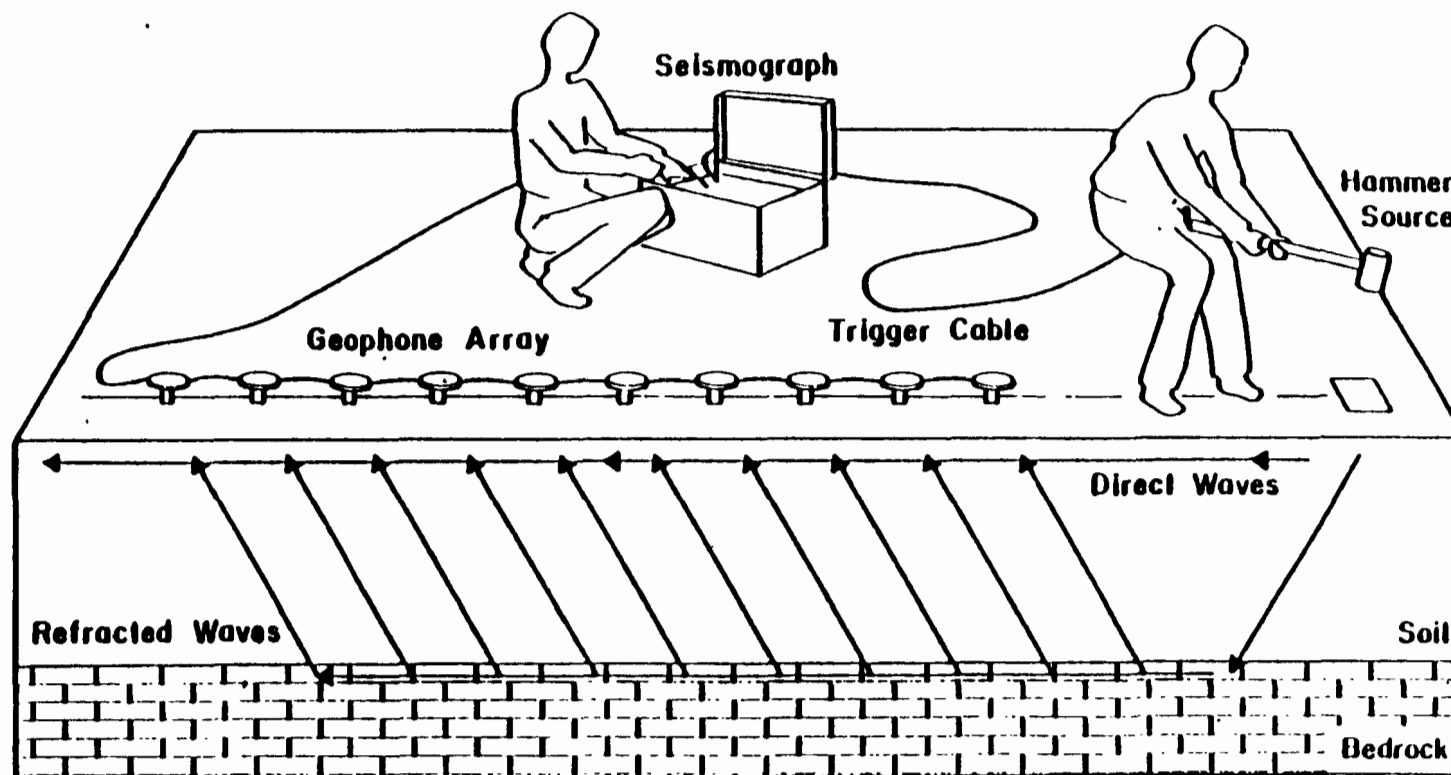


Figure C-2. Field layout of a 12-channel seismograph showing the path of direct and refracted seismic waves in a two-layer soil/rock system.



Specific details regarding the use of seismic refraction surveys, and the capabilities and limitations of this method can be found in Chapter VII of Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982).

## RESISTIVITY SURVEYS

The resistivity method is used to measure the electrical resistivity of the geohydrologic section which includes the soil, rock, and ground water. Accordingly, the method may be used to assess lateral changes and vertical cross- sections of the natural geohydrologic settings. In addition, it can be used to evaluate contaminant plumes and locate buried wastes at hazardous waste sites. Figure C-3 is a graphical representation of the concept of a resistivity survey.

Applications of the resistivity method at hazardous waste sites include:

- Locating and mapping contaminant plumes;
- Establishing direction and rate of flow of contaminant plumes;
- Defining burial sites by:
  - locating trenches,
  - defining trench boundaries, and
  - determining the depths of trenches; and
- Defining natural geohydrologic conditions such as:
  - depth to water table or to water-bearing horizons; and
  - depth to bedrock, thickness of soil, etc.

Chapter VI of Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982), discusses methods, use, capabilities, and limitations of the resistivity method.

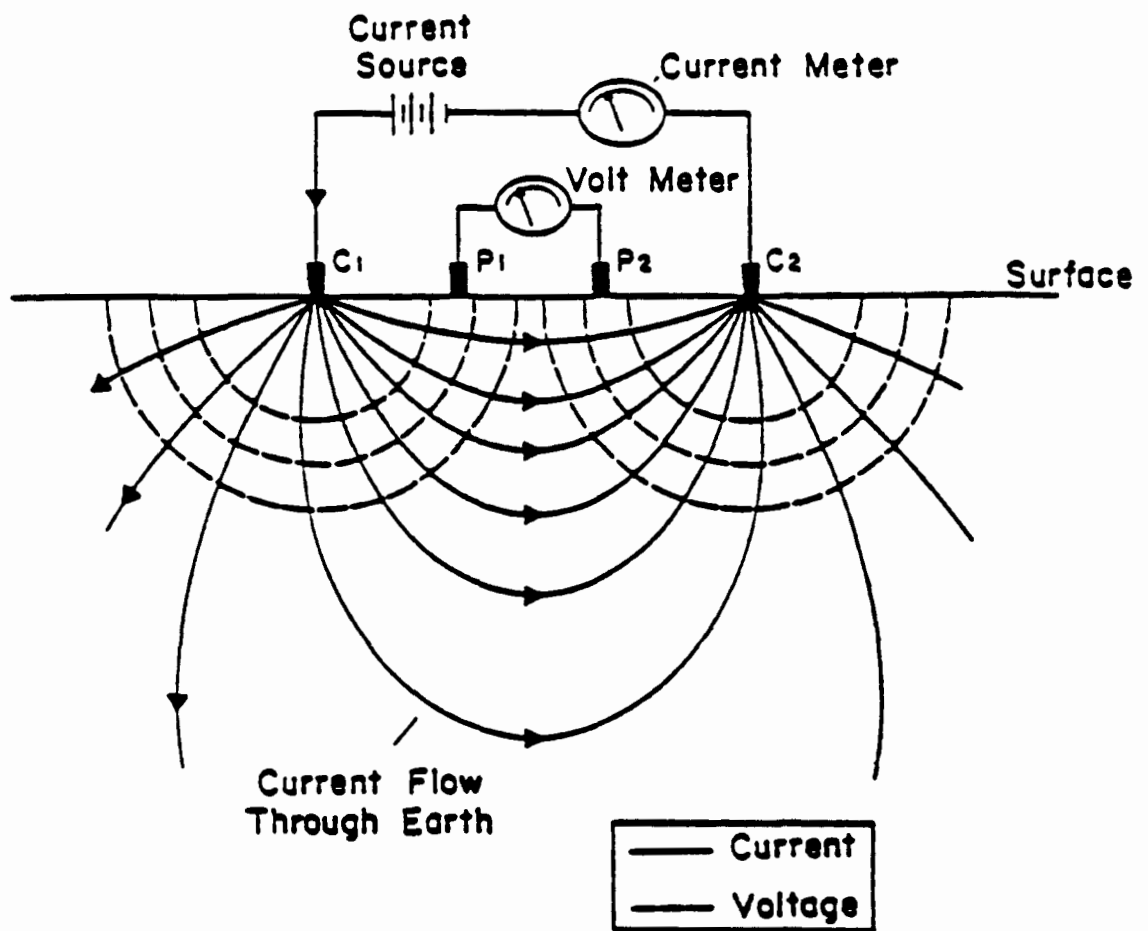


Figure C-3. Diagram showing basic concept of resistivity measurement.

## GROUND PENETRATING RADAR SURVEYS

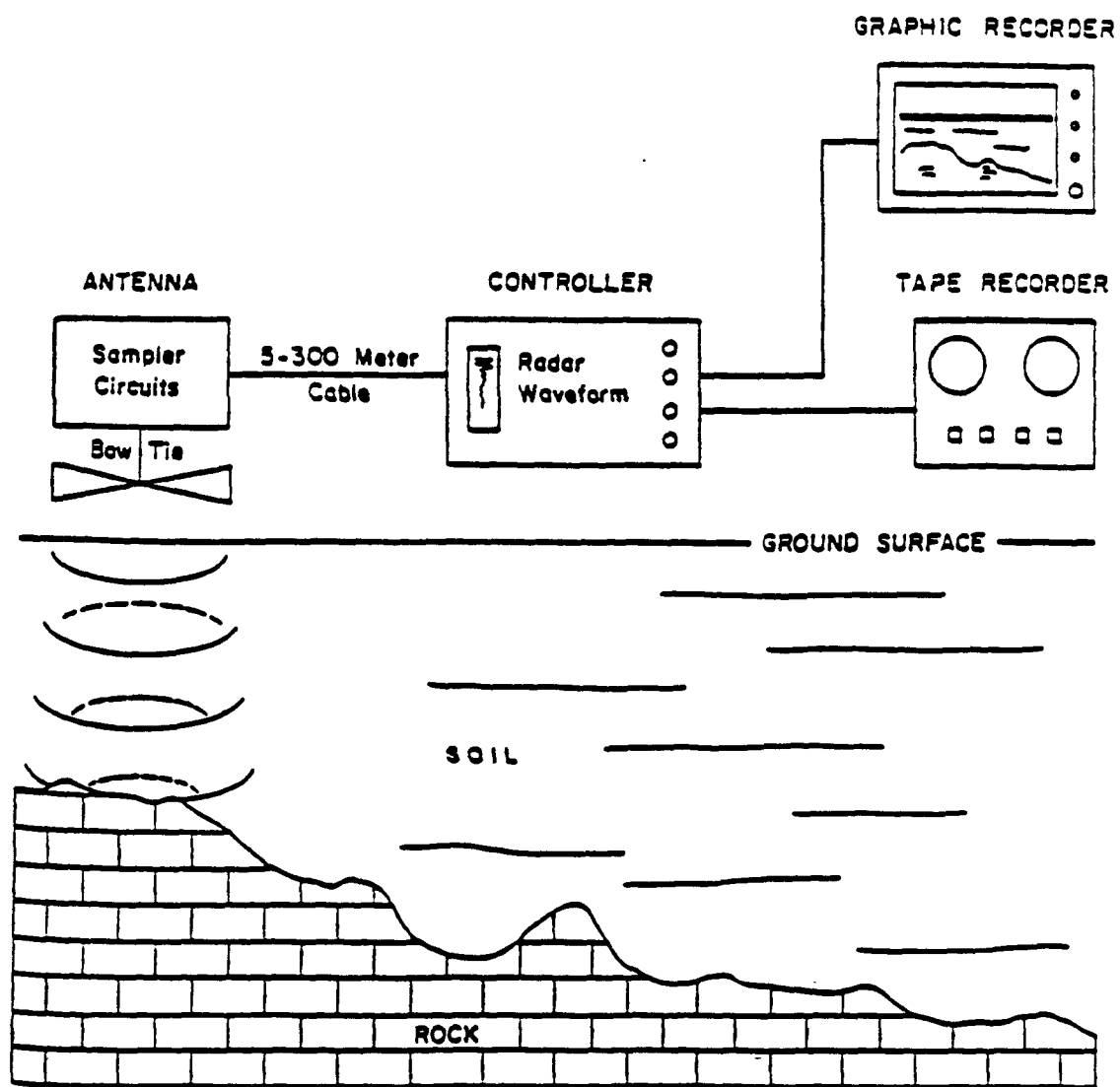
Ground penetrating radar (GPR)\* uses high frequency radio waves to acquire subsurface information. From a small antenna which is moved slowly across the surface of the ground, energy is radiated downward into the subsurface, then reflected back to the receiving antenna, where variations in the return signal are continuously recorded. This produces a continuous cross-sectional "picture" or profile of shallow subsurface conditions. These responses are caused by radar wave reflections from interfaces of materials having different electrical properties. Such reflections are often associated with natural geohydrologic conditions such as bedding, cementation, moisture and clay content, voids, fractures, and intrusions, as well as man-made objects. The radar method has been used at numerous sites to evaluate natural soil and rock conditions, as well as to detect buried wastes. Figure C-4 depicts the ground penetrating radar method.

Radar responds to changes in soil and rock conditions. An interface between two soil or rock layers having sufficiently different electrical properties will show up in the radar profile. Buried pipes and other discrete objects will also be detected.

Radar has effectively mapped soil layers, depth of bedrock, buried stream channels, rock fractures, and cavities in natural settings. Radar applications include:

- Evaluation of the natural soil and geologic conditions;
- Location and delineation of buried waste materials, including both bulk and drummed wastes;

**\*GPR has been called by various names: ground piercing radar, ground probing radar, and subsurface impulse radar. It is also known as an electromagnetic method (which in fact it is); however, since there are many other methods which are also electromagnetic, the term GPR has come into common use today, and is used herein.**



**Figure C-4.** Block diagram of ground penetrating radar system. Radar waves are reflected from soil/rock interface.

- Location and delineation of contaminant plume areas; and
- Location and mapping of buried utilities (both metallic and nonmetallic).

In areas where sufficient ground penetration is achieved, the radar method provides a powerful assessment tool. Of the geophysical methods discussed in this document, radar offers the highest resolution. Ground penetrating radar methods are further detailed in Chapter IV of Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982), as are this method's capabilities and limitations.

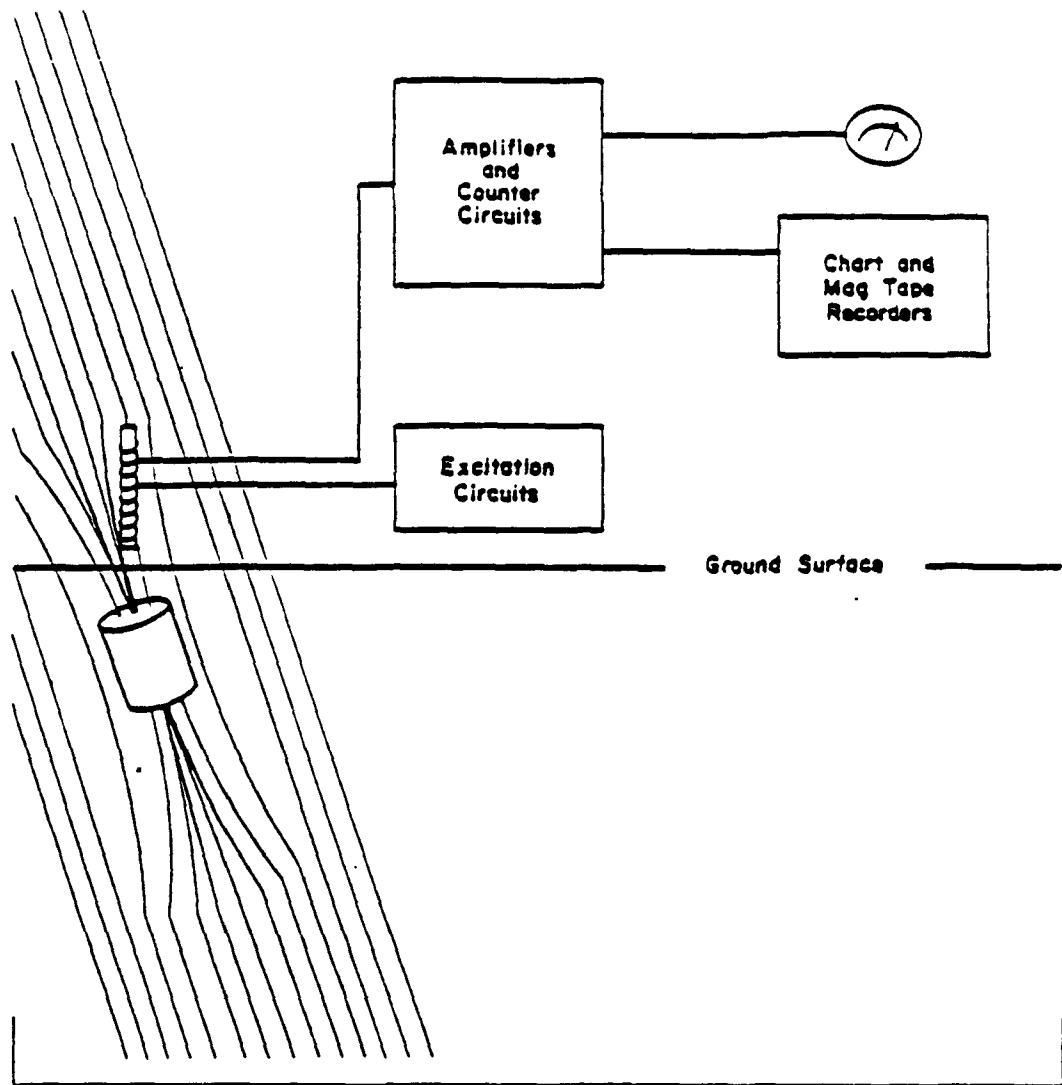
## **MAGNETOMETER SURVEYS**

Magnetic measurements are commonly used to map regional geologic structure and to explore for minerals. They are also used to locate pipes and survey stakes or to map archeological sites. In addition, they are commonly used to locate buried drums and trenches.

A magnetometer measures the intensity of the earth's magnetic field. The presence of ferrous metals creates variations in the local strength of that field, permitting their detection. A magnetometer's response is proportional to the mass of the ferrous target. Typically, a single drum can be detected at distances up to 6 meters, while massive piles of drums can be detected at distances up to 20 meters or more. Figure C-5 shows the use of a magnetometer in detecting a buried drum.

Magnetometers may be used to:

- Locate buried drums;
- Define boundaries of trenches filled with ferrous containers;
- Locate ferrous underground utilities, such as iron pipes or tanks, and the permeable pathways often associated with them; and



**Figure C-5.** Simplified block diagram of a magnetometer. A magnetometer senses change in the earth's magnetic field due to buried iron drum.

- Aid in selecting drilling locations that are clear of buried drums, underground utilities, and other obstructions.

The use, capabilities, and limitations of magnetometer surveys at hazardous waste sites are provided in Chapter IX of Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982).

## **BOREHOLE GEOPHYSICAL METHODS**

There are several different types of borehole geophysical methods used in the evaluation of subsurface lithology, stratigraphy, and structure. Much of the data collected in boreholes is analyzed in conjunction with surface geophysical data to develop a more detailed description of subsurface features. In this section, the major and most applicable types of borehole geophysical methods are identified and briefly discussed. They include:

- I. Electrical Surveys
  - a. Spontaneous Potential
  - b. Resistivity
- II. Nuclear Logging
  - a. Natural Gamma
  - b. Gamma Gamma
  - c. Neutron
- III. Seismic Surveys
  - a. Up and Down Hole
  - b. Crosshole Tests
  - c. Vertical Seismic Profiling
- IV. Sonic Borehole Surveys
  - a. Sonic Borehole Imagery
  - b. Sonic Velocity
- V. Auxiliary Surveys
  - a. Temperature
  - b. Caliper
  - c. Fluid Resistivity

All of the borehole methods presented in this section are detailed in the Army Corps of Engineers Geophysical Explorations Manual (Engineering Manual 1110-1-1802, 1979), with the exception of vertical seismic profiling. This method is relatively new and further information can be found in Balch and Lee, 1984.

## **Electrical Surveys**

The two types of electrical subsurface surveys of geotechnical interest, both of which involve continuous logging with depth of the electrical characteristics of the borehole walls, are the spontaneous potential log and the borehole resistivity log.

The spontaneous potential log (also known as self potential) is a record of the variation with depth of naturally occurring electrical potentials (voltages) between an electrode at the depth in a fluid filled borehole and another at the surface

The known origins for spontaneous potentials arise from the relative mobility and concentrations of the different elemental ions dissolved in the borehole fluid and the fluid in adjacent strata. The electrochemical activities of the minerals in the strata also cause a component of the measured spontaneous potentials (Figure C-6). The relative senses and magnitudes of the several causes from which spontaneous potentials arise are affected by the nature of the borehole fluid, by the mineralogical characteristics of all the strata the borehole penetrates, and by the dissolved solid concentration in the ground water in all potential layers.

The second type of electric survey is the electrical resistivity log. The electrical resistivity of strata is one of the basic parameters that correlates to lithology and hydrology. Direct access to individual layers of the subsurface materials by means of the borehole is the primary advantage of electrical resistivity logging over the more indirect use of apparent electrical resistivity surveys from the surface.

Electrical current can be passed through in situ earth materials between two electrodes. Electric fields created within the three dimensional earth medium are related to the medium's structure and the nature of the aqueous fluid in the medium. Figure C-7 demonstrates the conceptual field configuration for borehole electrical resistivity survey.



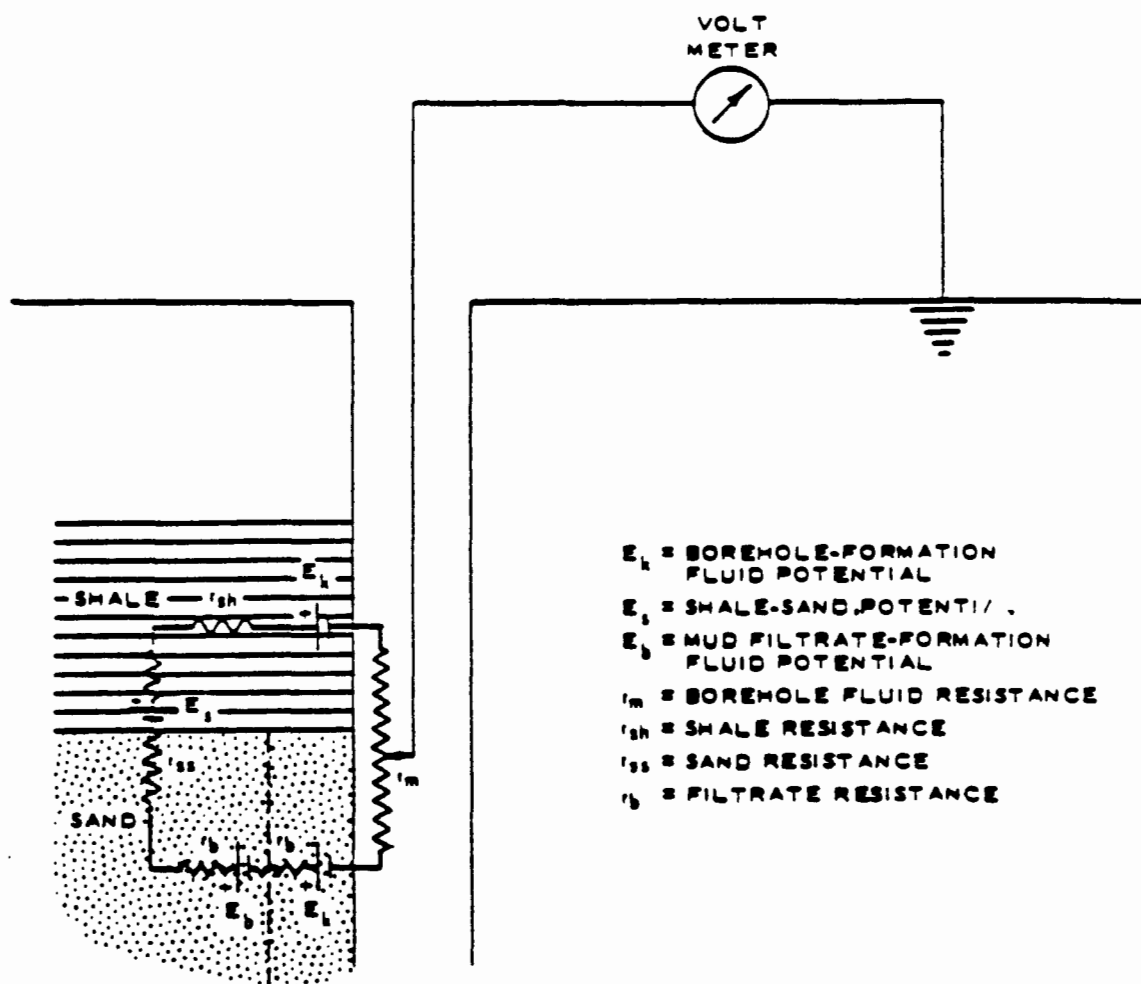
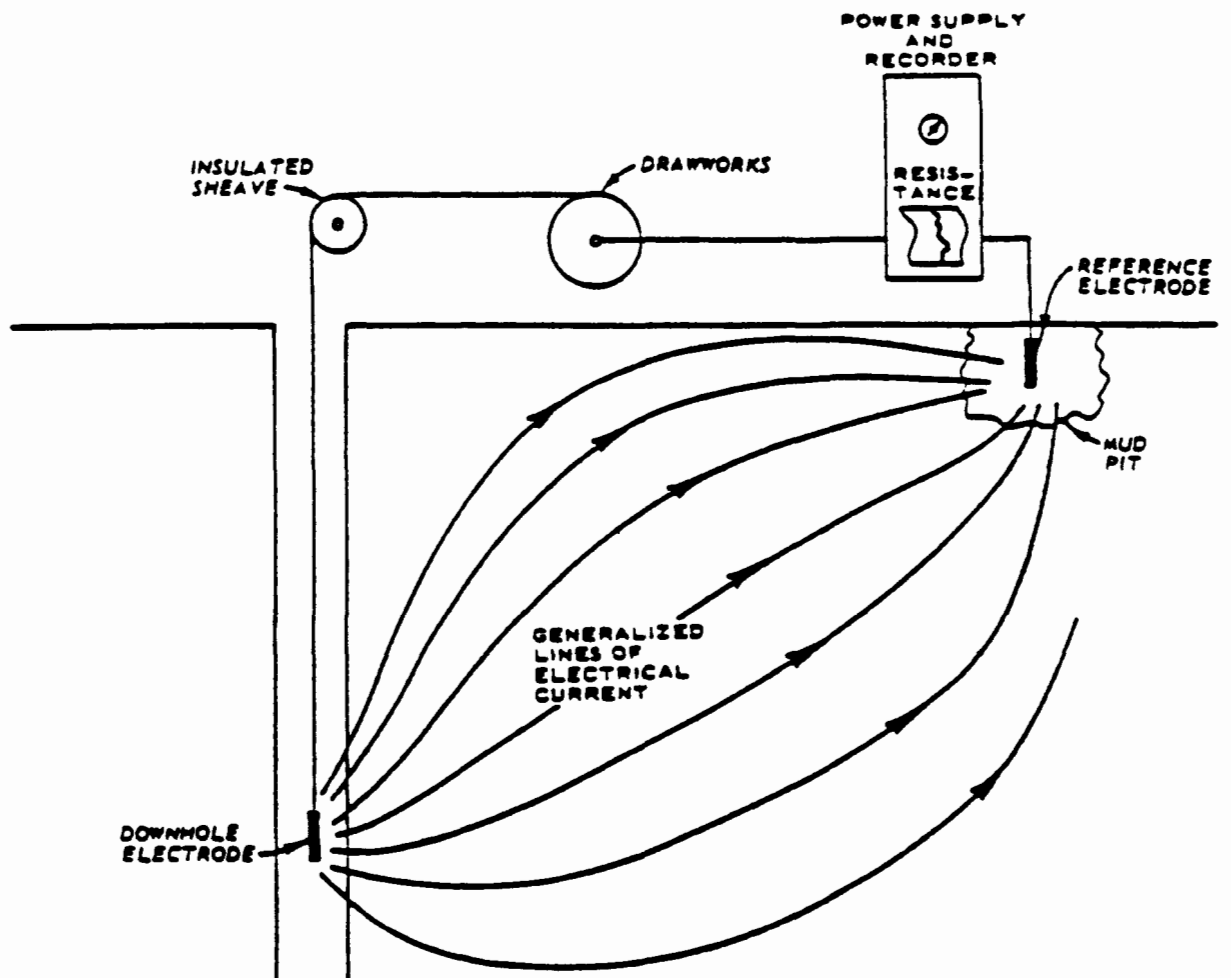


Figure C-6. Conceptual equivalent circuit for self-potential data (prepared by the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi).



**Figure C-7.** Single-point resistance log (prepared by the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi).

Resistivity logging is a valuable tool in correlating beds from borehole to borehole. In addition, they can be used together with knowledge of ground water and rock matrix resistivities (obtained from samples) to calculate porosities and/or water saturations. Also, if porosity is known and a borehole temperature log is available, contaminant concentrations can be inferred by electrical resistivity variations.

### **Nuclear Logging**

Nuclear borehole logging can be used quite effectively for borehole depths ranging from 10 to more than 1,000 feet. At considerable depths, as for large buried structures, nuclear logging is a very effective means of expanding a small number of data points obtained from direct measurements on core samples to continuous records of clay content, bulk density, water content, and/or porosity. The logs are among the simplest to perform and interpret, but the calibrations required for meaningful quantitative interpretations must be meticulously complete in attention to detail and consideration of all factors affecting nuclear radiation in earth materials. Under favorable conditions, nuclear measurements approach the precisions of direct density tests on rock cores. The gamma-gamma density log and the neutron water content log require the use of isotopic sources of nuclear radiation. Potential radiation hazards mandate thorough training of personnel working around these sources. Strict compliance with U.S. NRC Title 10, Part 20, as well as local safety regulations, is required. Additional information on natural gamma, gamma-gamma, and neutron gamma methods is provided below.

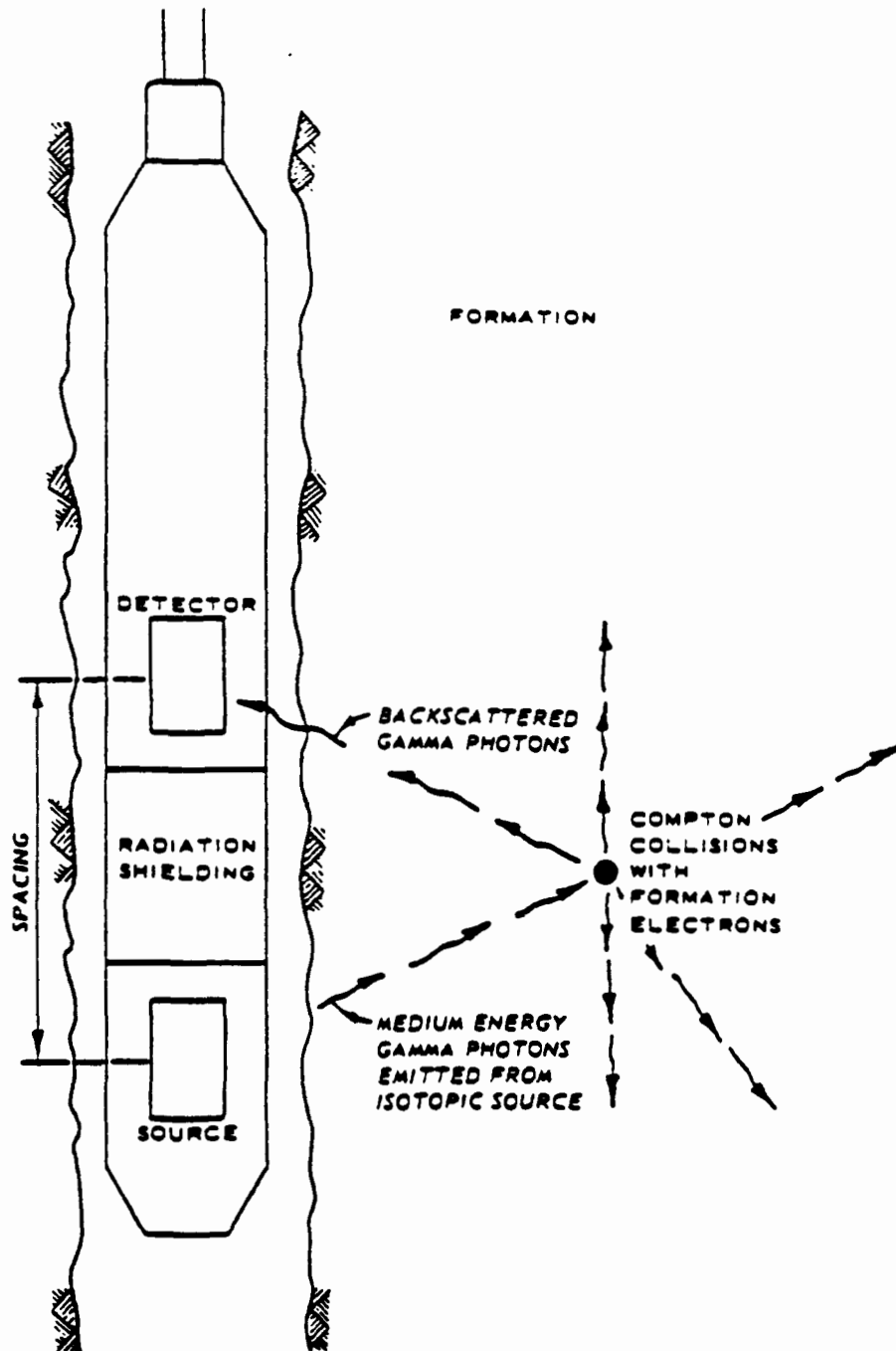
The natural gamma radiation tool is a passive device measuring the amount of gamma radiation naturally occurring in the strata being logged. The primary sources of radiation are trace amounts of the potassium isotope  $K^{40}$  and isotopes of uranium and thorium.  $K^{40}$  is most prevalent, by far, existing as an average of 0.012 percent by weight of all potassium. Because potassium is part of the crystal lattices of illites, micas, montmorillonites, and other clay materials, the engineering gamma log is mainly a qualitative indication of the clay content of the strata.

The natural gamma log is put to its simplest and most frequently used applications in qualitative lithologic interpretation (specifically identification of shale and clay layers) and bed correlations from hole to hole. Since clay fractions

frequently reduce the primary porosity and permeability of sediments, inferences as to those parameters may sometimes be possible from the natural gamma log. Environmentally based surveys may utilize the log for tracing radioactive pollutants. If regulatory restrictions allow the use of radioactive tracers, the natural gamma log can be used to locate ground water flow paths. The natural gamma radiation level is also a correction factor to the gamma-gamma density log.

In the gamma-gamma logging technique, a radioactive source and detector are used to determine density variations in the borehole. An isotopic source of gamma radiation can be placed on the gamma radiation tool and shielded so that direct paths of that radiation from source to detector are blocked. The source radiation then permeates the space and materials near itself. As the gamma photons pass through the matter, they are affected by several factors among which is "Compton scattering." Part of each photon's energy is lost to orbital electrons in the scattering material. The amount of scattering is proportional to the number of electrons present. Therefore, if the portion of radiation able to escape through the logged earth materials without being widely scattered and de-energized is measured, then that is an inverse active measure of electron density. A schematic representation of the borehole gamma-gamma tool is shown in Figure C-8.

The neutron water detector logging method is much like the gamma-gamma technique in that it uses a radioactive source and detector. The difference is that the neutron log measures water content rather than density of the borehole material. A composite isotopic source of neutron radiation can be placed on a probe together with a neutron detector. A neutron has about the same mass and diameter as a hydrogen nucleus and is much lighter and smaller than any other geochemically common nucleus. Upon collision with a hydrogen nucleus the neutron loses about half its kinetic energy to the nucleus and is slowed down as well as scattered. Collision with one of the larger nuclei scatters the neutron but does not slow it. After a number of collisions with hydrogen nuclei, a neutron is slowed, or it is captured by a hydrogen atom and produces a secondary neutron emission of thermal energy plus a secondary gamma photon. Detectors can be "tuned" to be sensitive to the epithermal (slowed) neutron or to the thermal



**Figure C-8. Schematic of the borehole gamma-gamma density tool (prepared by the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi).**

neutron or to the gamma radiation. One of these detectors plus the neutron source is then a device capable of measuring the amount of hydrogen in the vicinity of the tool. In the geologic environment, hydrogen exists most commonly in water (H<sub>2</sub>O) and in hydrocarbons. If it can be safely assumed that hydrocarbons are not present in appreciable amounts, then the neutron-epithermal neutron, the neutron-thermal neutron, and the neutron-gamma logs are measures of the amount of water present if the tool is calibrated in terms of its response to saturated rocks of various porosities.

The neutron log can be used for hole to hole stratigraphic correlation. Its designed purpose is to measure water quantities in the formation. Therefore, the gamma-gamma density, the neutron water detector, the natural gamma, and the caliper logs together form a "suite" of logs that, when taken together, can produce continuous interpreted values of water content, bulk density, dry density, void ratio, porosity, and percent of water saturation.

### **Seismic Surveys**

The principles involved in subsurface seismic surveys are the same as those discussed earlier under surface seismic surveys. The travel times for P- and S- waves between source and detector are measured, and wave velocities are determined on the basis of theoretical travel paths. These calculated wave velocities can then be used to complement and supplement other geophysical surveys conducted in the area of investigation.

Three common types of borehole seismic surveys are discussed in this section. They include Uphole and Downhole surveys, Crosshole Tests, and Vertical Seismic Surveys. The applications and limitations are discussed for each of these methods.

In the uphole and downhole seismic survey, a seismic signal travels between a point in a borehole and a point on the ground near the hole. In an uphole survey the energy source is in the borehole, and the detector on the ground surface; in a downhole survey, their positions are reversed. The raw data obtained are the travel times for this signal and distances between the seismic source and the geophones. A plot of travel time versus depth yields, from the slope of the curve, the average

wave propagation velocities at various intervals in the borehole. Figure C-9 depicts a downhole seismic survey technique.

Uphole and downhole surveys are usually performed to complement other seismic tests and provide redundancy in a geophysical test program. However, because these surveys force the seismic signals to traverse all of the strata between the source and detector, they provide a means of detecting features, such as a low velocity layer underlying a higher velocity layer or a "blind" or "hidden" zone (a layer with insufficient thickness and velocity contrast to be detected by surface refraction).

Crosshole tests are conducted to determine the P- and S-wave velocity of each earth material or layer within the depth of interest through the measurement of the arrival time of a seismic signal that has traveled from a source in one borehole to a detector in another. The crosshole test concept is shown in Figure C-10.

In addition to providing true P- and S-wave velocities as a function of depth, their companion purpose is to detect seismic anomalies, such as a lower velocity zone underlying a higher velocity zone or a layer with insufficient thickness and velocity contrast to be detected by surface refraction seismic tests.

The vertical seismic profiling technique involves the recording of seismic waves at regular and closely spaced geophones in the borehole. The surface source can be stationary or it can be moved to evaluate seismic travel times to borehole geophones, calculate velocities, and determine the nature of subsurface features in the vicinity of the borehole.

Vertical seismic profiling surveys are different from downhole surveys in that they provide data on not only direct path seismic signals, but reflected signals as well. By moving the surface source to discrete distances and azimuths from the borehole, this method provides a means of characterizing the nature and configuration of subsurface interfaces (bedding, ground water-table, faults), and anomalous velocity zones around the borehole.

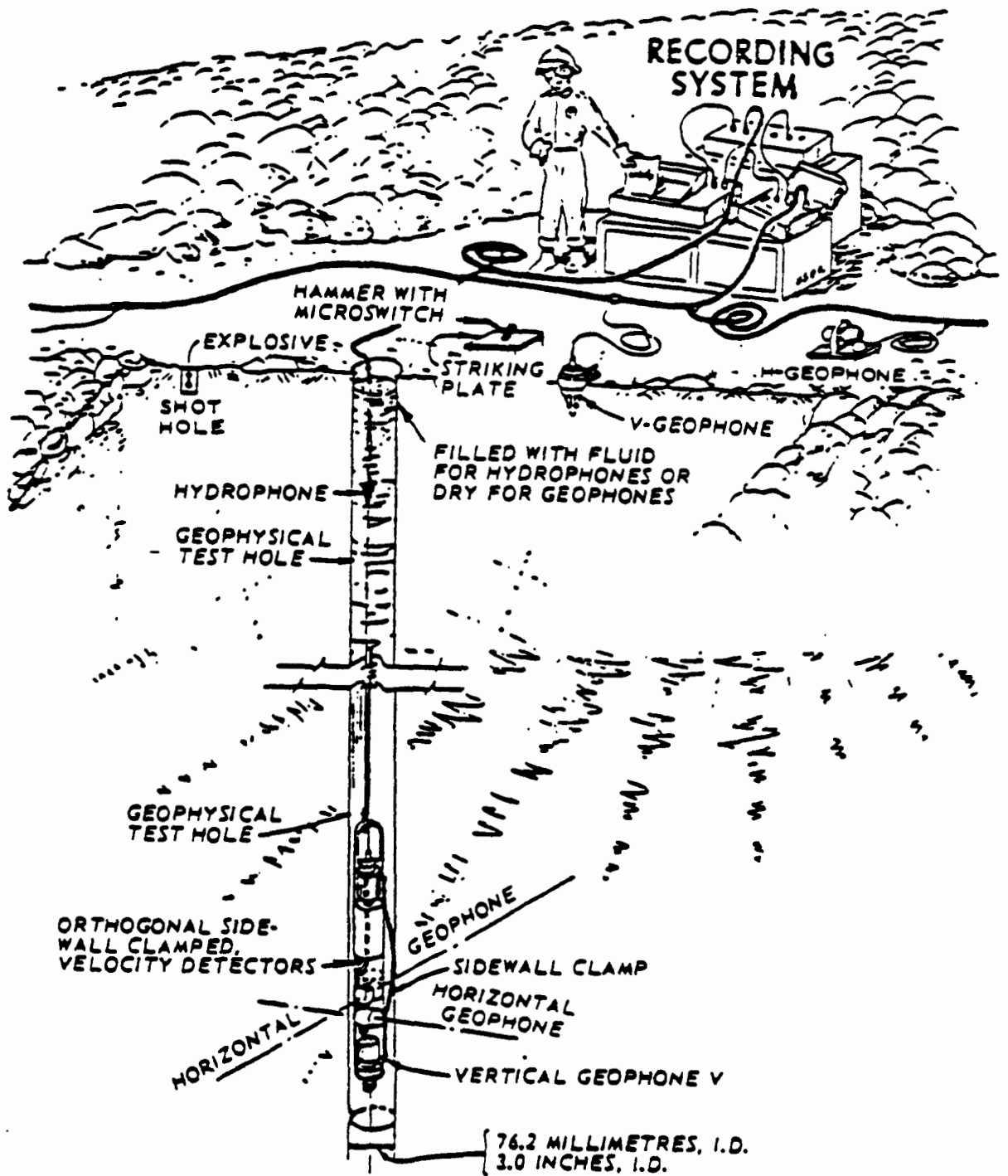
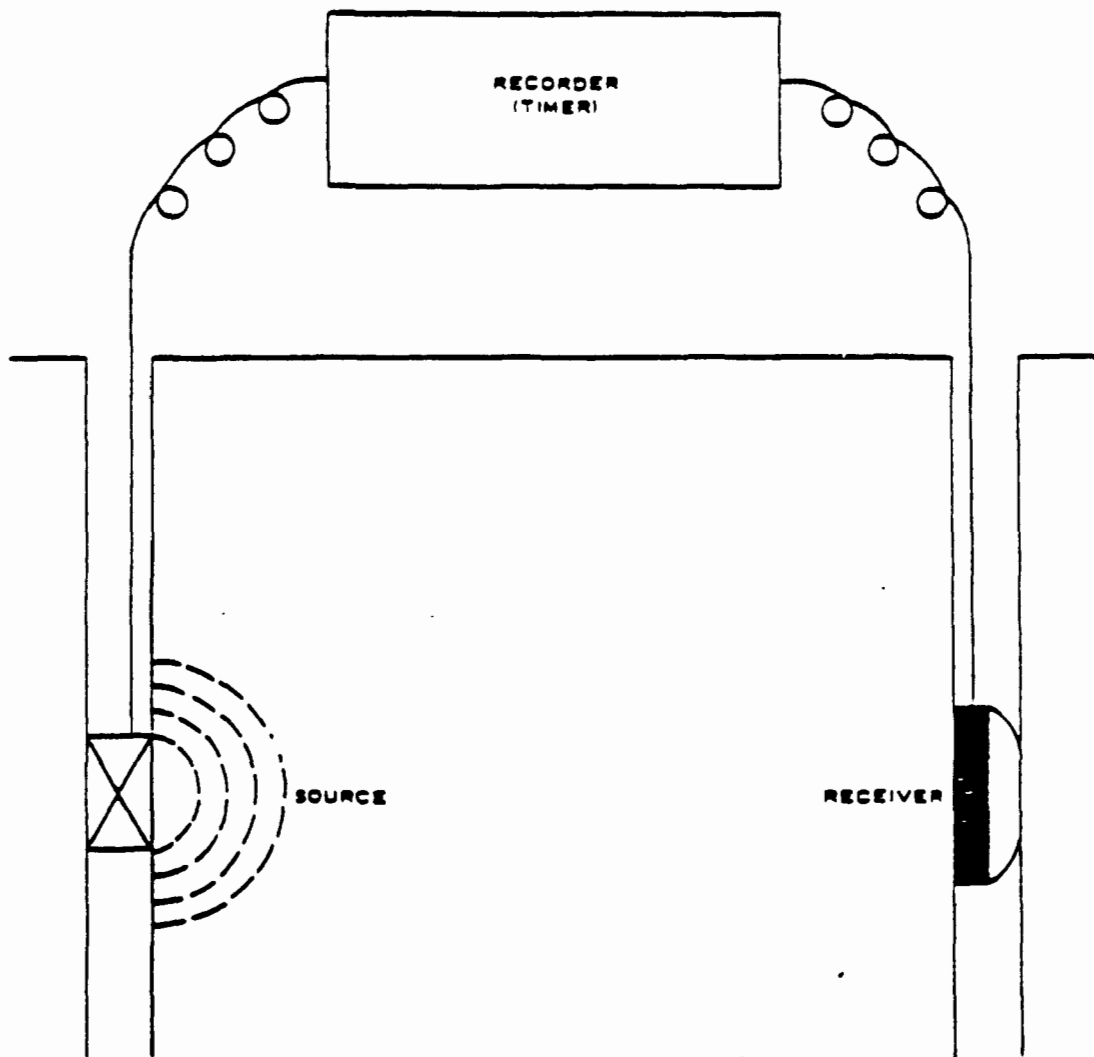


Figure C-9. Downhole survey techniques for P-wave data (prepared by the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi).





**Figure C-10. Basic crosshole test concept (prepared by the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi).**

The interpretation of processed vertical seismic profiling data is used in conjunction with surface seismic surveys as well as other geophysical surveys in the evaluation of subsurface lithology, stratigraphy, and structure. Vertical seismic profiling survey interpretations also provide a basis for correlation between boreholes.

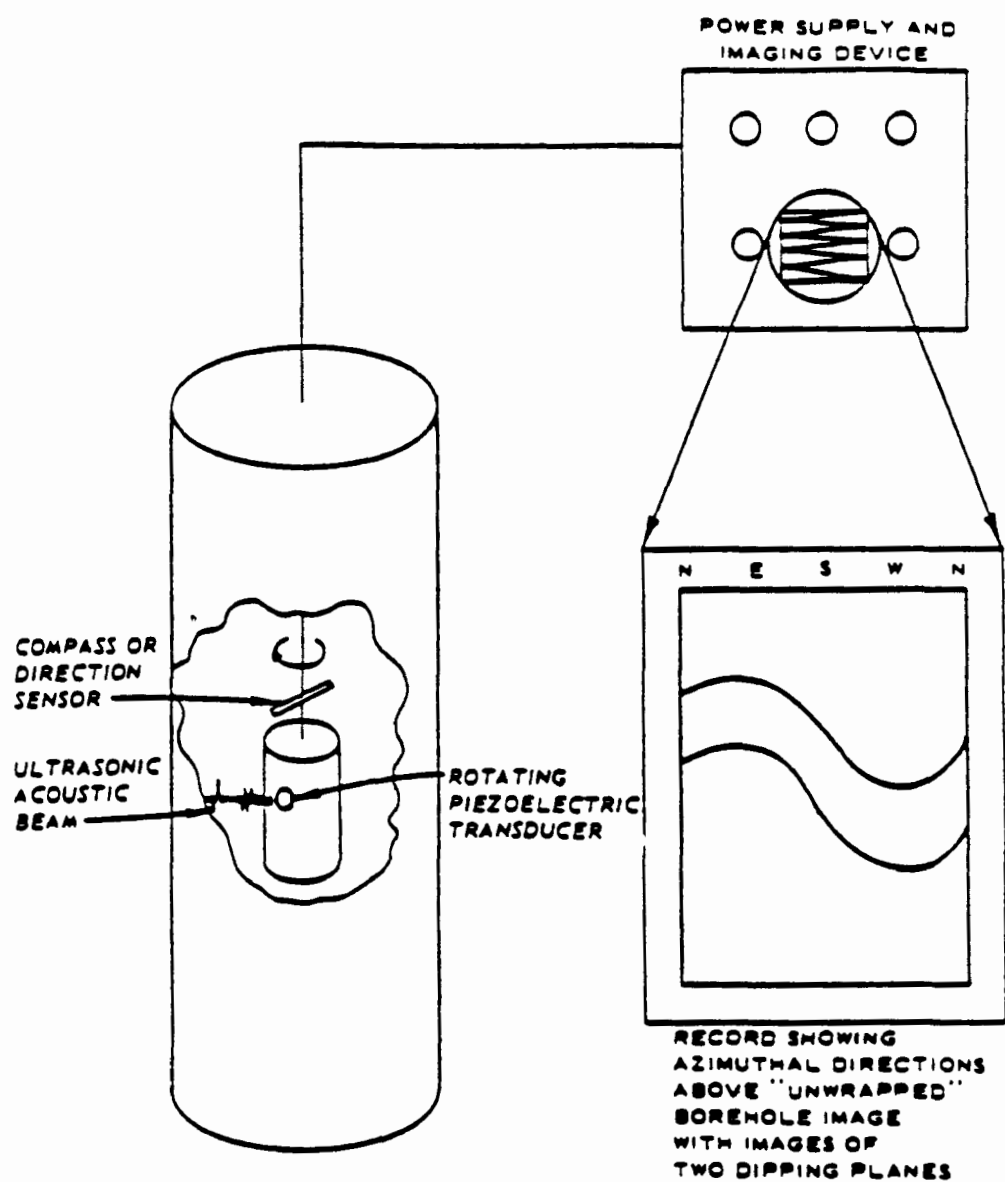
### **Sonic Borehole Surveys**

In this section, two types of continuous borehole surveys involving high frequency sound wave propagation are discussed. Sound waves are physically identical to seismic P-waves. The term sound wave is usually employed when the frequencies include the audible range and the propagating medium is air to water. Ultrasonic waves are also physically the same, except that the frequency range is above the audible range.

The Sonic borehole imagery log provides a record of the surface configuration of the cylindrical wall of the borehole. Pulses of high frequency sound are used in a way similar to marine sonar to probe the wall of the borehole and, through electronic and photographic means, to create a visual image representing the surface configuration of the borehole wall. The physical principle involved is wave reflection from a high impedance surface, the same principle used in reflection seismic surveying and acoustic subbottom profiling. The sonic borehole imagery logging concept is depicted in Figure C-11.

The sonic borehole imagery log can be used to detect discontinuities in competent rock lining the borehole. Varying lithologies, such as shale, sandstone, and limestone, can sometimes be distinguished on high quality records by experienced personnel.

Another method of sonic borehole logging is referred to as the continuous sonic velocity logging technique. The continuous sonic velocity logging device is used to measure and record the transit time of seismic waves along the borehole wall between two transducers as it is moved up or down the hole. A diagram of the continuous sonic velocity logging device is provided in Figure C-12.



**Figure C-11. Sonic imagery logger (prepared by the Waterways Experiment Station, U.S. Army Corp of Engineers, Vicksburg, Mississippi).**

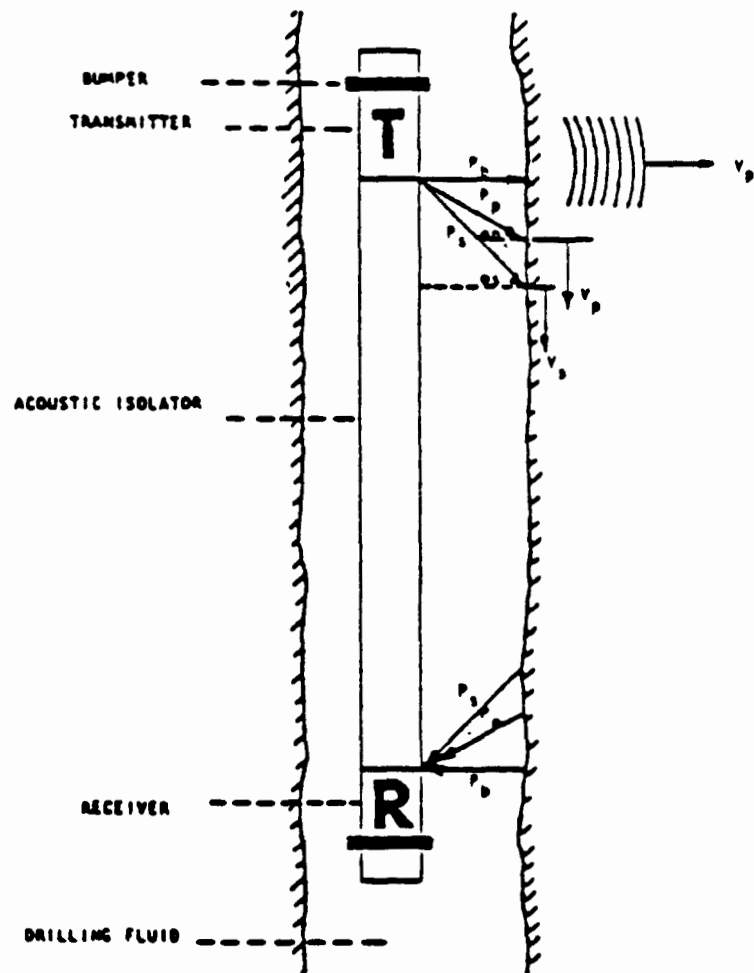


Figure C-12. Diagram of three-dimensional velocity tool (courtesy of Seismograph Service Corporation, Birdwell Division).

This subsurface logging method provides data on fractures and abrupt lithology changes along the borehole wall that can be effective in characterizing the nature of surrounding material as well as borehole correlation in lithology and structure.

### **Auxiliary Surveys**

An auxiliary survey is the direct measurement of some parameter of the borehole or its contained fluid to provide information that will either permit the efficient evaluation of the lithology penetrated by the boring or aid in the interpretation or reduction of the data from other borehole logging operations. In most instances, auxiliary logs are made where the property recorded is essential to the quantitative evaluation of other geophysical logs. In some instances, however, the auxiliary results can be interpreted and used directly to infer the existence of certain lithologic or hydrologic conditions.

Discussed here are three different auxiliary logs; fluid temperature, caliper, and fluid resistivity, that are especially applicable to the logging methods discussed in this text. A description of each auxiliary log is presented below.

Temperature logs are the continuous records of the temperature encountered at successive elevations in a borehole. The two basic types of temperature logs are standard (gradient) and differential. Both types of logs rely upon a downhole probe, containing one or more temperature sensors (thermistors) and surface electronics to monitor and record the temperature changes encountered in a borehole. The standard temperature log is the result of a single thermistor continuously sensing the thermal gradient of the fluid in the borehole as the sonde is raised or lowered in the hole. The differential temperature log depicts the difference in temperature over a fixed interval of depth in the borehole by employing two thermistors spaced from one to several feet apart or through use of a single thermistor and an electronic memory to compare the temperature at one depth with that of a selected previous depth.

Temperature logs provide useful information in both cased and uncased borings and are necessary for correct interpretation of other geophysical logs (particularly resistivity logs). Temperature logs can also be used directly to indicate the source and movement of water into a borehole, to identify aquifers, to locate zones of potential recharge, to determine areas containing wastes discharged into the ground, and to detect sources of thermal pollution. The thermal conductivity and permeability of rock formations can be inferred from temperature logs as can be the location of grout behind casing by the presence of anomalous zones of heat buildup due to the hydration of the setting cement.

The caliper log is a record of the changes in borehole casing or cavity size as determined by a highly sensitive borehole measuring device. The record may be presented in the form of a continuous vertical profile of the borehole or casing wall, which is obtained with normal or standard caliper logging systems, or as a horizontal cross section at selected depths, used for measuring voids or large subsurface openings. There are two basic methods of obtaining caliper logs. One technique utilizes mechanically activated measuring arms or bown springs, and the other employs piezoelectric transducers for sending and receiving a focused acoustic signal. The acoustic method requires that the hole be filled with water or mud, but the mechanical method operates equally well in water, mud, or air. Reliable mechanically derived caliper logs can be obtained in small (2 in.) diameter exploratory borings as well as large (36 in.) inspection or access calyx-type borings.

Caliper or borehole diameter logs represent one of the most useful and possibly the simplest of all techniques employed in borehole geophysics. They provide a means for determining inhole conditions and should be obtained in all borings in which other geophysical logs are contemplated. Borehole diameter logs provide information on subsurface lithology and rock quality. Borehole diameter varies with the hardness, fracture frequency, and cementation of the various beds penetrated. Borehole diameter logs can be used to accurately identify zones of enlargement (washouts) or constriction (swelling), or to aid in the structural evaluation of an area by the accurate location of fractures or solution openings, particularly in borings where core loss has presented a problem. Caliper logs also are a means of identifying the more porous zones in a boring by locating the intervals in which excessive mud filter cake has built up on the walls of the borehole. One of the major uses of standard or borehole caliper logs is to provide

information by which other geophysically derived raw data logs can be corrected for borehole diameter effects. This is particularly true for such nonfocused logs as those obtained in radiation logging or the quantitative evaluation of flowmeter logs or tracer and water quality work where inhole diameters must be considered. Caliper logs also can be useful to evaluate inhole conditions for placement of water well screens or for the selection of locations of packers for permeability testing.

The fluid resistivity log is a continuous graphical record of the resistivity of the fluid within a borehole. Such records are made by measuring the voltage drop between two closely spaced electrodes enclosed within a downhole probe through which a representative sample of the borehole fluid is channeled. Some systems, rather than recording in units of resistivity, are designed to provide a log of fluid conductivity. As conductivity is merely the reciprocal of resistivity, either system can be used to collect the information on inhole fluid required for the correct interpretation of other downhole logs.

The primary use of fluid resistivity or conductivity logs is to provide information for the correct interpretation of other borehole logs. The evaluation of nuclear and most electrical logs requires corrections for salinity of the inhole fluids, particularly when quantitative parameters are desired for determining porosity from formation resistivity logs.

**APPENDIX D**

**SUBSURFACE GAS MIGRATION MODEL  
ADAPTED FROM**

**GUIDANCE MANUAL FOR THE CLASSIFICATION  
OF SOLID WASTE DISPOSAL FACILITIES  
U.S. EPA, 1981**



## **APPENDIX D**

### **SUBSURFACE GAS MIGRATION MODEL**

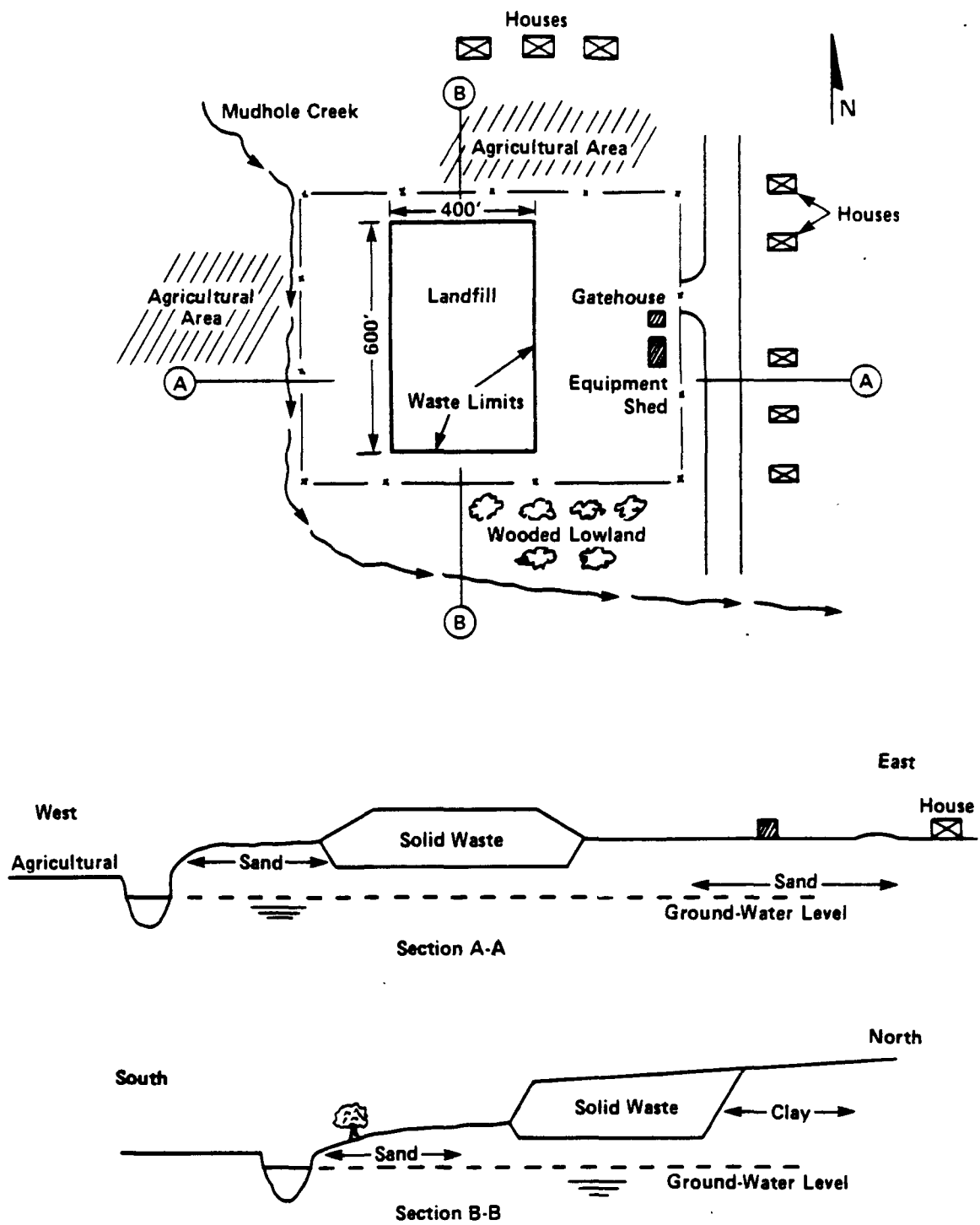
#### **METHANE MIGRATION DISTANCE PREDICTION CHARTS**

Migration distance charts have been developed to estimate methane distances and to plan the monitoring program. The basic methane migration distance prediction chart and appropriate corrective factor charts were produced by imposing a set of simplifying assumptions on a general methane migration computer model. These charts are based on a number of assumptions that were made to produce them. Case Study Number 24 (Volume IV) illustrates the use of the Subsurface Gas Migration Model.

To illustrate the use of the charts, an example landfill is shown in Figure D-1 along with two cross-sections. Conditions along each side of the waste deposit are typical conditions that could be encountered. A similar sketch or plan of a facility being evaluated should be prepared. The land use within 1/4-mile of the solid waste limits, including offsite and facility structures, should be on the map. The property boundaries and solid waste deposit limits should also be plotted, as has been done in Figure D-1.

Additional data needs are:

1. The age of the site from the initial deposit of organic waste in years;
2. The average elevation of the bottom of the solid waste;
3. Natural boundaries and topography around the site; and
4. The average elevation below the solid waste of a gas impervious boundary such as unfractured rock.



Note: Not to Scale

FIGURE D-1. EXAMPLE LANDFILL

Two calculations of migration distance from the waste boundary are needed for each side of the landfill:

1. The 5 percent (Lower Explosion Limit or LEL) distance for property boundaries.
2. The 1.25 percent (1/4 of the LEL) distance for onsite facility structures.

After preparation of the sketch and cross-sections, the determination of the estimated migration distances begins with the use of Figure D-2 for the 5 percent methane (LEL) migration distance and for the 1.25 percent (1/4 LEL) distance. These distances are then modified, if necessary, with the corrective factors for each depth and surrounding soil surface permeability (Figures D-3 and D-4). The final distances of migration for each side of the landfill can then be plotted on the landfill sketch for comparison to property boundary and structures locations.

#### UNCORRECTED MIGRATION DISTANCES

The use of Figure D-2 requires the age of the site and the type of soil extending out from each side of the solid waste deposit. The graph is entered with the site age, moving up to the appropriate soil type and methane concentration (1.25 or 5 percent). Interpolations between the sand and clay lines on the graph can be made for other soils, using the following general guidance:

<u>Soil Name</u>	<u>USCS Classification</u>	<u>Chart Use</u>
Clean (no fines) gravels and sands	GW, GP, SW, SP	Sand
Silty gravels and sands, silt, silty and sandy loam, organic silts	GM, SM, ML, OL, MH	Interpolate
Clayey gravels and sands, lean, fat, and organic clays	GC, SC, CL, CH, OH	Clay

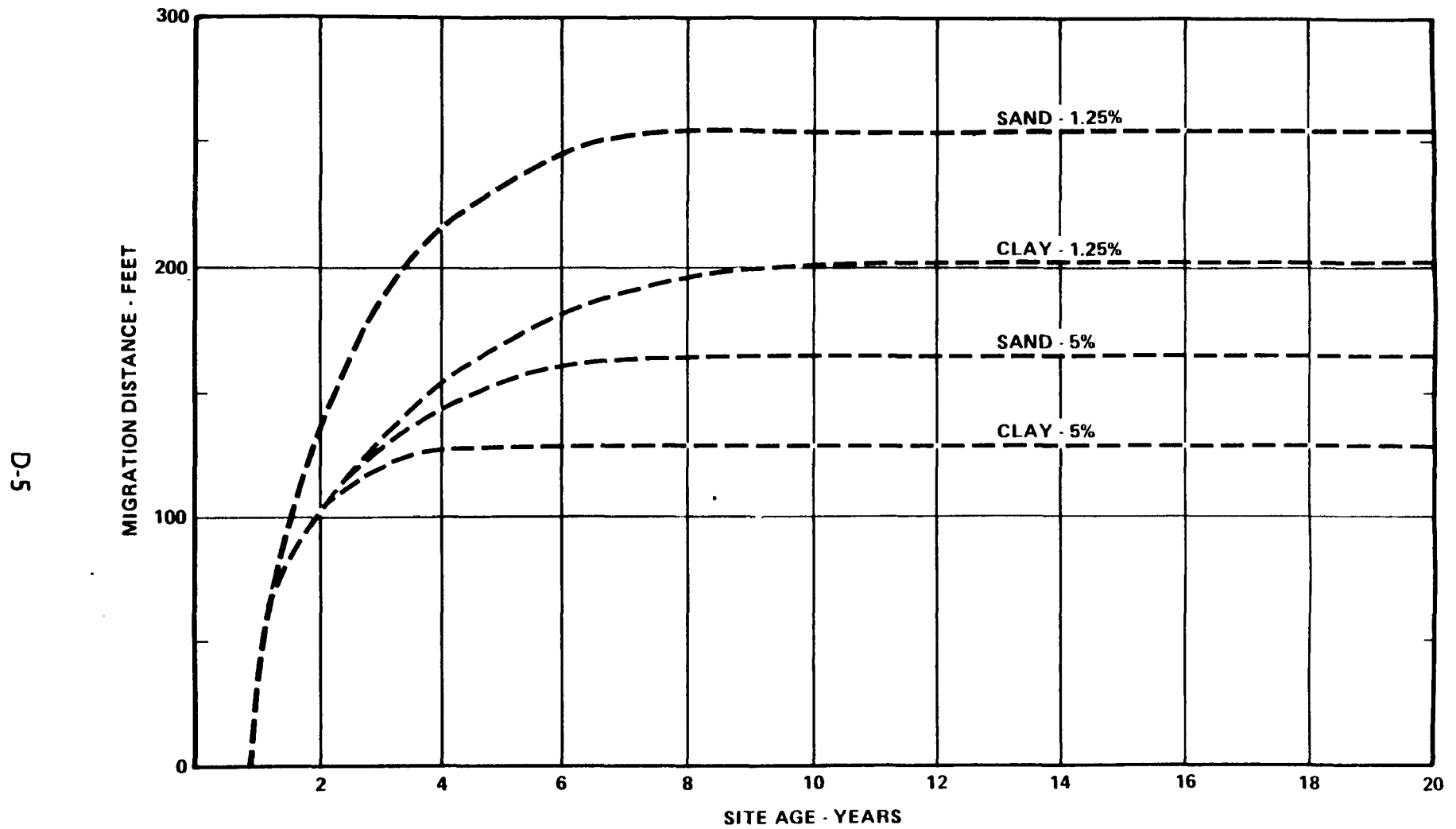


FIGURE D-2. FIVE PERCENT AND 1.25 PERCENT METHANE MIGRATION DISTANCE

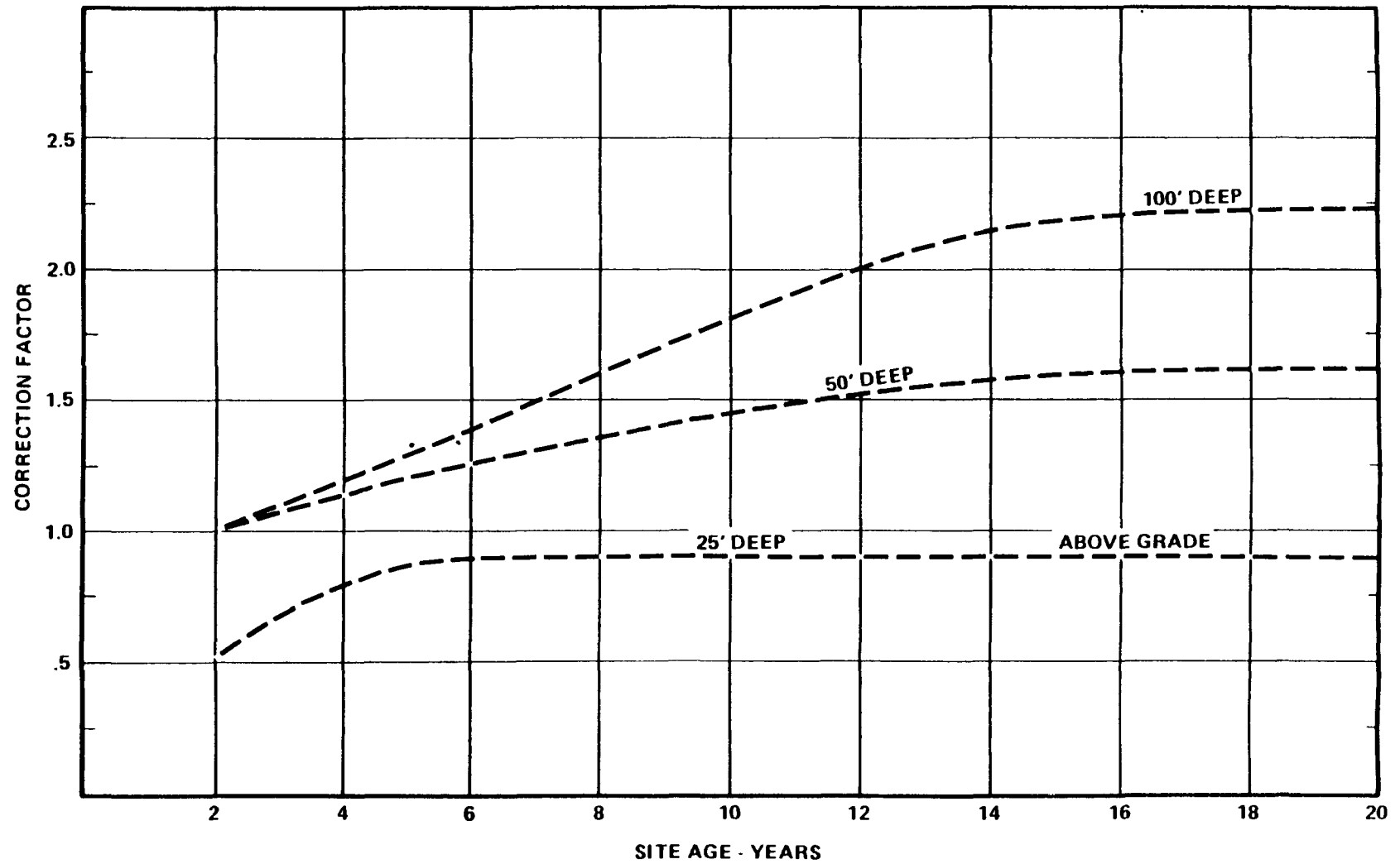


FIGURE D-3. CORRECTION FACTORS FOR LANDFILL DEPTH BEFORE GRADE

D-7

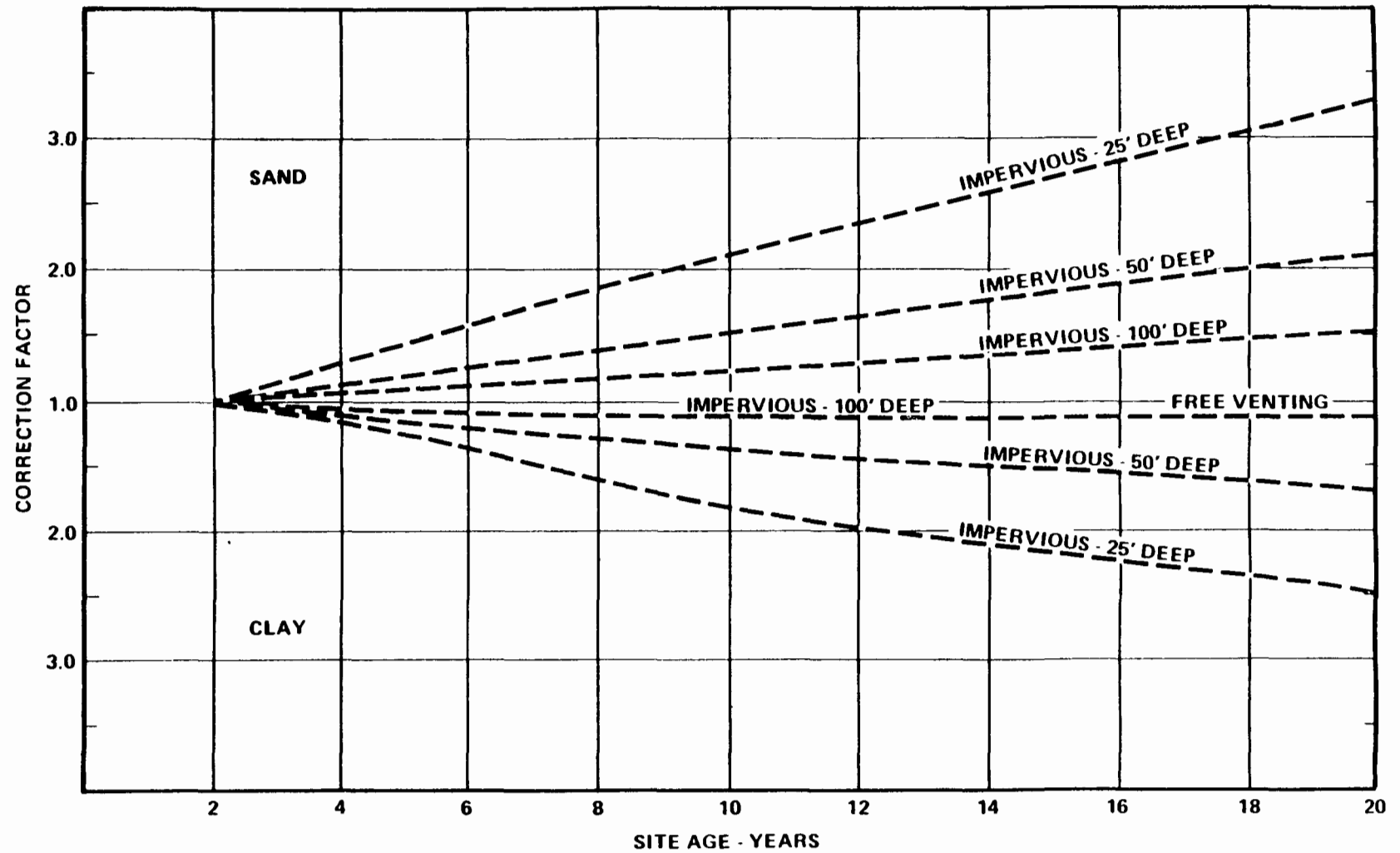


FIGURE D-4. CORRECTION FACTORS FOR SOIL SURFACE VENTING CONDITION AROUND LANDFILL

The uncorrected migration distance from the solid waste limit can then be read on the left for the appropriate site age and soil type.

If the soil along a given boundary is stratified and the variability extends from the waste deposit to the property boundary, the most permeable unsaturated thickness should be used in entering the charts. For example, if dry, clean sand underlies surficial silty clays, the uncorrected migration distance should be obtained using the sand line of the chart. If there are questions as to the extent of particular soils along a boundary, helpful information might be obtained from Soil Conservation Services (SCS) Soil Survey Maps or the landfill operator. Field inspection, SCS maps, and permit boring information are sufficient. Additional borings are not necessary as this is only a ranking procedure. Where there is doubt, use the most permeable soil group present.

For the example landfill in Figure D-1, the uncorrected 5 percent methane migration distances for a 10-year old landfill would be (Figure C-2):

Section A-A: East side, 10 years, sand = 165'  
West side, 10 years, sand = 165'

Section B-B: South side, 10 years, sand = 165'  
North side, 10 years, clay = 130'

The corresponding uncorrected distances for the 1.25 percent methane migration would be:

Section A-A: East side, 10 years, sand = 225'  
West side, 10 years, sand = 135'

Section B-B: South side, 10 years, sand = 255'  
North side, 10 years, clay = 200'

The depth to corrective multipliers for the example sites would be:

Section A-A: East side, 10 years, 20' deep = 1.0  
West side, 10 years, 20' deep = 1.0

Section B-B: South side, 10 years, 10' deep = 0.95  
North side, 10 years, 50' deep = 1.4

## VENTING CONDITIONS CORRECTION

The corrective factors for the surrounding soil venting conditions are obtained using the chart in Figure D-4. This chart is based on the assumption that the surrounding surficial soil is impervious 100 percent of the time. Thus, the value read from the chart must be adjusted, based on the percentage of time the surrounding surficial soil is saturated or frozen and the percentage of land along the path of gas migration from which gas venting to the atmosphere is blocked all year (asphalt or concrete roads or parking lots, shallow perched ground water, surface water bodies not interconnected to ground water). The totally impervious corrective factor is only used when the landfill is entirely surrounded at all times by these conditions. Both time and area adjustments are necessary, and the percentages are additive. Estimates to the nearest 20 percent are sufficient. An adjusted corrective factor is obtained by entering the chart with site age and obtaining the totally impervious corrective factor for the appropriate depth and soil type and then entering this value in the following equation:

$$\text{Adjusted corrected factor} = [(\text{Impervious corrective factor}) - 1] \\ \times [5 \text{ of impervious time or area}] + 1$$

When free venting conditions are prevalent most of the year, simply use 1.0 (no correction). For depths less than 25 feet deep, use the 25 foot value. For the example site, the adjusted corrective factors for frozen or wet soil conditions 50 percent of the year are:

Section A-A: East side (ignore narrow road, sand 20' deep, 10 years old) =  $(2.1 - 1)(0.50) + 1 = 1.55$

West side (sand 20' deep, 10 years old) =  $(2.1 - 1)(0.50) + 1 = 1.55$



Section B-B: South side (sand, 10' deep,  $= (2.1-1)(0.50) + 1 = 1.55$   
10 years old)

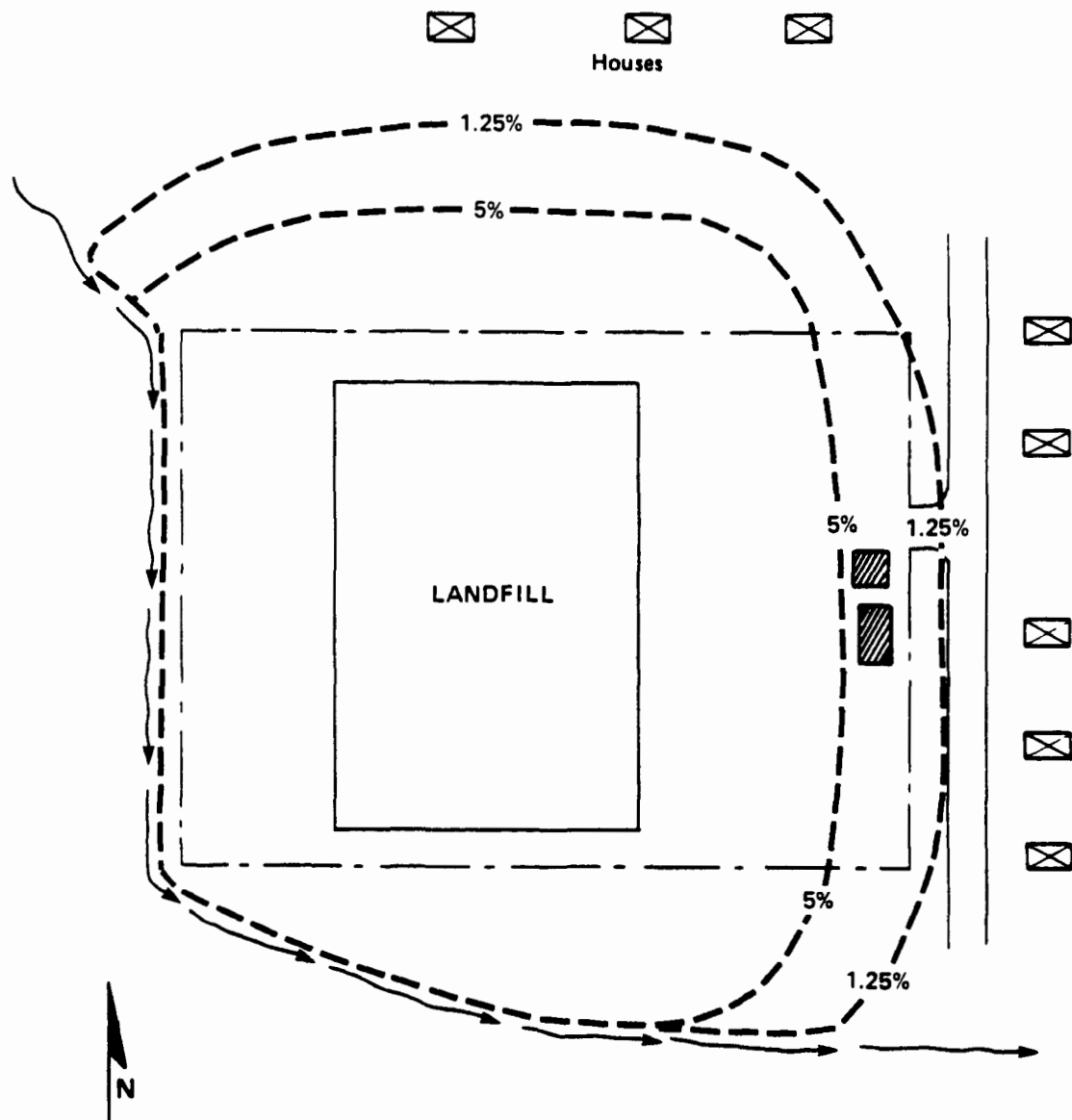
North side (clay, 50' deep,  $= (1.4-1)(0.50) + 1 = 1.2$   
10 years old)

Once the surface venting factors have been tabulated as in Table D-1, the corrective distance can be obtained by multiplying across the chart for each side of the landfill. These values can then be plotted on the scale plan to describe contours of the 5 percent and 1.25 percent methane concentrations or simply compared to the distance from the waste deposit to structures of concern (Figure D-5).

Table D-1. METHANE DISTANCE TABULATING FORM

Landfill Side	Methane Concentration	Uncorrected Distance	Correction for Depth	Correction for Venting	Corrected Distance
E	5%	165'	X 1.0	X 1.55	= 256'
	1.25%	255'	X 1.0	X 1.55	= 395'
W	5%	165'	X 1.0	X 1.55	= 256'*(225' max.)
	1.25%	255'	X 1.0	X 1.55	= 395'*(225' max.)
S	5%	165'	X 0.95	X 1.55	= 243'*(225' max.)
	1.25%	255'	X 0.95	X 1.55	= 375'*(225' max.)
N	5%	130'	X 1.4	X 1.2	= 218'
	1.25%	200'	X 1.4	X 1.2	= 336'

\* When these distances are plotted on the landfill sketch, they exceed the distance to the creek, which acts as a barrier to the gas migration. Thus the distance to the creek is the maximum migration distance.



NOTE: NOT TO SCALE

FIGURE D-5. EXAMPLE LANDFILL METHANE CONDITIONS

## **APPENDIX E**

### **ESTIMATION OF BASEMENT AIR CONTAMINANT CONCENTRATIONS DUE TO VOLATILE COMPONENTS IN GROUND WATER SEEPED INTO THE BASEMENT**

## APPENDIX E

### ESTIMATION OF BASEMENT AIR CONTAMINANT CONCENTRATIONS DUE TO VOLATILE COMPONENTS IN GROUND WATER SEEPED INTO THE BASEMENT

Ground water can reach the basement and the walls of a house in several ways. If ground water is contaminated by volatile components, there are several possibilities that the indoor ambient air can be affected by these constituents. There are several methods which can be applied to estimating the ambient air concentrations in the basement into which the contaminants are volatilized from ground water. The manner in which and the extent to which the ground water reaches the basement or the walls will dictate the choice of a method.

Two cases are considered as example scenarios: Case 1) Ground water is seeped inside the basement completely wetting the basement, with a visual indication of water on the floor. Case 2) The basement is partially wetted without a visual indication of liquid on the floor. This latter case can be subdivided into two subcases: Subcase 1) involving a damp floor evident on the surface; Subcase 2) involving a floor without observable dampness on the floor surface but with ground water underneath the concrete floor.

The way the emission rates are estimated will be different for the three cases. If the emission flux rate per unit square area of the exposed surface is denoted by  $E$  ( $\text{g}/\text{m}^2 \text{ day}$ ), then in all cases the air concentration,  $C$  ( $\mu\text{g}/\text{m}^3$ ), in the basement can be estimated from:

$$C (\mu\text{g}/\text{m}^3) = E \times 10^6 A t_e / V_B \quad (1)$$

where  $A$  = basement floor and wall area exposed to ground water,  $\text{m}^2$

$V_B$  = volume of the basement,  $\text{m}^3$ , and

$t_e$  = air exchange time for the basement, days.

The air exchange time should be determined on a site-specific or situation-specific basis. The tight room will have a longer time per air exchange in the room, and the room with an exhaust fan will have a shorter time per air exchange. The default value for a typical house could be  $t_e = 0.05$  days.

The emission rates in Eq. (1) can be estimated for the various case scenarios illustrated above.

#### Case 1. Wet basement with visible liquid.

The volatilization is a mass transfer phenomenon from the liquid phase of ground water on the floor to the basement air. Emission flux rate can be estimated from:

$$E = K_{OL} (C_L - C_L^*) \quad (2)$$

where  $K_{OL}$  = overall mass transfer coefficient in the liquid phase unit, m/day,  $C_L$  = concentration of contaminant in water, g/m<sup>3</sup>, and  $C_L^*$  = liquid phase concentration in equilibrium concentration with the basement air, g/m<sup>3</sup>. The equilibrium concentration  $C^*$  could be assumed to be approaching a small value compared to the ground water contaminant concentration when the air exchange rate is high, or when the time per air exchange is small. But this assumption would not be valid at a low air exchange rate or at a longer time for a room air exchange. In this case, the emission flux rate should be estimated by a trial and error method using Equation (2) in combination with Equation (1), and Henry's Law constant.

It is a well-established scientific principle to use the two-resistance theory to obtain the overall mass transfer coefficient,  $K_{OL}$ , as follows:

$$K_{OL} = \frac{1}{k_L} + \frac{1}{H_C k_g} \quad (3)$$

where  $k_L$  and  $k_g$  = individual mass transfer coefficients in liquid and gas phases, respectively, m/day, and  $H_C$  = dimensionless Henry's Law constant obtained from

concentration units for gas and liquid phase concentrations. The numerical value for  $H_c$  can be calculated from Henry's Law constant given in atm/g-mol.m<sup>3</sup> by multiplying by 41. Default values for the individual mass transfer coefficients can be estimated from:

$$k_L = 3 \quad \frac{\text{cm}}{\text{hr}} \left( \frac{44}{\text{MW}} \right)^{\frac{1}{2}} \left( \frac{24}{100} \quad \frac{\text{M}}{\text{cm}} \quad \frac{\text{hr}}{\text{day}} \right) \quad (4)$$

$$k_g = 3000 \quad \frac{\text{cm}}{\text{hr}} \left( \frac{18}{\text{MW}} \right)^{\frac{1}{2}} \left( \frac{24}{100} \quad \frac{\text{M}}{\text{cm}} \quad \frac{\text{hr}}{\text{day}} \right) \quad (5)$$

where MW = molecular weight of the contaminant.

**Case 2. Basement partially wetted with no visual indication of liquid.**

(a) Subcase 1. Dampness evident on the floor or wall surface. The volatilization process can be treated as a diffusional process from the air at the water-air interface through the air pores in the basement floor material and into the basement air. The diffusional process can be solved using the approach described in the EPA report Development of Advisory Levels for Polychlorinated Biphenyls (PCBs) Cleanup (PB86-232774). The final result needed for emission flux estimation would be:

$$\epsilon = \frac{2\epsilon D_{ei}}{\sqrt{\pi \alpha T}} H_c C_L \quad (6)$$

where  $\epsilon$  = porosity of the floor material,  $D_{ei}$  = effective diffusivity in the air pores ( $= D_i \epsilon^{1/3}$ ),  $m^2/day$ ,  $D_i$  = molecular diffusivity,  $m^2/day$ ,  $T$  = averaging time, days, and  $\alpha = D_{ei} \epsilon / (\epsilon + (1-\epsilon)) / H_C$ . If steady state conditions are achieved as a result of a continuous supply of contaminated water to the floor surface, it may be more appropriate to treat the emission rate problem using Eq. (2) rather than Eq. (6).

(b) Subcase 2. No dampness evident on the floor or wall surface but ground water underneath the basement or wall material. Diffusion through the air space of the floor or wall material will result in a slow release of volatile contaminants from ground water to the basement air. The steady state flux rate can be estimated from:

$$\epsilon = D_i \epsilon^{4/3} \frac{H_C C_L - C}{h} \quad (7)$$

where  $h$  = thickness of the barrier between the surface of ground water and the air-basement floor interface,  $m$ . When the basement air concentration is small compared to the  $H_C C_L$  term in Eq. (7), the  $C$  term can be ignored in estimating  $\epsilon$  from Eq. (7). Otherwise Eq. (7) should be solved along with Eq. (1) requiring a trial and error solution.



## **APPENDIX F**

### **METHOD 1312: SYNTHETIC PRECIPITATION LEACH TEST FOR SOILS**

## METHOD 1312

### SYNTHETIC PRECIPITATION LEACH TEST FOR SOILS

#### 1.0 SCOPE AND APPLICATION

1.1 Method 1312 is designed to determine the mobility of both organic and inorganic contaminants present in soils.

1.2 If a total analysis of the soil demonstrates that individual contaminants are not present in the soil, or that they are present but at such low concentrations that the appropriate regulatory thresholds could not possibly be exceeded, Method 1312 need not be run.

#### 2.0 SUMMARY OF METHOD

2.1 The particle size of the soil is reduced (if necessary) and is extracted with an amount of extraction fluid equal to 20 times the weight of the soil. The extraction fluid employed is a function of the region of the country where the soil site is located. A special extractor vessel is used when testing for volatiles. Following extraction, the liquid extract is separated from the soil by 0.6-0.8  $\mu$ m glass fiber filter.

#### 3.0 INTERFERENCES

3.1 Potential interferences that may be encountered during analysis are discussed in the individual analytical methods.

#### 4.0 APPARATUS AND MATERIALS

4.1 Agitation apparatus - an acceptable agitation apparatus is one which is capable of rotating the extraction vessel in an end-over-end fashion at  $30 \pm 2$  rpm (see Figure 1). Suitable devices known to EPA are identified in Table 2.

4.2 Extraction vessel - acceptable extraction vessels are those that are listed below:

4.2.1 Zero Headspace Extraction Vessel (ZHE) - This device is for use only when the soil is being tested for the mobility of volatile constituents (see Table 1). The ZHE is an extraction vessel that allows for liquid/solid separation within the device and which effectively precludes headspace (as depicted in Figure 3). This type of vessel allows for initial liquid/solid separation, extraction, and final extract filtration without having to open the vessel (see Step 4.3.1). These vessels shall have an internal volume of 500 to 600 mL and be equipped to accommodate a 90-mm filter. Suitable ZHE devices known to EPA are identified in Table 3. These devices contain viton O-rings which should be replaced frequently. For the ZHE to be acceptable for use, the piston within the ZHE should be able to be moved

with approximately 15 psi or less. If it takes more pressure to move the piston, the O-rings in the device should be replaced. If this does not solve the problem, the ZHE is unacceptable for 1312 analyses and the manufacturer should be contacted. The ZHE should be checked after every extraction. If the device contains a built-in pressure gauge, pressurize the device to 50 psi, allow it to stand unattended for 1 hour, and recheck the pressure. If the device does not have a built-in pressure gauge, pressurize the device to 50 psi, submerge it in water and check for the presence of air bubbles escaping from any of the fittings. If pressure is lost, check all fittings and inspect and replace O-rings, if necessary. Retest the device. If leakage problems cannot be solved, the manufacturer should be contacted.

4.2.2 When the soil is being evaluated for other than volatile contaminants, an extraction vessel that does not preclude headspace (e.g. a 2-liter bottle) is used. Suitable extraction vessels include bottles made from various materials, depending on the contaminants to be analyzed and the nature of the waste (see Step 4.3.3). It is recommended that borosilicate glass bottles be used over other types of glass, especially when inorganics are of concern. Plastic bottles may be used only if inorganics are to be investigated. Bottles are available from a number of laboratory suppliers. When this type of extraction vessel is used, the filtration device discussed in Step 4.3.2 is used for initial liquid/solid separation and final extract filtration.

4.2.3 Some ZHEs use gas pressure to actuate the ZHE piston, while others use mechanical pressure (see Table 3). Whereas the volatiles procedure (see Step 7.4) refers to pounds-per-square inch (psi), for the mechanically actuated piston, the pressure applied is measured in torque-inch-pounds. Refer to the manufacturer's instructions as to the proper conversion.

4.3 Filtration devices - It is recommended that all filtrations be performed in a hood.

4.3.1 Zero-Headspace Extractor Vessel (see Figure 3) - When the waste is being evaluated for volatiles, the zero-headspace extraction vessel is used for filtration. The device shall be capable of supporting and keeping in place the fiber filter, and be able to withstand the pressure needed to accomplish separation (50 psi).

NOTE: When is it suspected that the glass fiber filter has been ruptured, an in-line glass fiber filter may be used to filter the material within the ZHE.

4.3.2 Filter holder - when the soil is being evaluated for other than volatile compounds, a filter holder capable of

supporting a glass fiber filter and able to withstand 50 psi or more of pressure shall be used. These devices shall have a minimum internal volume of 300 mL and be equipped to accommodate a minimum filter size of 47 mm (filter holders having an internal capacity of 1.5 liters or greater are recommended).

4.3.3 Materials of construction - filtration devices shall be made of inert materials which will not leach or absorb soil components. Glass, polytetrafluoroethylene (PTFE) or type 316 stainless steel equipment may be used when evaluating the mobility of both organic and inorganic components. Devices made of high density polyethylene (HDPE), polypropylene, or polyvinyl chloride may be used only when evaluating the mobility of metals. Borosilicate glass bottles are recommended for use over other types of glass bottles, especially when inorganics are constituents of concern.

4.4 Filters - filters shall be made of borosilicate glass fiber, shall have an effective pore size of 0.6 - 0.8  $\mu$ m and shall contain no binder materials. Filters known to EPA to meet these requirements are identified in Table 5. When evaluating the mobility of metals, filters should be acid-washed prior to use by rinsing with 1.0N nitric acid followed by three consecutive rinses with deionized distilled water (a minimum of 1-liter per rinse is recommended). Glass fiber filters are fragile and should be handled with care.

4.5 pH meters - any of the commonly available pH meters are acceptable.

4.6 ZHE extract collection devices - TEDLAR bags, glass, stainless steel or PTFE gas tight syringes are used to collect the volatile extract.

4.7 Laboratory balance - any laboratory balance accurate to within  $\pm 0.01$  g may be used (all weight measurements are to be within  $\pm 0.1$  g).

4.8 ZHE extraction fluid transfer devices - any device capable of transferring the extraction fluid into the ZHE without changing the nature of the extraction fluid is recommended.

## 5.0 REAGENTS

5.1 Reagent water - reagent water is defined as water in which an interferent is not observed at or above the method detection limit of the analyte(s) of interest. For non-volatile extractions, ASTM Type II water, or equivalent meets the definition of reagent water. For volatile extractions, it is recommended that reagent water be generated by any of the following methods. Reagent water should be monitored periodically for impurities.

5.1.1 Reagent water for volatile extractions may be generated by passing tap water through a carbon filter bed containing about 500 g of activated carbon (Calgon Corp., Filtrasorb 300 or equivalent).

5.1.2 A water purification system (Millipore Super-Q or equivalent) may also be used to generate reagent water for volatile extractions.

5.1.3 Reagent water for volatile extractions may also be prepared by boiling water for 15 minutes. Subsequently, while maintaining the water temperature at  $90 \pm 5^\circ\text{C}$ , bubble a contaminant-free inert gas (e.g. nitrogen) through the water for 1 hour. While still hot, transfer the water to a narrow-mouth screw-cap bottle under zero headspace and seal with a Teflon lined septum and cap.

5.2 Sulfuric acid/nitric acid (60/40 weight percent mixture)  $\text{H}_2\text{SO}_4/\text{HNO}_3$ . Cautiously mix 60 g of concentrated sulfuric acid with 40 g of concentrated nitric acid.

### 5.3 Extraction fluids:

5.3.1 Extraction fluid #1 - this fluid is made by adding the 60/40 weight percent mixture of sulfuric and nitric acids to reagent water until the pH is  $4.20 \pm 0.05$ .

5.3.2 Extraction fluid #2 - this fluid is made by adding the 60/40 weight percent mixture of sulfuric and nitric acids to reagent water until the pH is  $5.00 \pm 0.05$ .

5.3.3 Extraction fluid #3 - this fluid is reagent water (ASTM Type II water, or equivalent) used to determine cyanide leachability.

Note: It is suggested that these extraction fluids be monitored frequently for impurities. The pH should be checked prior to use to ensure that these fluids are made up accurately.

5.4 Analytical standards shall be prepared according to the appropriate analytical method.

## 6.0 SAMPLE COLLECTION, PRESERVATION, AND HANDLING

6.1 All samples shall be collected using an appropriate sampling plan.

6.2 At least two separate representative samples of a soil should be collected. The first sample is used to determine if the soil requires particle-size reduction and, if desired, the percent solids of the soil. The second sample is used for extraction of volatiles and non-volatiles.

6.3 Preservatives shall not be added to samples.

6.4 Samples shall be refrigerated to minimize loss of volatile organics and to retard biological activity.

6.5 When the soil is to be evaluated for volatile contaminants, care should be taken to minimize the loss of volatiles. Samples shall be taken and stored in a manner to prevent the loss of volatile contaminants. If possible, it is recommended that any necessary particle-size reduction be conducted as the sample is being taken.

6.6. 1312 extracts should be prepared for analysis and analyzed as soon as possible following extraction. If they need to be stored, even for a short period of time, storage shall be at 4°C, and samples for volatiles analysis shall not be allowed to come into contact with the atmosphere (i.e. no headspace). See Section 8.0 (Quality Control) for acceptable sample and extract holding times.

## 7.0 PROCEDURE

7.1 The preliminary 1312 evaluations are performed on a minimum 100 g representative sample of soil that will not actually undergo 1312 extraction (designated as the first sample in Step 6.2).

7.1.1 Determine whether the soil requires particle-size reduction. If the soil passes through a 9.5 mm (0.375-inch) standard sieve, particle-size reduction is not required (proceed to Step 7.2). If portions of the sample do not pass through the sieve, then the oversize portion of the soil will have to be prepared for extraction by crushing the soil to pass the 9.5 mm sieve.

7.1.2 Determine the percent solids if desired.

7.2 Procedure when volatiles are not involved - Enough solids should be generated for extraction such that the volume of 1312 extract will be sufficient to support all of the analyses required. However, a minimum sample size of 100 grams shall be used. If the amount of extract generated by a single 1312 extract will not be sufficient to perform all of the analyses, it is recommended that more than one extraction be performed and the extracts be combined and then aliquoted for analysis.

7.2.1 Weigh out a representative subsample of the soil and transfer to the filter holder extractor vessel.

7.2.2 Determine the appropriate extraction fluid to use. If the soil is from a site that is east of the Mississippi River, extraction fluid #1 should be used. If the soil is from a site that is west of the Mississippi River, extraction fluid #2 should be used. If the soil is to be tested for cyanide leachability, extraction fluid #3 should be used.

Note: Extraction fluid #3 (reagent water) must be used when evaluating cyanide-containing soils because leaching of cyanide-containing soils under acidic conditions may result in the formation of hydrogen cyanide gas.

7.2.3 Determine the amount of extraction fluid to add based on the following formula:

$$\text{amount of extraction fluid (mL)} = 20 \times \text{weight of soil (g)}$$

Slowly add the amount of appropriate extraction fluid to the extractor vessel. Close the extractor bottle tightly (it is recommended that Teflon tape be used to ensure a tight seal), secure in rotary extractor device, and rotate at  $30 \pm 2$  rpm for  $18 \pm 2$  hours. Ambient temperature (i.e. temperature of room in which extraction is to take place) shall be maintained at  $22 \pm 3^\circ\text{C}$  during the extraction period.

Note: As agitation continues, pressure may build up within the extractor bottle for some types of soil (e.g. limed or calcium carbonate containing soil may evolve gases such as carbon dioxide). To relieve excess pressure, the extractor bottle may be periodically opened (e.g. after 15 minutes, 30 minutes, and 1 hour) and vented into a hood.

7.2.4 Following the  $18 \pm 2$  hour extraction, the material in the extractor vessel is separated into its component liquid and solid phases by filtering through a glass fiber filter.

7.2.5 Following collection of the 1312 extract it is recommended that the pH of the extract be recorded. The extract should be immediately aliquoted for analysis and properly preserved (metals aliquots must be acidified with nitric acid to  $\text{pH} < 2$ ; all other aliquots must be stored under refrigeration ( $4^\circ\text{C}$ ) until analyzed). The 1312 extract shall be prepared and analyzed according to appropriate analytical methods. 1312 extracts to be analyzed for metals, other than mercury, shall be acid digested.

7.2.6 The contaminant concentrations in the 1312 extract are compared to thresholds in the clean closure guidance manual. Refer to Section 8.0 for Quality Control requirements.

### 7.3 Procedure when volatiles are involved:

7.3.1 The ZHE device is used to obtain 1312 extracts for volatile analysis only. Extract resulting from the use of the ZHE shall not be used to evaluate the mobility of non-volatile analytes (e.g. metals, pesticides, etc.). The ZHE device has approximately a 500 mL internal capacity. Although a minimum sample size of 100 g was required in the Step 7.2 procedure, the ZHE can only accommodate a maximum of 25 g of solid, due to the need to add an amount of extraction fluid equal to 20 times the

weight of the soil. The ZHE is charged with sample only once and the device is not opened until the final extract has been collected. Although the following procedure allows for particle-size reduction during the conduct of the procedure, this could result in the loss of volatile compounds. If possible particle-size reduction (see Step 7.1.1) should be conducted on the sample as it is being taken (e.g., particle-size may be reduced by crumbling). If necessary particle-size reduction may be conducted during the procedure. In carrying out the following steps, do not allow the soil to be exposed to the atmosphere for any more time than is absolutely necessary. Any manipulation of these materials should be done when cold (4°C) to minimize the loss of volatiles. Pre-weigh the evacuated container which will receive the filtrate (see Step 4.6), and set aside. If using a TEDLAR® bag, all air must be expressed from the device.

7.3.2 Place the ZHE piston within the body of the ZHE (it may be helpful first to moisten the piston O-rings slightly with extraction fluid). Adjust the piston within the ZHE body to a height that will minimize the distance the piston will have to move once it is charged with sample. Secure the gas inlet/outlet flange (bottom flange) onto the ZHE body in accordance with the manufacturer's instructions. Secure the glass fiber filter between the support screens and set aside. Set liquid inlet/outlet flange (top flange) aside.

7.3.3 Quantitatively transfer 25 g of soil to the ZHE. Secure the filter and support screens into the top flange of the device and secure the top flange to the ZHE body in accordance with the manufacturer's instructions. Tighten all ZHE fittings and place the device in the vertical position (gas inlet/outlet flange on the bottom). Do not attach the extraction collection device to the top plate. Attach a gas line to the gas inlet/outlet valve (bottom flange) and, with the liquid inlet/outlet valve (top flange) open, begin applying gentle pressure of 1-10 psi to a maximum of 50 psi to force most of the headspace out of the device.

7.3.4 With the ZHE in the vertical position, attach a line from the extraction fluid reservoir to the liquid inlet/outlet valve. The line used shall contain fresh extraction fluid and should be preflushed with fluid to eliminate any air pockets in the line. Release gas pressure on the ZHE piston (from the gas inlet/outlet valve), open the liquid inlet/outlet valve, and begin transferring extraction fluid (by pumping or similar means) into the ZHE. Continue pumping extraction fluid into the ZHE until the appropriate amount of fluid has been introduced into the device.

7.3.5 After the extraction fluid has been added, immediately close the inlet/outlet valve and disconnect the extraction fluid line. Check the ZHE to ensure that all valves are in their closed positions. Physically rotate the device in an end-over-end fashion.



2 or 3 times. Reposition the ZHE in the vertical position with the liquid inlet/outlet valve on top. Put 5-10 psi behind the piston (if necessary) and slowly open the liquid inlet/outlet valve to bleed out any headspace (into a hood) that may have been introduced due to the addition of extraction fluid. This bleeding shall be done quickly and shall be stopped at the first appearance of liquid from the valve. Re-pressurize the ZHE with 5-10 psi and check all ZHE fittings to ensure that they are closed.

7.3.6 Place the ZHE in the rotary extractor apparatus (if it is not already there) and rotate the ZHE at  $30 \pm 2$  rpm for  $18 \pm 2$  hours. Ambient temperature (i.e. temperature of the room in which extraction is to occur) shall be maintained at  $22 \pm 3^{\circ}\text{C}$  during agitation.

7.3.7 Following the  $18 \pm 2$  hour agitation period, check the pressure behind the ZHE piston by quickly opening and closing the gas inlet/outlet valve and noting the escape of gas. If the pressure has not been maintained (i.e. no gas release observed), the device is leaking. Check the ZHE for leaking and redo the extraction with a new sample of soil. If the pressure within the device has been maintained, the material in the extractor vessel is separated into its component liquid and solid phases.

7.3.8 Attach the evacuated pre-weighed filtrate collection container to the liquid inlet/outlet valve and open the valve. Begin applying gentle pressure of 1-10 psi to force the liquid phase into the filtrate collection container. If no additional liquid has passed through the filter in any 2 minute interval, slowly increase the pressure in 10-psi increments to a maximum of 50 psi. After each incremental increase of 10 psi, if no additional liquid has passed through the filter in any 2 minute interval, proceed to the next 10 psi increment. When liquid flow has ceased such that continued pressure filtration at 50 psi does not result in any additional filtrate within any 2 minute period, filtration is stopped. Close the inlet/outlet valve, discontinue pressure to the piston, and disconnect the filtration collection container.

NOTE: Instantaneous application of high pressure can degrade the glass fiber filter and may cause premature plugging.

7.3.9 Following collection of the 1312 extract, the extract should be immediately aliquoted for analysis and stored with minimal headspace at  $4^{\circ}\text{C}$  until analyzed. The 1312 extract will be prepared and analyzed according to the appropriate analytical methods.

## 8.0 QUALITY CONTROL

8.1 All data, including quality assurance data, should be

maintained and available for reference or inspection.

8.2 A minimum of one blank (extraction fluid # 1) for every 10 extractions that have been conducted in an extraction vessel shall be employed as a check to determine if any memory effects from the extraction equipment are occurring.

8.3 For each analytical batch (up to twenty samples), it is recommended that a matrix spike be performed. Addition of matrix spikes should occur once the 1312 extract has been generated (i.e. should not occur prior to performance of the 1312 procedure). The purpose of the matrix spike is to monitor the adequacy of the analytical methods used on the 1312 extract and for determining if matrix interferences exist in analyte detection.

8.4 All quality control measures described in the appropriate analytical methods shall be followed.

8.5 The method of standard addition shall be employed for each analyte if: 1) recovery of the compound from the 1312 extract is not between 50 and 150%, or 2) if the concentration of the constituent measured in the extract is within 20% of the appropriate regulatory threshold. If more than one extraction is being run on samples of the same waste (up to twenty samples), the method of standard addition need be applied only once and the percent recoveries applied on the remainder of the extractions.

8.6 Samples must undergo 1312 extraction within the following time period after sample receipt: Volatiles, 14 days; Semi-Volatiles, 40 days; Mercury, 28 days; and other Metals, 180 days. 1312 extracts shall be analyzed after generation and preservation within the following periods: Volatiles, 14 days; Semi-Volatiles, 40 days; Mercury, 28 days; and other Metals, 180 days.

## 9.0 METHOD PERFORMANCE

9.1 None available.

## 10.0 REFERENCES

10.1 None available.

TABLE 1. -- VOLATILE CONTAMINANTS

Compounds	CAS No.
Acetone.....	67-64-1
Acrylonitrile.....	107-13-1
Benzene.....	71-43-2
n-Butyl alcohol.....	71-36-6
Carbon disulfide.....	75-15-0
Carbon tetrachloride.....	56-23-5
Chlorobenzene.....	108-90-7
Chloroform.....	67-66-3
1,2-Dichloroethane.....	107-06-2
1,1-Dichloroethylene.....	75-35-4
Ethyl acetate.....	141-78-6
Ethyl benzene.....	100-41-4
Ethyl ether.....	60-29-7
Isobutanol.....	78-83-1
Methanol.....	67-56-1
Methylene chloride .....	75-09-2
Methyl ethyl ketone .....	78-93-3
Methyl isobutyl ketone .....	108-10-1
1,1,1,2-Tetrachloroethane.....	630-20-6
1,1,2,2-Tetrachloroethane.....	79-34-5
Tetrachloroethylene .....	127-18-4
Tolulene .....	108-88-3
1,1,1-Trichloroethane .....	71-55-6
1,1,2-Trichloroethane.....	79-00-5
Trichloroethylene .....	79-01-6
Trichlorofluoromethane.....	75-69-4
1,1,2-Trichloro-1,2,2-trifluoroethane.....	76-13-1
Vinyl chloride.....	75-01-7
Xylene .....	1330-20-7

TABLE 2. -- SUITABLE ROTARY AGITATION APPARATUS<sup>1</sup>

Company	Location	Model
Analytical Testing and Consulting Services, Inc.	Warrington, PA (215) 343-4490	4-vessel device
Associated Design and Manufacturing Company	Alexandria, VA (703) 549-5999	4-vessel device, 6-vessel device
Environmental Machine and Design, Inc.	Lynchburg, VA (804) 845-6424	4-vessel device, 6-vessel device
IRA Machine Shop and Laboratory	Santurce, PR (809) 752-4004	16-vessel device
Lars Lande Manufacturing	Whitmore Lake, MI (313) 449-4116	10-vessel device 5-vessel device
Millipore Corp.	Bedford, MA (800) 225-3384	4-vessel ZHE device or 4-one litter bottle extractor device
REXNORD	Milwaukee, WI (414) 643-2850	6-vessel device

<sup>1</sup>Any device that rotates the extraction vessel in an end-over-end fashion at  $30 \pm 2$  rpm is acceptable.

TABLE 3. -- SUITABLE ZERO-HEADSPACE EXTRACTOR VESSELS

Company	Location	Model No.
Analytical Testing & Consulting Services, Inc.	Warrington, PA, (215) 343-4490	C102, Mechanical Pressure Device
Associated Design & Manufacturing Co.	Alexandria, VA (703) 549-5999	3740-ZHB, Gas Pressure Device
Lars Lande Mfg.	Whitmore Lake, MI (313) 449-4116	Gas Pressure Device
Millipore Corp.	Bedford, MA, (800) 225-3384	SD1 P581 C5, Gas Pressure Device

TABLE 4. -- SUITABLE ZHE FILTER HOLDERS<sup>1</sup>

Company	Location	Model	Size
Micro Filtration Systems	Dublin, CA (415) 828-6010	302400	142 mm
Millipore Corp.	Bedford, MA (800) 225-3384	YT30142HW XX1004700	142 mm 47 mm
Nucleopore Corp.	Pleasanton, CA (800) 882-7711	425910 410400	142 mm 47 mm

<sup>1</sup>Any device capable of separating the liquid from the solid phase of the soil is suitable, providing that it is chemically compatible with the soil and the constituents to be analyzed. Plastic devices (not listed above) may be used when only inorganic contaminants are of concern. The 142 mm size filter holder is recommended.

TABLE 5. -- SUITABLE FILTER MEDIA

Company	Location	Model	Size <sup>1</sup>
Millipore Corp.	Bedford, MA (800) 225-3384	AP40	0.7
Nucleopore Corp.	Pleasanton, CA (415) 463-2530	211625	0.7
Whatman Laboratory Products, Inc.	Clifton, NJ (201) 773-5800	GFF	0.7

<sup>1</sup>Nominal pore size

Figure 1. Rotary Agitation

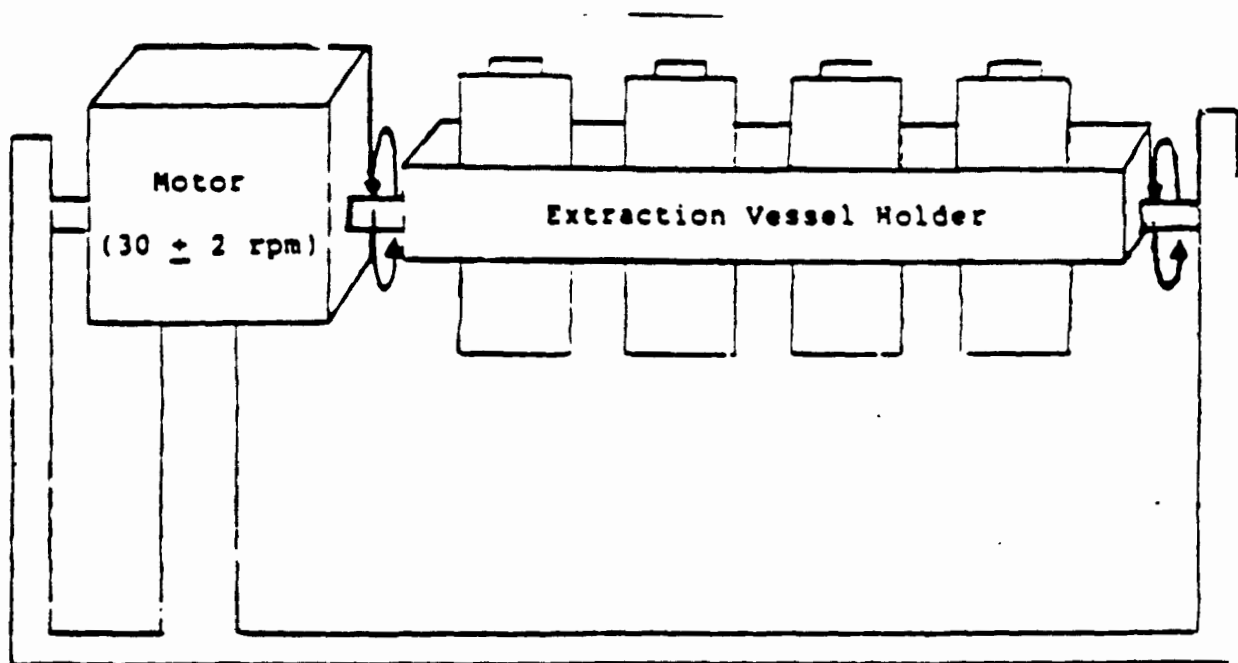
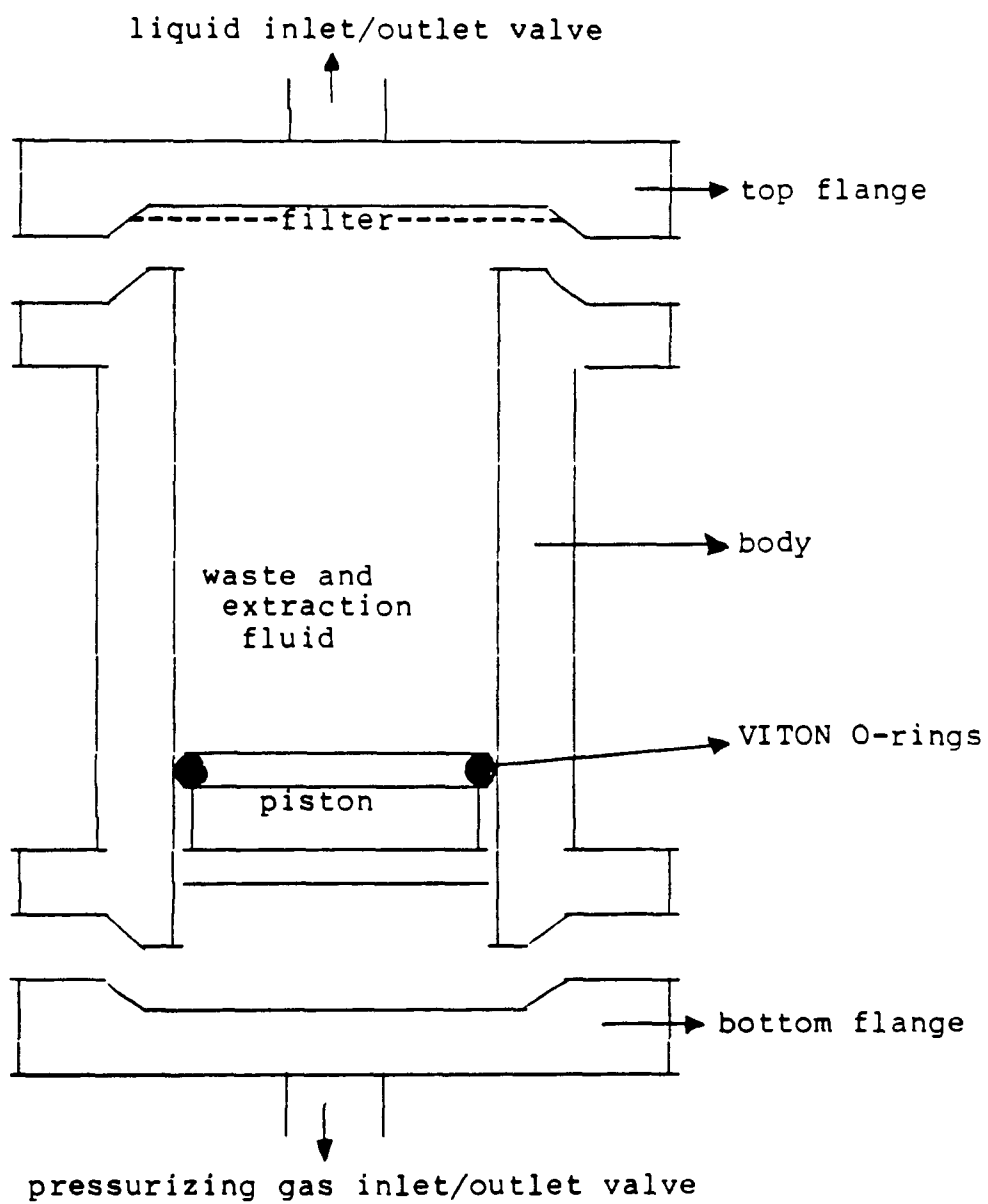
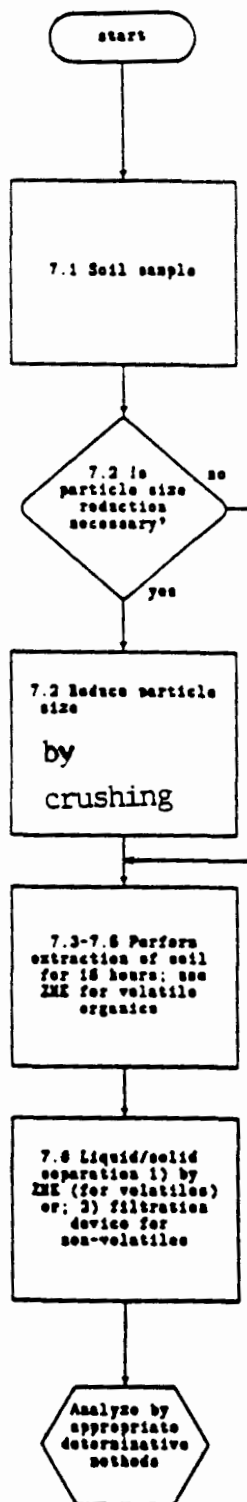


Figure 2. Zero-Headspace Extraction Vessel



METHOD 1312  
SYNTHETIC ACID PRECIPITATION LEACH TEST FOR SOILS





**INTERIM FINAL**  
**RCRA FACILITY INVESTIGATION (RFI) GUIDANCE**  
**VOLUME III OF IV**

**AIR AND SURFACE WATER RELEASES**

**EPA 530/SW-89-031**

**MAY 1989**

**WASTE MANAGEMENT DIVISION**  
**OFFICE OF SOLID WASTE**  
**U.S. ENVIRONMENTAL PROTECTION AGENCY**

## **ABSTRACT**

On November 8, 1984, Congress enacted the Hazardous and Solid Waste Amendments (HSWA) to RCRA. Among the most significant provisions of HSWA are §3004(u), which requires corrective action for releases of hazardous waste or constituents from solid waste management units at hazardous waste treatment, storage and disposal facilities seeking final RCRA permits; and §3004(v), which compels corrective action for releases that have migrated beyond the facility property boundary. EPA will be promulgating rules to implement the corrective action provisions of HSWA, including requirements for release investigations and corrective measures.

This document, which is presented in four volumes, provides guidance to regulatory agency personnel on overseeing owners or operators of hazardous waste management facilities in the conduct of the second phase of the RCRA Corrective Action Program, the RCRA Facility Investigation (RFI). Guidance is provided for the development and performance of an investigation by the facility owner or operator based on determinations made by the regulatory agency as expressed in the schedule of a permit or in an enforcement order issued under §3008(h), §7003, and/or §3013. The purpose of the RFI is to obtain information to fully characterize the nature, extent and rate of migration of releases of hazardous waste or constituents and to interpret this information to determine whether interim corrective measures and/or a Corrective Measures Study may be necessary.

## **DISCLAIMER**

**This document is intended to assist Regional and State personnel in exercising the discretion conferred by regulation in developing requirements for the conduct of RCRA Facility Investigations (RFIs) pursuant to 40 CFR 264. Conformance with this guidance is expected to result in the development of RFIs that meet the regulatory standard of adequately detecting and characterizing the nature and extent of releases. However, EPA will not necessarily limit acceptable RFIs to those that comport with the guidance set forth herein. This document is not a regulation (i.e., it does not establish a standard of conduct which has the force of law) and should not be used as such. Regional and State personnel must exercise their discretion in using this guidance document as well as other relevant information in determining whether an RFI meets the regulatory standard.**

**Mention of company or product names in this document should not be considered as an endorsement by the U.S. Environmental Protection Agency.**

# RCRA FACILITY INVESTIGATION (RFI) GUIDANCE

## VOLUME III

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## LIST OF ACRONYMS

AA	-	Atomic Absorption
AI	-	Soil Adsorption Isotherm Test
ASCS	-	Agricultural Stabilization and Conservation Service
ASTM	-	American Society for Testing and Materials
BCF	-	Bioconcentration Factor
BOD	-	Biological Oxygen Demand
CAG	-	EPA Carcinogen Assessment Group
CPF	-	Carcinogen Potency Factor
CBI	-	Confidential Business Information
CEC	-	Cation Exchange Capacity
CERCLA	-	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	-	Code of Federal Regulations
CIR	-	Color Infrared
CM	-	Corrective Measures
CMI	-	Corrective Measures Implementation
CMS	-	Corrective Measures Study
COD	-	Chemical Oxygen Demand
COLIWASA	-	Composite Liquid Waste Sampler
DNPH	-	Dinitrophenyl Hydrazine
DO	-	Dissolved Oxygen
DOT	-	Department of Transportation
ECD	-	Electron Capture Detector
EM	-	Electromagnetic
EP	-	Extraction Procedure
EPA	-	Environmental Protection Agency
FEMA	-	Federal Emergency Management Agency
FID	-	Flame Ionization Detector
Foc	-	Fraction organic carbon in soil
FWS	-	U.S. Fish and Wildlife Service
GC	-	Gas Chromatography
GC/MS	-	Gas Chromatography/Mass Spectroscopy
GPR	-	Ground Penetrating Radar
HEA	-	Health and Environmental Assessment
HEEP	-	Health and Environmental Effects Profile
HPLC	-	High Pressure Liquid Chromatography
HSWA	-	Hazardous and Solid Waste Amendments (to RCRA)
HWM	-	Hazardous Waste Management
ICP	-	Inductively Coupled (Argon) Plasma
ID	-	Infrared Detector
Kd	-	Soil/Water Partition Coefficient
Koc	-	Organic Carbon Absorption Coefficient
Kow	-	Octanol/Water Partition Coefficient
LEL	-	Lower Explosive Limit
MCL	-	Maximum Contaminant Level
MM5	-	Modified Method 5
MS/MS	-	Mass Spectroscopy/Mass Spectroscopy
NFIP	-	National Flood Insurance Program
NIOSH	-	National Institute for Occupational Safety and Health
NPDES	-	National Pollutant Discharge Elimination System
OSHA	-	Occupational Safety and Health Administration

## LIST OF ACRONYMS (Continued)

OVA	-	Organic Vapor Analyzer
PID	-	Photo Ionization Detector
pKa	-	Acid Dissociation Constant
ppb	-	parts per billion
ppm	-	parts per million
PUF	-	Polyurethane Foam
PVC	-	Polyvinyl Chloride
QA/QC	-	Quality Assurance/Quality Control
RCRA	-	Resource Conservation and Recovery Act
RFA	-	RCRA Facility Assessment
RfD	-	Reference Dose
RFI	-	RCRA Facility Investigation
RMCL	-	Recommended Maximum Contaminant Level
RSD	-	Risk Specific Dose
SASS	-	Source Assessment Sampling System
SCBA	-	Self Contained Breathing Apparatus
SCS	-	Soil Conservation Service
SOP	-	Standard Operating Procedure
SWMU	-	Solid Waste Management Unit
TCLP	-	Toxicity Characteristic Leaching Procedure
TEGD	-	Technical Enforcement Guidance Document (EPA, 1986)
TOC	-	Total Organic Carbon
TOT	-	Time of travel
TOX	-	Total Organic Halogen
USGS	-	United States Geologic Survey
USLE	-	Universal Soil Loss Equation
UV	-	Ultraviolet
VOST	-	Volatile Organic Sampling Train
VSP	-	Verticle Seismic Profiling
WQC	-	Water Quality Criteria





## **SECTION 12**

### **AIR**

#### **12.1 Overview**

The objective of an investigation of a release to air is to characterize the nature, extent, and rate of migration of the release of hazardous waste or constituents to that medium. This is done by characterizing long-term air concentrations (commensurate with the long-term exposures which are the basis for the health and environmental criteria presented in Section 8) associated with unit releases of hazardous wastes or constituents to air. This section provides:

- An example strategy for characterizing releases to air, which includes characterization of the source and the environmental setting of the release, and conducting a monitoring and/or modeling program which will characterize the release itself;
- Formats for data organization and presentation;
- Modeling and field methods which may be used in the investigation; and
- A checklist of information that may be needed for release characterization.

The exact type and amount of information required for sufficient release characterization will be site-specific and should be determined through interactions between the regulatory agency and the facility owner or operator during the RFI process. This guidance does not define the specific data needed in all instances; it identifies possible information necessary to perform release characterizations and methods for obtaining this information. The RFI Checklist, presented at the end of this section, provides a tool for planning and tracking information for release characterization. This list is not a list of requirements for all releases to air. Some release investigations will involve the collection of only a subset of the items listed, while other releases may involve the collection of additional data.

Case studies 25 and 26 in Volume IV (Case Study Examples) illustrate several of the air investigation concepts discussed in this section.

## **12.2 Approach for Characterizing Releases to Air**

### **12.2.1 General Approach**

The intent of the air release investigation is to determine actual or potential effects at the facility property boundary. This differs from the other media discussed in this Guidance. During the health and environmental assessment process for the air medium (see Section 8), the decision as to whether interim corrective measures or a Corrective Measures Study will be necessary is based on actual or potential effects at the facility property boundary.

Characterization of releases from waste management units to air may be approached in a tiered or phased fashion as described in Section 3. The key elements to this approach are shown in Table 12-1. Tasks for implementing the release characterization strategy for releases to air are summarized in Table 12-2. An overview of the release characterization strategy for air is illustrated in Figures 12-1 through 12-5.

Two major elements can be derived from this strategy:

- Collection and review of data to be used for characterization of the source of the air release and the environmental setting for this source. Source characterization will include obtaining information on the unit operating conditions and configuration, and may entail a sampling and analytical effort to characterize the waste material in the unit or the incoming waste streams. This effort will lead to development of a conceptual model of the release that provides a working hypothesis of the release mechanism, transport pathway/mechanism, and exposure route (if any), which can be used to guide the investigation.
- Development and implementation of modeling and/or monitoring procedures to be used for characterization of the release (e.g., from a

**TABLE 12-1**

**EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO AIR\***

---

**INITIAL PHASE**

1. Collect and review existing information on:
  - Waste
  - Unit
  - Environmental setting (e.g., climate, topography)
  - Contaminant releases, including inter-media transport
  - Receptors at and beyond the facility property boundary
2. Identify additional information necessary to fully characterize release:
  - Waste
  - Unit
  - Environmental setting (e.g., climate, topography)
  - Contaminant releases, including inter-media transport
  - Receptors at and beyond the facility property boundary
3. Conduct screening assessments:
  - Formulate conceptual model of release
  - Determine monitoring/modeling program objectives
  - Obtain source characterization data needed for modeling input
  - Select release constituent surrogates
  - Calculate emission estimates based on emission rate screening modeling results
  - Calculate concentration estimates based on dispersion screening modeling results
  - Compare results to health based criteria
  - Conduct screening monitoring at source (as warranted)
  - Perform sensitivity analysis of modeling input/output
  - Obtain additional waste/unit data as needed for refined modeling
  - Consider conduct of more refined emission/dispersion modeling
4. Collect, evaluate and report results:
  - Account for unit/waste temporal and spatial variability and modeling input/output uncertainties
  - Determine completeness and adequacy of screening assessment results
  - Evaluate potential for inter-media contaminant transfer
  - Summarize and present results in appropriate format
  - Determine if monitoring program objectives were met
  - Compare screening results to health and environmental criteria and identify and respond to emergency situations and identify priority situations that may warrant interim corrective measures - Notify regulatory agency
  - Determine whether the conduct of subsequent release characterization phases are necessary to obtain more refined concentration estimates

**TABLE 12-1 (continued)**

**EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO AIR\***

---

**SUBSEQUENT PHASES (if necessary)**

1. Conduct emission monitoring and dispersion modeling if necessary:
  - Conduct onsite meteorological monitoring if representative data are not available for dispersion modeling input
  - Conduct emission rate monitoring
  - Conduct dispersion modeling using emission rate monitoring data as input
  - Evaluate results and determine need for confirmatory air monitoring
2. Conduct confirmatory air monitoring if necessary:
  - Develop monitoring procedures
  - Conduct initial monitoring
  - Conduct additional monitoring if additional information is necessary to characterize the release
3. Collect, evaluate and report results:
  - Account for source and meteorological data variability during modeling and monitoring program
  - Evaluate long-term representativeness of air monitoring data
  - Apply dispersion models as appropriate to aid in data evaluation and to provide concentration estimates at the facility property boundary
  - Compare monitoring results to health and environmental criteria and identify and respond to emergency situations and identify priority situations that may warrant interim corrective measures - Notify regulatory agency
  - Determine completeness and adequacy of collected data
  - Summarize and present data in appropriate format
  - Determine if modeling and monitoring locations, constituents, and frequency were adequate to characterize release (nature, extent, and rate)
  - Determine if monitoring/modeling program objectives were met
  - Identify additional information needs, if necessary
  - Determine need to expand modeling and monitoring program
  - Evaluate potential role of inter-media transport

---

\* The potential for inter-media transport of contamination should be evaluated continually throughout the investigation.

**TABLE 12-2  
RELEASE CHARACTERIZATION TASKS FOR AIR**

Investigatory Tasks	Investigatory Techniques	Data Presentation Formats/Outputs
<b>Waste/Unit Characterization</b> <ul style="list-style-type: none"> <li>- Identification of waste constituents and properties</li> <li>- Prioritization of air emission constituents</li> <li>- Identification of unit characteristics which may promote an air release</li> </ul>	<ul style="list-style-type: none"> <li>- See Section 3, 7 and Volume I, Appendix B List 2; Section 12.3, Section 12.4, Appendix F</li> <li>- Waste sampling and characterization</li> <li>- See Section 7, Section 12.3, Section 12.4, Appendix F</li> </ul>	<ul style="list-style-type: none"> <li>- Listing of potential release constituents</li> <li>- Listing of target air emission constituents for monitoring</li> <li>- Description of the unit</li> </ul>
<b>Environmental Setting Characterization</b> <ul style="list-style-type: none"> <li>- Definition of climate</li> <li>- Definition of site-specific meteorological conditions</li> <li>- Definition of soil conditions to characterize emission potential for particulate emissions and for certain units (e.g., landfills and land treatment) for gaseous emissions</li> <li>- Definition of site-specific terrain</li> <li>- Identification of potential air-pathway receptors</li> </ul>	<ul style="list-style-type: none"> <li>- Climate summaries for regional National Weather Service stations (may require onsite meteorological monitoring survey)</li> <li>- Onsite meteorological monitoring concurrent with air monitoring</li> <li>- See Section 9</li> <li>- See Section 7, 9 and Appendix A (Volume 1) of RFI and recent aerial photographs and U.S. Geological Survey maps</li> <li>- Census data, area surveys, recent aerial photographs and U.S. Geological Survey topographic maps</li> </ul>	<ul style="list-style-type: none"> <li>- Wind roses and statistical tabulations for parameters of interest</li> <li>- Wind roses and tabulations for parameters of interest</li> <li>- Soil physical properties (e.g., porosity, organic matter content)</li> <li>- Topographic map of site area</li> <li>- Map with identification of nearby populations and buildings</li> </ul>
<b>Release Characterization</b> <ul style="list-style-type: none"> <li>- Emission rate modeling</li> <li>- Dispersion modeling</li> <li>- Emission rate monitoring</li> <li>- Air monitoring</li> </ul>	<ul style="list-style-type: none"> <li>- Air emission models as discussed in Section 12.4</li> <li>- Atmospheric dispersion models as discussed in Section 12.5</li> <li>- Direct emission source tests for point sources, isolation flux chamber for area sources or onsite air monitoring (Section 12.8)</li> <li>- Upwind/downwind air monitoring for "release mapping"</li> </ul>	<ul style="list-style-type: none"> <li>- Unit-specific and constituent-specific emission rates</li> <li>- Air concentration estimates at facility property boundary (tabular summaries or graphical presentations which may include release concentration isopleths)</li> <li>- Listing of emission rate monitoring results</li> <li>- Air concentration estimates at facility property boundary (tabular summaries or graphical presentations which may include release concentration isopleths)</li> </ul>

FIGURE 12-1  
RELEASE CHARACTERIZATION STRATEGY FOR AIR-OVERVIEW

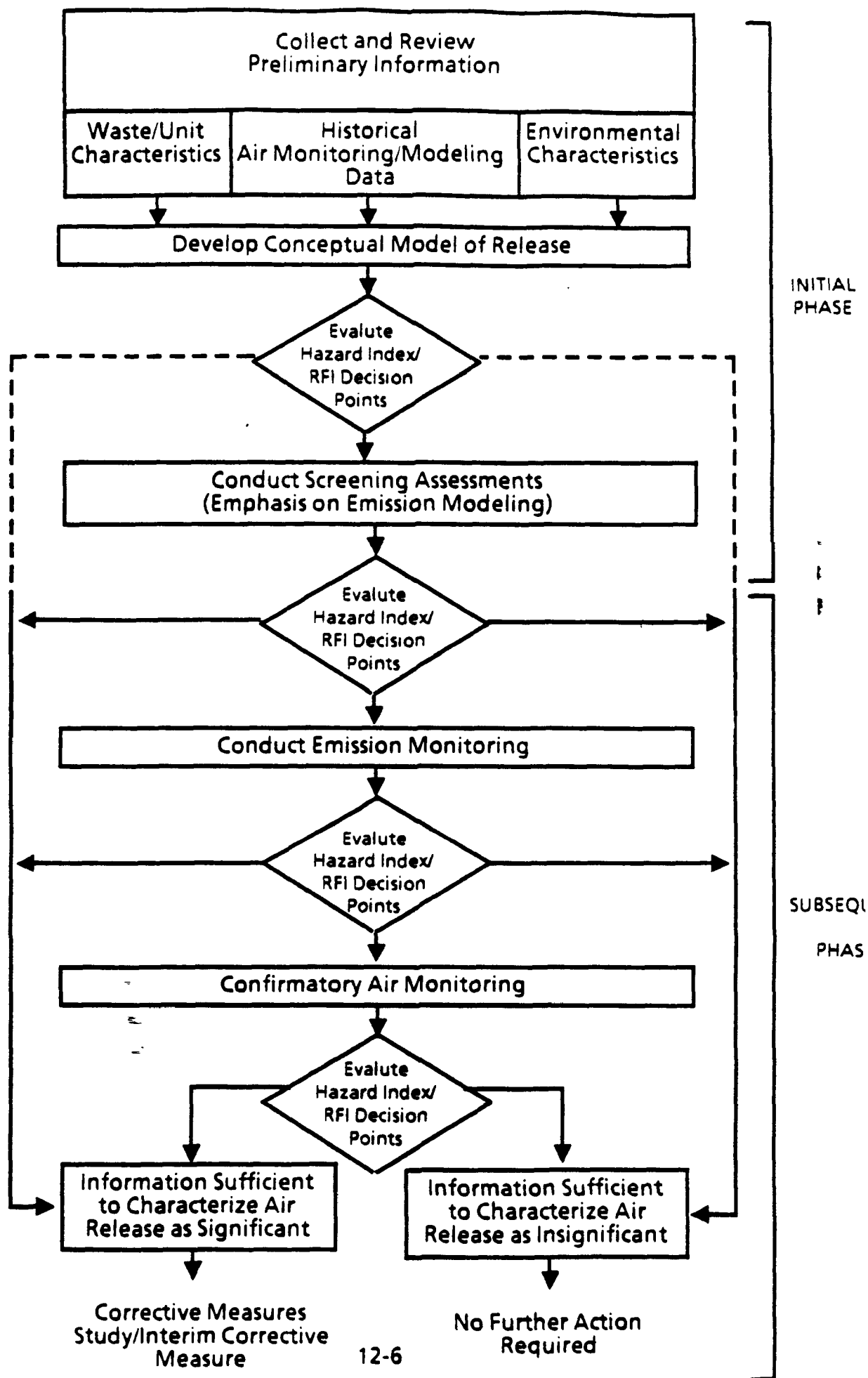


FIGURE 12-2  
CONDUCT SCREENING ASSESSMENTS - OVERVIEW

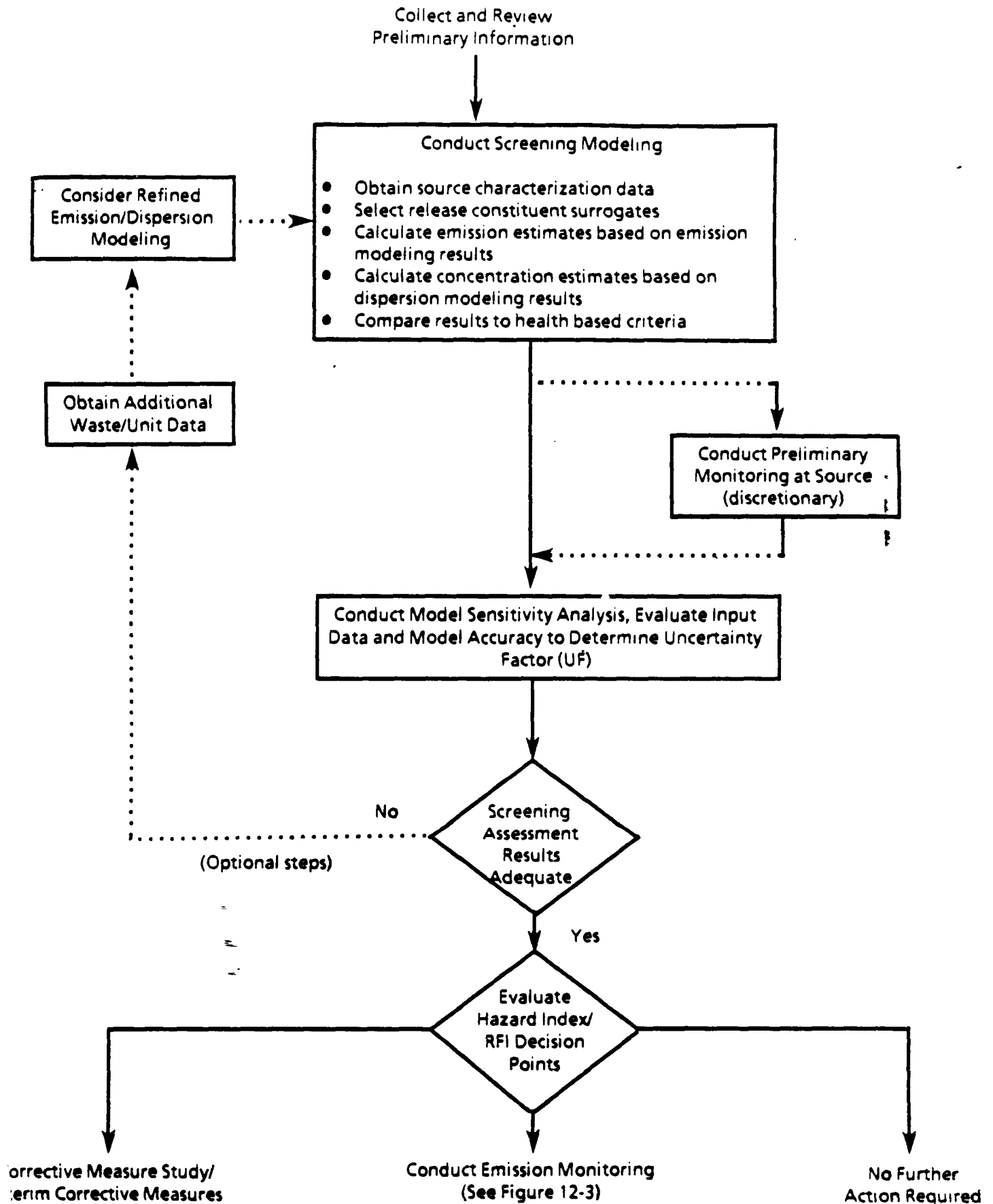




FIGURE 12-3  
CONDUCT EMISSION MONITORING - OVERVIEW

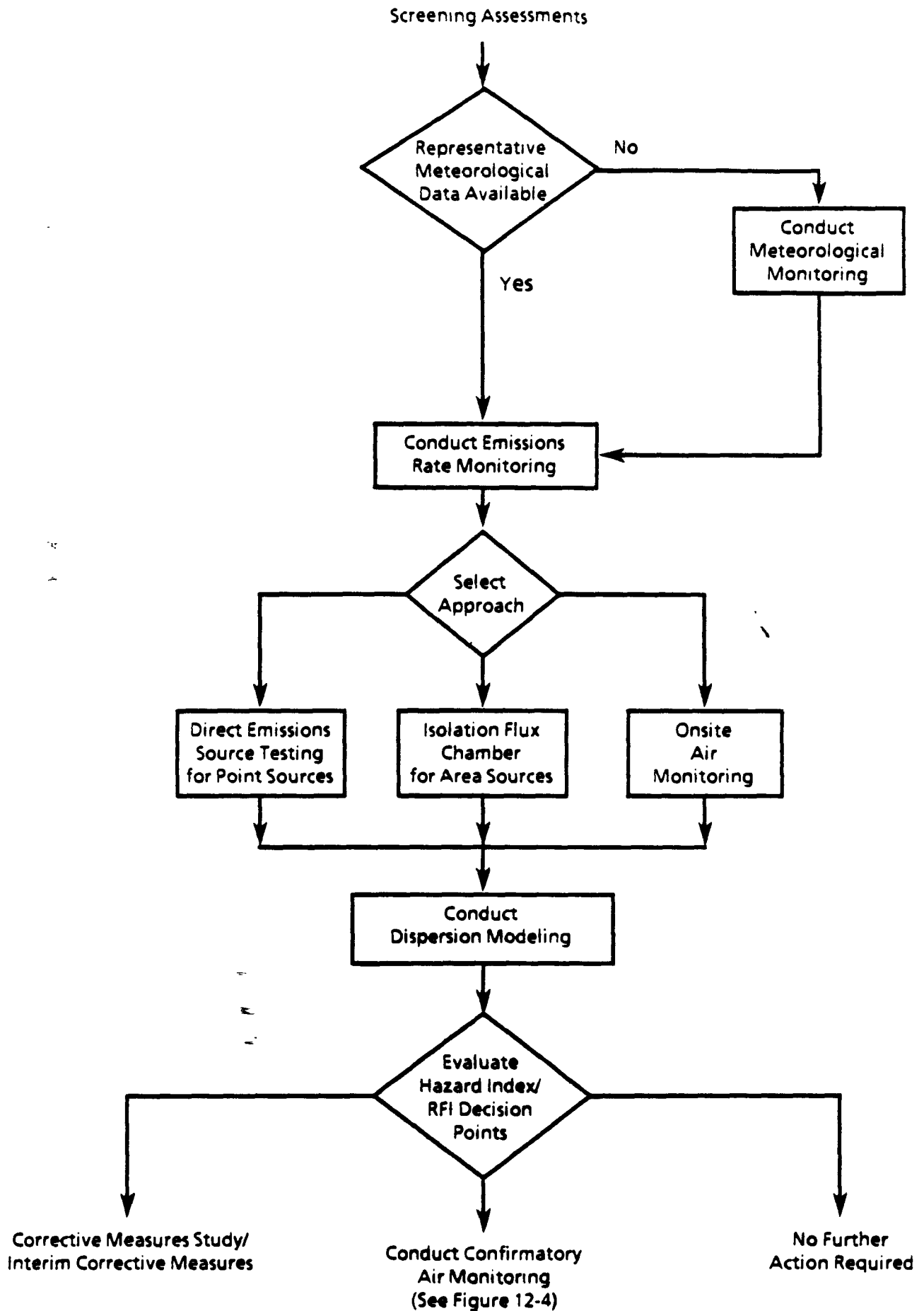
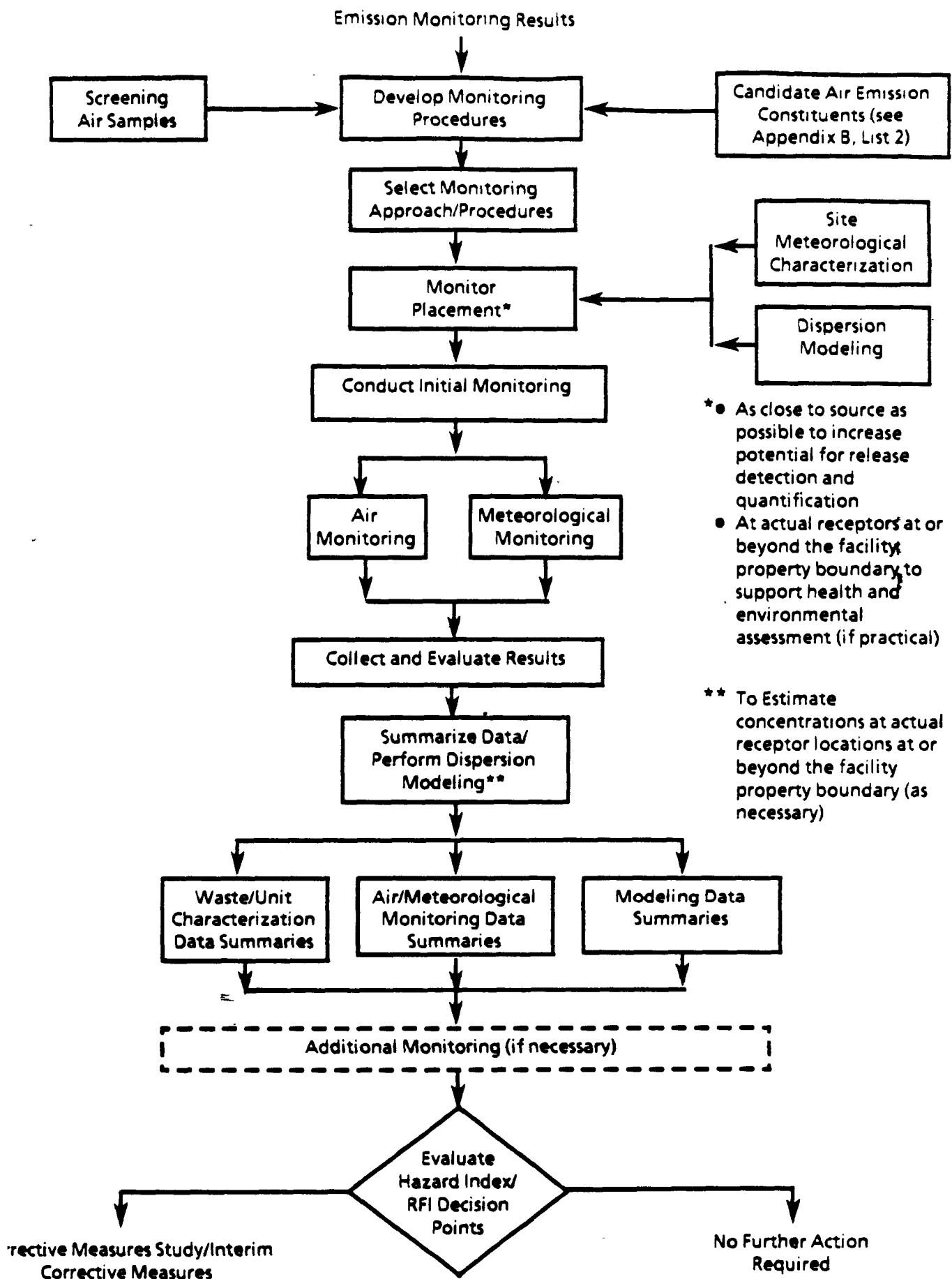
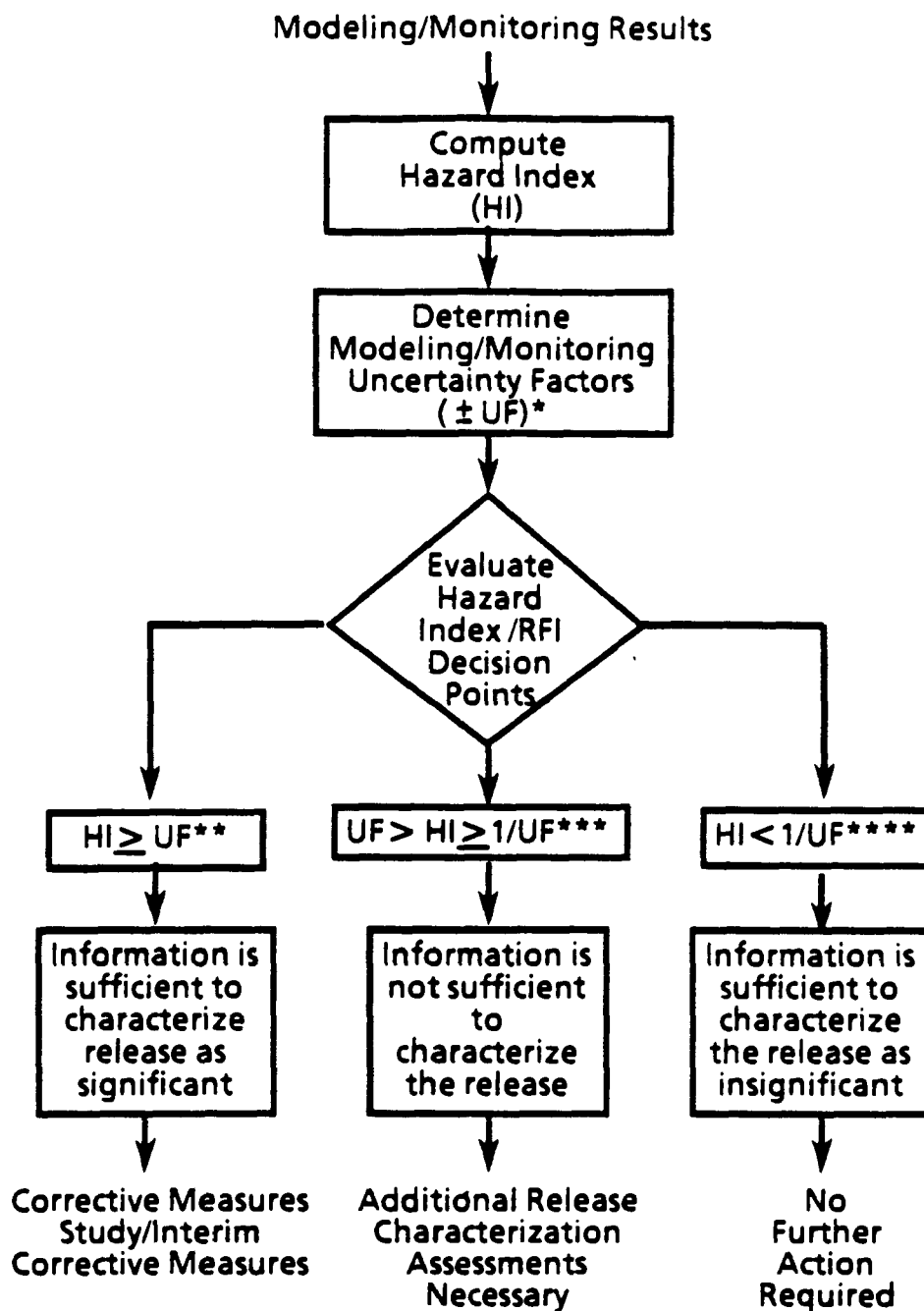


FIGURE 12-4  
CONDUCT CONFIRMATORY AIR MONITORING



**FIGURE 12-5  
EVALUATION OF MODELING/MONITORING RESULTS**



\* **Uncertainty Factor assumed to be  $\geq 1.0$**

\*\*  **$HI \geq 1$  Generally used for evaluation of confirmatory air monitoring results.**

\*\*\* **This alternative is generally not used to evaluate confirmatory air monitoring results. However, additional air monitoring may be warranted if monitoring objectives were not achieved. Confirmatory air monitoring will generally be conducted during worst-case long-term emission/dispersion conditions. Therefore, this facilitates the use of more rigorous evaluation criteria for this final air release characterization step prior to RFI decisionmaking.**

\*\*\*\*  **$HI < 1$  Criterion generally used for evaluation of confirmatory air monitoring results.**

unit or contaminated soil). Utilizing a phased approach, the air release is characterized in terms of the types and amounts of hazardous constituents being emitted, leading to a determination of actual or potential exposure at the facility property boundary. This may involve emission modeling (to estimate unit-specific emission rates), air monitoring (to determine concentrations at the facility property boundary), emission monitoring (monitoring at the source to determine emission rates), and dispersion modeling (to estimate concentrations at the facility property boundary). A phased approach utilizing both modeling and monitoring may not always be necessary to achieve adequate release characterization.

As indicated in Section 1 of this Guidance (See Volume I), standards for the control and monitoring of air emissions at hazardous waste treatment, storage and disposal (TSD) facilities are being developed by the Agency pursuant to HSWA, Section 3004(n). These standards will address specific methodologies and regulatory requirements for the identification and control of air releases at TSD facilities. The Guidance provided herein is intended to provide interim methodologies and procedures for the identification and delineation of significant air releases. In particular, the Guidance addresses those releases which may pose an existing and significant hazard to human health and the environment, and thus, should be addressed without delay, i.e., prior to the issuance of the Section 3004(n) regulations.

The RFI release characterization strategy for air includes several decision points during the characterization process to evaluate the adequacy of available information and to determine an appropriate course of action from the following alternatives (as illustrated in Figures 12-1 through 12-5).

- Information is sufficient to characterize the air release as significant and a Corrective Measures Study/Interim Corrective Measures is warranted.
- Information is sufficient to characterize the air release as insignificant, therefore, no further air assessments are required.

- Information is not sufficient to characterize the air release, therefore further release characterization is warranted.

Criteria for decisionmaking involves consideration of the uncertainty associated with release characterization results (modeling/monitoring), which is facilitated by use of a Hazard Index as illustrated in Figure 12-5. The Hazard Index is defined as the ratio of exposure concentration levels or estimates, to specific health criteria for an individual constituent or a mixture of constituents with similar potential health impacts. Further guidance on the computation and application of the Hazard Index is provided in Section 8.

The uncertainty associated with concentration estimates based on air pathway modeling and monitoring results is factored into the decision making effort through use of uncertainty analyses. A primary component of the uncertainty analysis is the accuracy of the modeling and/or monitoring approach utilized for the release characterization. Model-specific and monitoring method-specific accuracies should be used as available for the uncertainty analysis. The quality of the input data to models is another important component of the uncertainty analysis that should be accounted for. Generally, conduct of a model sensitivity analysis (i.e., varying the values of input parameters based on their uncertainty range to evaluate the effect on model output), will provide a quantitative basis to characterize input data quality. This step is particularly important for some unit-specific models. For example, the spatial variability of wastes at a landfill and the uncertainty of other input parameters (e.g., soil porosity) can significantly affect the overall uncertainty associated with emission modeling results.

As concentration measurements or estimates at the facility property boundary become available, both within and at the conclusion of discrete investigation phases, they should be reported to the regulatory agency as directed. The regulatory agency will compare the concentrations with applicable health and environmental criteria to determine the need for (1) interim corrective measures; and/or (2) a Corrective Measures Study. In addition, the regulatory agency will evaluate the data with respect to adequacy and completeness to determine the need for any additional characterization efforts. The health and environmental criteria and a general discussion of how the regulatory agency will apply them are

provided in Section 8. A flow diagram illustrating RFI Decision Points is provided in Section 3 (See Figure 3-2).

Notwithstanding the above process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For these situations, the owner or operator is advised to follow the RCRA Contingency Plan requirements under 40 CFR Part 264, Subpart D and Part 265, Subpart D.

The strategy for characterizing releases to air consists of an initial phase and, if necessary, subsequent phases, as illustrated in Table 12-1 and Figure 12-1. Additional phases may not be needed depending on the site-specific modeling/monitoring data available, and the nature and magnitude of the release. A summary discussion of the initial phase is presented in Section 12.2.1.1 and the subsequent phases in Section 12.2.1.2.

#### 12.2.1.1 Initial Phase

The initial phase of the release characterization strategy for air involves the collection and review of preliminary information and the conduct of a screening assessment.

##### 12.2.1.1.1 Collect and Review Preliminary Information

The first step is to collect, review and evaluate available waste, unit, environmental setting and release (monitoring and modeling) data. The air pathway data collection effort should be coordinated, as appropriate, with similar efforts for other media investigations.

Evaluation of these data may, at this point, clearly indicate that a Corrective Measures Study and/or interim corrective measures are necessary or that no further action is required. For example, the source may involve a large, active storage surface impoundment containing volatile constituents located adjacent to residential housing. Therefore, action instead of further studies may be appropriate. Another case may involve a unit in an isolated location, where an acceptable modeling/monitoring data base may be available which definitively

indicates that the air release can be considered insignificant and therefore further studies are not warranted. In most cases, however, further release characterization will be necessary.

A conceptual model (as discussed in Volume I - Summary Section and Section 3.2) of the release should then be developed based on available information. This model (not a computer or numerical simulation model) should provide a working hypothesis of the release mechanism, transport pathway/mechanism, and exposure route (if any). The model should be testable/verifiable and flexible enough to be modified as new data become available. For example, transport pathway and exposure modes for a contaminated surface area may involve air emissions due to volatilization, wind erosion and mechanical disturbances. These air emissions are expected to result in inhalation exposure for offsite receptors. In addition, the deposition of air emissions on soil, water bodies and crops, and infiltration and runoff from the onsite source, may contribute to overall exposures.

#### 12.2.1.1.2 Conduct Screening Assessment

Following review of existing information and development of the conceptual model, a screening assessment should be conducted to characterize the air release (see Figure 12-2). The initial screening should be based on conservative (i.e., worst-case assumptions). A screening assessment based on more realistic assumptions should be conducted if initial air concentration predictions exceed health criteria.

The Draft Final Air Release Screening Assessment Methodology, presented in Appendix G, describes the screening assessment in detail. It consists of emission rate and dispersion models and involves the following steps:

- Obtain source characterization input data
- Select release (target) constituents which may be present in the waste and have health criteria for the air pathway (see Section 8.0)
- Calculate emission estimates
- Calculate concentration estimates at facility property boundary
- Compare results to health based criteria

In order to assure adequate source characterization input data, it may be necessary to collect additional waste/unit data. This may involve field sampling of the waste to identify waste constituents and determine concentration levels. At this early RFI stage, it may be more effective and conclusive to sample the wastes (with relatively higher concentration levels) instead of the release. In general, if obtaining source-specific data is not practical, conservative source assumptions should be used.

Preliminary monitoring at the source may also be conducted to aid in the evaluation of the screening/modeling results. Preliminary monitoring may involve the use of screening or quantitative methods, and is discussed in Section 12.6. The preliminary monitoring period will generally be limited to a few days. Although preliminary monitoring results may identify release constituents that were not expected based on modeling, or vice versa, the limitations of modeling and monitoring should be considered when comparing these data and determining appropriate followup activities.

A sensitivity analysis should also be conducted to evaluate model input data quality. The results of the sensitivity analysis as well as consideration of model accuracy should be used to compute the UF for the screening assessment. The results of the screening assessment should then be compared to the health and environmental assessment criteria (as previously discussed) to determine appropriate followup actions. Collection of additional waste/unit data and/or considering the application of more refined emission/dispersion models are also possible options if initial results from the screening assessment are inconclusive.

#### 12.2.1.2 Subsequent Phases

Subsequent phases of the release characterization strategy for air may be necessary if screening assessment results are not conclusive to characterize the air release, and should involve the conduct of emission monitoring and confirmatory air monitoring as indicated in Figure 12-1. These are discussed below.



#### 12.2.1.2.1 Conduct Emission Monitoring

Source monitoring should be used in conjunction with dispersion modeling to further characterize the release, as indicated in Figure 12.3. Direct emission sampling should be used for point sources such as vents and stacks. An isolation flux chamber may be used for area source emission measurements. Onsite air monitoring (particularly near the emission source) is an alternative approach for characterizing area source emissions if direct emission monitoring is not practical (e.g., considering equipment availability). Guidance for the conduct of these field programs is presented in Section 12.6 and 12.8.

The development of emission monitoring procedures should address selection of target air emission constituents. One acceptable approach is to monitor for all potential Appendix VIII air emission constituents (see Appendix B, List 3) applicable to the unit or release of concern. An alternative approach is to use unit and waste-specific information to identify constituents that are expected to be present, thus reducing the number of target constituents (see Section 3.6). The target constituents selected should be limited to those which may be present in the waste and have health criteria for the air pathway (see Section 8).

Representative meteorological data as well as emission monitoring results should be available as input data for dispersion modeling. Therefore, it may be necessary to conduct an onsite meteorological monitoring survey. The meteorological monitoring survey should be conducted, at a minimum, for a period sufficient to identify and define wind and stability patterns for the season associated with worst-case, long-term source emission/dispersion conditions. However, it may also be desirable to obtain sufficient data to characterize annual dispersion conditions at the site. The season associated with the highest long-term air concentration is determined by evaluating seasonal emission/dispersion modeling results based on available meteorological data (e.g., National Weather Service data). This modeling application accounts for the complex relationships between meteorological conditions and emissions potential and dispersion potential. For example, high average wind speeds may increase the long-term emission potential of organics at a surface impoundment, but worst case long-term dispersion conditions would be associated with low average wind speed conditions. Seasonal temperature conditions would also affect the emission potential.

Therefore, it would be necessary to compare seasonal air concentration results to identify the season with worst case long term exposure conditions. This season would be the candidate period to collect several months of onsite meteorological data to support more refined modeling analyses (e.g., dispersion modeling using emission rate monitoring data as input). Guidance on selection of the emission monitoring period within this worst case season is presented in Section 12.6.4.2. Guidance on the conduct of a meteorological monitoring program is provided in Sections 12.6.3 and 12.8.1.

Dispersion models are used to estimate constituent concentrations based on source and meteorological monitoring input data. Guidance on the selection and application of dispersion models is presented in Section 12.5 and in Guidance on Air Quality Models (U.S. EPA, July 1986) and Procedures for Conducting Air Pathway Analyses for Superfund Applications (U.S. EPA, December 1988). The results of the dispersion modeling assessment should then be compared to the health and environmental assessment criteria (as previously discussed) to determine appropriate followup actions.

#### 12.2.1.2.2 Confirmatory Air Monitoring

Confirmatory air monitoring (as outlined in Figure 12-4), may also be appropriate to provide additional release characterization information for RFI decisionmaking. Air monitoring data will provide a basis for release mapping and for evaluation and confirmation of modeling estimates. The conduct of an air monitoring program should include the following components:

- Develop monitoring procedures
- Conduct initial monitoring
- Collect and evaluate results
- Conduct additional air monitoring (if necessary)

The development of monitoring procedures should address selection of target air emission constituents. One acceptable approach is to monitor for all potential Appendix VIII air emission constituents (See Appendix B, List 3) applicable to the unit or release of concern. An alternative approach is to use unit and waste-specific information to identify constituents that are expected to be present, thus reducing

the number of target monitoring constituents (See Section 3.6). The target constituents selected should be limited to those which may be present in the waste and have health criteria for the air pathway (see Section 8.0).

The development of monitoring procedures should also include selection of appropriate field and analytical methods for conducting the air monitoring program. Candidate methods and criteria for monitoring program design (e.g., relevant to sampling schedule and monitor placement) should be limited to standard published protocols (such as those available from EPA, NIOSH, and ASTM). The selection of appropriate methods will be dependent on site and unit-specific conditions, and is discussed further in Section 12.8.

A limited screening-type sampling program may be appropriate for determining the design of the air monitoring program. The objective of this screening sampling will be to verify a suspected release, if appropriate, and to further assist in identifying and quantifying release constituents of concern. Screening sampling at each unit for a multiple-unit facility, for example, can be used to prioritize release sources. The emphasis during this screening will generally be on obtaining air samples near the source, or collecting a limited number of source emission samples. The availability of air monitoring data on units with a limited set of air emission constituents may preclude the need for screening sampling during the investigation.

An initial air monitoring program should be conducted, as necessary, to characterize the magnitude and distribution of air concentration levels for the target constituents selected. Initial monitoring should be conducted for a period sufficient to characterize air concentrations at the facility property boundary, as input to the health and environmental assessment (e.g., a 90-day period may be appropriate for a flat terrain site with minimal variability of dispersion and source conditions).

The basic approach for the initial air monitoring will consist of collection of ambient air samples for four target zones: the first zone located upwind of the source to define background concentration levels; the second zone located downwind at the unit boundary; the third zone located downwind at the facility property boundary for input into the health and environmental assessment; and a

fourth zone offsite, as practical, to determine the need for interim corrective measures. Multiple monitoring stations will generally be required for each of the four target zones. It should be noted that offsite air monitoring may not always be practical due to various problems (e.g., vandalism, public tampering with equipment, public relations and legal access problems). Dispersion modeling can be used to estimate offsite concentrations if monitoring data are not available for the actual receptor locations of interest.

The location of air monitors within each zone should be based on site-specific diurnal and seasonal wind patterns appropriate for the monitoring period. An onsite meteorological monitoring survey (as previously discussed) may be necessary to characterize local wind patterns. The objective of the air monitoring network should be to provide adequate coverage for primary air flowpaths for each of the zones enumerated above.

The conduct of the initial air monitoring program generally includes the collection of meteorological data concurrent with air quality measurements. The meteorological data are needed during the air monitoring program to characterize emission potential and atmospheric dispersion conditions. This information is also used to evaluate source/receptor relationships and to interpret and extrapolate the air monitoring data.

Additional air monitoring may be warranted if initial monitoring program objectives are not met (e.g., data recovery goals were not adequate) or results are not adequate to characterize the release (e.g., additional monitoring stations are needed).

The air monitoring program data should be evaluated, and a dispersion model used, as needed, to estimate concentrations at the facility property boundary. These results should then be compared to the health and environmental assessment criteria (as previously discussed). Subsequent monitoring may also be conducted during or after the implementation of corrective measures to characterize changes in downwind release concentrations attributed to mitigation efforts.

### 12.3 Characterization of the Contaminant Source and the Environmental Setting

Release investigations can be conducted in an efficient, effective and representative manner if certain information is obtained prior to implementation of the effort. This information consists of both waste/unit characterization and characterization of the environmental setting. Review of information from existing sources can be used to identify data gaps and to initiate data collection activities to fill these data gaps. Waste/unit characterization and characterization of the environmental setting are discussed below:

Waste and unit specific information: Data on the specific constituents present in the unit that are likely to be released to the air can be used to design sampling efforts and identify candidate constituents to be monitored. This information can be obtained from either a review of the existing information on the waste or from new sampling and analysis. The manner in which the wastes are treated, stored or disposed may have a bearing on the magnitude of air emissions from a unit. In many cases, this information may be obtained from facility records, contact with the manufacturer of any control devices, or, in some cases, from the facility's RCRA permit application.

Environmental setting information: Environmental setting information, particularly climatological data, is essential in characterizing an air release. Climatological parameters such as wind speed and temperature will have a significant impact on the distribution of a release and in determining whether a particular constituent will be released. Climatological and meteorological information for the area in which the facility is located can be obtained either through an onsite monitoring effort or from the National Climatic Data Center (Asheville, NC). The climatological data should be evaluated considering site topography and other local influences that can affect the data representatives.

Information pertaining to the waste, unit, and environmental setting can be found in many readily available sources. General information concerning waste/unit characterization is discussed in Section 7. Air specific information is provided in the following discussions.

### 12.3.1 Waste Characterization

Several waste characteristics contribute to the potential for a waste constituent to be released via the air pathway. These characteristics, in conjunction with the type of unit and its operation, will determine whether a release will be via volatilization of the constituent or as particulate entrainment. Major factors include the types and number of hazardous constituents present, the concentrations of these constituents in the waste(s), and the chemical and physical characteristics of the waste and its constituents. All of these factors should be considered in the context of the specific unit operation involved. It is important to recognize that the constituents of concern in a particulate release may involve constituents that are either sorbed onto the particulate, or constituents which actually comprise the particulate.

#### 12.3.1.1 Presence of Constituents

The composition of the wastes managed in the unit of concern will influence the nature of a release to air. Previous studies may indicate that the constituents are present in the unit or that there is a potential for the presence of these constituents. In determining the nature of a release, it may be necessary to determine the specific waste constituents in the unit if this has not already been done. Guidance on selecting monitoring constituents is presented in Section 3 (and Appendix B); waste characterization guidance is presented in Section 7.

#### 12.3.1.2 Physical/Chemical Properties

The physical and chemical properties of the waste constituents will affect whether they will be released, and if released, what form the release will take (i.e., vapor, particulate, or particulate-associated). These parameters are identified in Table 12-3 as a function of emission and waste type. Important parameters to consider when assessing the volatilization of a constituent include the following:

- Water solubility. The solubility in water indicates the maximum concentration at which a constituent can dissolve in water at a given temperature. This value can help the investigator estimate the

**TABLE 12-3**  
**PARAMETERS AND MEASURES FOR USE IN EVALUATING POTENTIAL**  
**RELEASES OF HAZARDOUS WASTE CONSTITUENTS TO AIR**

<u>Emission and Waste Type</u>	<u>Units of Concern<sup>1/</sup></u>	<u>Useful Parameters and Measures</u>
<b>A. Vapor Phase Emissions</b>		
- Dilute Aqueous Solution <sup>2/</sup>	Surface Impoundments, Tanks, Containers	Solubility, Vapor Pressure, Partial Pressure <sup>3/</sup>
- Conc. Aqueous Solution <sup>2/</sup>	Tanks, Containers, Surface Impoundments	Solubility, Vapor Pressure, Partial Pressure, Raoult's Law
- Immiscible Liquid	Containers, Tanks	Vapor Pressure, Partial Pressure
- Solid	Landfills, Waste Piles, Land Treatment	Vapor Pressure, Partial Pressure, Octanol/Water Partition Coefficient, Porosity
<b>B. Particulate Emissions</b>		
- Solid	Landfills, Waste Piles, Land Treatment	Particle Size Distribution, Unit Operations, Management Methods

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<sup>1/</sup> Incinerators are not specifically listed on this table because of the unique issues concerning air emissions from these units. Although incinerators can burn many forms of waste, the potential for release from these units is primarily a function of incinerator operating conditions and emission controls, rather than waste characteristics.

<sup>2/</sup> Although the octanol/water partition coefficient of a constituent is usually not an important characteristic in these waste streams, there are conditions where it can be critical. Specifically, in waste containing high concentrations of organic particulates, constituents with high octanol/water partition coefficients will adsorb to the particulates. They will become part of the sludge or sediment matrix, rather than volatilizing from the unit.

<sup>3/</sup> Applicable to mixtures of volatile components.

distribution of a constituent between the dissolved aqueous phase in the unit and the undissolved solid or immiscible liquid phase. Considered in combination with the constituent's vapor pressure, solubility can provide a relative assessment of the potential for volatilization of a constituent from an aqueous environment.

- Vapor pressure. This property is a measure of the pressure of vapor in equilibrium with a pure liquid. It is best used in a relative sense; constituents with high vapor pressures are more likely to be released than those with low vapor pressures, depending on other factors such as relative solubility and concentration (e.g., at high concentrations releases can occur even though a constituent's vapor pressure is relatively low).
- Octanol/water partition coefficient. The octanol/water partition coefficient indicates the tendency of an organic constituent to sorb to organic components of soil or waste matrices. Constituents with high octanol/water partition coefficients tend to adsorb readily to organic carbon, rather than volatilizing to the atmosphere. This is particularly important in landfills and land treatment units, where high organic carbon content in soils or cover material can significantly reduce the release potential of volatile constituents.
- Partial pressure. For constituents in a mixture, particularly in a solid matrix, the partial pressure of a constituent will be more significant than pure vapor pressure. A partial pressure measures the pressure which each component of a mixture of liquid or solid substances will exert in order to enter the gaseous phase. The rate of volatilization of an organic chemical when either dissolved in water or present in a solid mixture is characterized by the partial pressure of that chemical. In general, the greater the partial pressure, the greater the potential for release. Partial pressure values are unique for any given chemical in any given mixture and may be difficult to obtain. However when waste characterization data are available, partial pressure can be estimated using methods commonly found in engineering and environmental science handbooks.



- Henry's Law constant. Henry's law constant is the ratio of the vapor pressure of a constituent to its aqueous solubility (at equilibrium). This constant can be used to assess the relative ease with which the compound may vaporize from the aqueous phase. It is applicable only for low concentration (i.e., less than 10 percent) wastes in aqueous solution and will be most useful when the unit being assessed is a surface impoundment or tank containing dilute wastewaters. The potential for significant vaporization increases as the value for Henry's Law Constant increases; when it is greater than  $10E-3$ , rapid volatilization will generally occur.
- Raoult's Law. Raoult's Law accurately predicts the behavior of most concentrated mixtures of water and organic solvents (i.e., solutions over 10% solute). According to Raoult's Law, the rate of volatilization of each chemical in a mixture is proportional to the product of its concentration in the mixture and its vapor pressure. Therefore, Raoult's Law can be used to characterize volatilization potential. This will be especially useful when the unit of concern entails container storage, tank storage, or treatment of concentrated waste streams.

A summary of some of these factors for several constituents is given in Tables 12-4 and 12-5. The following document contains a compilation of chemical-physical properties for several hundred constituents. Additional references for these data are provided in Section 7.

U.S. EPA. December 1987. Hazardous Waste Treatment Storage and Disposal Facilities (TSDF) - Air Emission Models. EPA-450/3-87-026. Office of Air Quality Planning and Standards. Research Triangle Park, N.C. 27711

For airborne particulates, the particle size distribution plays an important role in both dispersion and actual inhalation exposure. Large particles tend to settle out of the air more rapidly than small particles. Very small particles (i.e., those that are less than 2.5 to 10 microns in diameter) are considered to be respirable and thus present a greater health hazard than the larger particles. Therefore, the source of the release should be examined to obtain information on particle size. Process information may be sufficient to grossly characterize the potential for particulate

**TABLE 12-4**  
**PHYSICAL PARAMETERS OF VOLATILE HAZARDOUS CONSTITUENTS**

Hazardous constituent	Molecular weight	Vapor pressure at 25°C (mmHg)	Solubility at 25°C (mg/l)	Henry's Law constant (atm <sup>3</sup> /mol)
Acetaldehyde	44	915	1.00E + 06	9.50E-05
Acrolein	56	244	4.00E + 05	4.07E-05
Acrylonitrile	53	114	7.90E + 04	8.80E-05
Allylchloride	76.5	340		340E-01
Benzene	78	95	1.78E + 03	5.50E-03
Benzyl chloride	126.6	1.21	1.00	
Carbon tetrachloride	154	109	8.00E + 02	2.00E-02
Chlorobenzene	112	12	5.00E + 02	2.00E-03
Chloroform	119	192	8.00E + 03	3.00E-03
Chloroprene	88.5	215		
Cresols	108	0.4	2.00E + 04	4.60E-07
Cumene (isopropylbenzene)	120	4.6	50.0	2.00E-04
1,4-dichlorobenzene	147	1.4	49.00	
1,2-dichloroethane	99	62	8.69E + 03	1.00E-04
Dichloromethane	85	360	2.00E + 04	2.00E-03
Dioxin	178	7.6E-7	3.17E-04	1.20E-03
Epichlorohydrin	92.5	13	6.00E + 04	3.08E-05
Ethylbenzene	106	10	152	7.00E-03
Ethylene oxide	44	1,095	1.35E + 05	
Formaldehyde	30	3,500	3.00E + 05	
Hexachlorobutadiene	261	0.15		
Hydrogen cyanide	27	726		
Hydrogen flouride	20	900		
Hydrogen sulfide	34	15,200		
Hexachlorocyclopentadiene	273	0.03		
Maleic anhydride	98	0.3	1.63E + 05	
Methyl acetate	74	170	3.19E + 05	1.00E-04
N-Dimethylnitrosamine	81	3.4		
Naphthlene	123	0.23		
Nitrobenzene		0.3	1.90E + 03	1.30E-05
Nitrosomorpholine		5.3		
Phenol	94	0.34	9.30E + 04	1.02E-05
Phosgene	98	1,300		
Phthalic anhydride	148	0.03	6.17E + 03	9.00E-07
Propylene oxide		400		
1,1,2,2-tetrachloroethane	168	9	2.90E + 03	2.00E-04
Tetrachloroethylene	166	15	200	
Toluene	92	30	534	5.00E-03
1,1,1-trichloroethane	133	123	720	2.15E-02
Trichloroethylene	131	90	1.10E + 03	8.92E-03
Vinylchloride	62.5	2,600	6.00E + 03	1.90E-01
Vinylidenechloride	97	500		
Xylenes	106	8.5	1.00	4.04E-04

**TABLE 12-5**  
**PHYSICAL PARAMETERS OF PCB MIXTURES\***

Arochlor (PCB)	Vapor pressure at 25°C (atm)	Solubility at 25°C (mg/l)	Henry's Law constant (atm-m <sup>3</sup> /mol)
1242	2.19E-07	2400	238E-08
1248	1.02E-07	520	1.02E-08
1254	1.85E-08	120	1.40E-08
1260	5.17E-09	30	6.46E-08

\* All values estimated based on calculations.

formation. For example, the presence of ash materials and similar wastes would be a case in which particulate emissions would be of concern.

### 12.3.2 Unit Characterization

Different types of units may have differing release potentials. The particular type of unit, its configuration, and its operating conditions will have a great effect on the nature, extent, and rate of the release. These practices or parameters should be determined and reasonable worst-case operating practices or conditions should also be identified prior to initial sampling.

#### 12.3.2.1 Type of Unit

The type of unit will affect its release potential and the types of releases expected. For the purpose of this guidance, units have been divided into three general types with regard to investigating releases to air. These are:

- Area sources having solid surfaces, including land treatment facilities, surfaces of landfills, and waste piles;
- Point sources, including vents, (e.g., breathing vents from tanks) and ventilation outlets from enclosed units (e.g., container handling facilities or stacks); and
- Area sources having liquid surfaces, including surface impoundments and open-top tanks.

The following discussion provides examples for each of these unit types and illustrates the kind of data that should be collected prior to establishing a sampling plan. Table 12-6 indicates types of releases most likely to be observed from each of these example unit types. It should also be recognized that releases to air can be continuous or intermittent in nature.

Waste piles--Waste piles are primary sources of particulate releases due to entrainment into the air of solid particles from the pile. Waste piles are generally comprised of dry materials which may be released into the air by wind or

**TABLE 12-6  
SUMMARY OF TYPICAL UNIT SOURCE TYPE AND AIR RELEASE TYPE**

Typical Unit Type	Source Type			Potential Phase of Release	
	Area Sources with Liquid Surface	Area Sources with Solid Surface	Point Sources	Vapor	Particulate
Waste Piles		X		X	X
Land Treatment Units		X		X	X
Landfills		X	X	X	X
Drum Handling Facilities			X	X	X
Tanks	X		X	X	
Surface Impoundments	X			X	
Incinerators*			X	X	X

\* Includes units (e.g., garbage incinerators) not covered by 40 CFR Part 264, Subpart O which pertains to hazardous waste incinerators.

operational activities. The major air contaminants of concern from waste piles will be those compounds that are part of or have been adsorbed onto the particulates. Additionally, volatilization of some constituents may occur. Important unit factors include the waste pile dimensions (e.g., length, width, height, diameter and shape), and the waste management practices (e.g., the frequency and manner in which the wastes are applied to the pile and whether any dust suppression procedures are employed). The pile dimensions determine the surface area available for wind erosion. Disturbances to the pile can break down the surface crust and thus increase the potential for particulate emissions. Dust suppression activities, however, can help to reduce particulate emissions.

Land treatment units--Liquid or sludge wastes may be applied to tracts of soil in various ways such as surface spreading of sludges, liquid spraying on the surface, and subsurface liquid injection. These methods may also involve cultivation or tilling of the soil. Vapor phase and particulate contaminant releases are influenced by the various application techniques. Particulate or volatile emission releases are most likely to occur during initial application or during tilling, because tilling keeps the soil unconsolidated and loose, and increases the air to waste surface area.

Important unit factors in assessing an air release from a land treatment unit include:

- **Waste application method** - Liquid spraying applications tend to minimize particulate releases while increasing potential volatile releases. Subsurface applications generally reduce the potential for particulate and volatile releases.
- **Moisture content of the waste** - Wastes with high moisture content will be less likely to be released as particulates; however, a potential vapor phase release may become more likely.
- **Soil characteristics** - Certain constituents, such as hydrophobic organics, will be more likely to be bound to highly organic soils than non-organic soils. Therefore, releases of these types of constituents are most likely to be associated with particulate emissions.

Landfills--Landfills can result in particulate and vapor phase releases. This process generally involves placement of waste in subsurface disposal cells and subsequent covering of the waste with uncontaminated soil. Landfill characteristics that can affect contaminant release include:

- Porosity and moisture content of the soil or clay covering can influence the rate at which vapor phase releases move through the soil towards the surface. Finer soils with lower porosities will generally slow movement of vapors through the unit. The frequency of applying soil cover to the open working face of a landfill will also affect the time of waste exposure to the air.
- Co-disposal of hazardous and municipal wastes will often increase the potential for vapor phase releases, because biodegradation of municipal wastes results in the formation of methane gas as well as other volatile organics. Methane gas may act as a driving force for release of other volatile hazardous components that may be in the unit (See Section 11 - Subsurface Gas.)
- Landfill gas vents, if present, can act as sources of vapor phase emissions of contaminated landfill gases.
- Leachate collection systems can be sites of increased vapor phase emissions due to the concentrated nature of the leachate collected. Open trenches are more likely to be emission sources than underground collection sumps due to the increased exposure to the atmosphere.
- Waste mixing or consolidation areas where bulk wastes are mixed with soil or other materials (e.g., fly ash) prior to landfilling can be contributors to both particulate and vapor phase air releases. Practices such as spreading materials on the ground to release moisture prior to landfilling will also increase exposure to the atmosphere.

Drum handling facilities--Emissions from drum or container handling areas can result from several types of basic operations. Frequently, emissions from these operations are vented to the air through ducts or ventilation systems. Air sampling

to assess emissions from these operations may include sampling of the control device outlets, the workplace atmosphere at each operation, or the ambient air downwind of the unit. Factors which effect emissions include:

- Filling operations can be a major source of either vapor or particulate emissions due to agitation of the materials during the filling process. Spillage which occurs during loading may also contribute to emissions. Organic waste components with high volatility will readily vaporize into the air. Similarly, particulate matter can be atmospherically entrained by agitation and wind action. The emission potential of filling operations will be affected by exposure to ambient air. Generally, fugitive emissions from an enclosed building will be less than emissions created during loading in an open structure.
- Cleaning operations can have a high potential for emissions. These emissions may be enhanced by the use of solvents or steam cleaning equipment. The waste collection systems at these operations usually provide for surface runoff to open or below ground sumps, which can also contribute to air emissions.
- Volatilization of waste components can also occur at storage units. Since it is common practice to segregate incompatible wastes during storage, the potential for air releases may differ within a storage unit depending on the nature of the wastes stored in any particular area. The most common source of air emission releases from drum storage areas is spills from drums ruptured during shipping and handling.
- For offsite facilities, storage areas frequently are located where drums are sampled during the waste testing/acceptance process. This process involves drum opening for sampling and could also include spillage of waste materials on the ground or floor.

Important release information includes emission rates, and data to estimate release rise (e.g., vent height and diameter as well as vent exit temperature and velocity). Information pertaining to building dimension/orientation of the unit and nearby structures is needed to assess the potential for aerodynamic behavior of the



stack/vent release. These input data would be needed if atmospheric dispersion modeling was necessary.

**Tanks**--Tanks can emit volatile waste components under various circumstances. A major determinant of any air emission will be the type of tank being studied. Closed or fixed roof storage tanks will most likely exhibit less potential for air emissions than open topped tanks. Some tanks are equipped with vapor recovery systems that are designed to reduce emissions. Important process variables for understanding air emissions from tanks can be classified as descriptive and operational variables:

- Descriptive variables include type, age, location, and configuration of the tank.
- Operational variables include aeration, agitation, filling techniques, surface area, throughput, operating pressure and temperature, sludge removal technique and frequency, cleaning technique and frequency, waste retention and vent pipe dimensions and flow rate.

Important release information includes emission rates, and data to estimate plume rise (e.g., height and diameter as well as exit temperature and velocity). Information pertaining to building dimensions/orientation of the unit and nearby structures is needed to assess the potential for aerodynamic behavior of the stack/vent release. These input data would be needed if atmospheric dispersion modeling was necessary.

**Surface impoundments**--Surface impoundments are similar in many ways to tanks in the manner in which air emissions may be created. Surface impoundments are generally larger, at least in terms of exposed surface areas, and are generally open to the atmosphere. The process variables important for the evaluation of releases to air from surface impoundments can also be classified as descriptive and operational.

- Descriptive parameters include dimensions, including length, width, and depth, berm design, construction and liner materials used, and the location of the unit on the site.

- Operational parameters include freeboard, filling techniques (in particular, splash versus submerged inlet), depth of liquid and sludge layers, presence of multiple liquid layers, operating temperature, sludge removal techniques and frequency, cleaning technique and frequency, presence of aerators or mixers, biological activity factors for biotreatment, and the presence of baffles, oil layers, or other control measures on the liquid surface. (These factors are relevant to some tanks as well.)

Some surface impoundments are equipped with leak collection systems that collect leaking liquids, usually into a sump. Air emissions can also occur from these sumps. Sump operational characteristics and dimensions should be documented and, if leaks occur, the volume of material entering the sump should be documented. (These factors are relevant to some tanks as well.)

Incinerators - Stack emissions from incinerators (i.e., incinerator units not addressed by RCRA in Part 264, Subpart O, e.g., municipal refuse incinerators) can contain both particulates and volatile constituents. The high temperatures of the incineration process can also cause volatilization of low vapor pressure organics and metals. Additional volatile releases can occur from malfunctioning valves during incinerator charging. The potential for air emissions from these units is primarily a function of incinerator operating conditions and emission controls. Important unit release information includes emission rates, and data to estimate plume rise (e.g., height and diameter as well as exit temperature and velocity), as well as building dimensions/orientation of the unit and nearby structures. This information is needed to assess the aerodynamic behavior of the stack/vent release and for input to atmospheric dispersion models.

#### 12.3.2.2 Size of Unit

The size of the unit(s) of concern will have an important impact on the potential magnitude of a release to air. The release of hazardous constituents to the air from an area source is often directly proportional to the surface area of the unit, whether this surface area is a liquid (e.g., in a tank) or a solid surface (e.g., a land treatment unit). The scope of the air investigation may be a function of the

size of the unit. Generally, more sampling locations will be required as the unit increases in size, due primarily to increased surface area. Also, as the total amount of waste material present in a particular unit increases, it will represent a larger potential reservoir or source of constituents which may be released.

Scaling factors, such as surface area to volume ratios should also be evaluated. One large waste pile, for instance, can exhibit a lower ratio of surface area to total volume than the sum of two smaller piles in which the total volume equals that of the larger pile. Other units such as tanks may exhibit a similar economy of surface area, based on the compact geometry of the unit.

Because releases to air generally occur at the waste/atmosphere interface, surface area is generally a more important factor than total waste volume. Consequently, operations that increase the atmosphere/waste interface, such as agitation or aeration, splash filling, dumping or filling operations, and spreading operations will tend to increase the emission rate. Total emissions, however, will be a function of the total mass of the waste constituent(s) and the duration of the release.

For point sources, the process or waste throughput rate will be the most important unit information needed to evaluate the potential for air emissions (i.e., stack/vent releases).

#### 12.3.2.3 Control Devices

The presence of air pollution control devices on units can have a major influence on the nature and extent of releases. Control devices can include wet or dry scrubbers, electrostatic precipitators, baghouses, filter systems, wetting practices for solid materials, oil layers on surface impoundments, charcoal or resin absorption systems, vapor flares, and vapor recovery systems. Many of these controls systems can be installed on many of the unit types discussed in this section. Due to the variety of types of devices and the range of operational differences, an in depth discussion of individual control devices is not presented here. Additional information on control technologies for hazardous air pollutants is available in the following references:

U.S. EPA. 1986. Handbook - Control Technologies for Hazardous Air Pollutants. EPA/625/6-86/014. Office of Research and Development. Research Triangle Park, N.C. 27711.

U.S. EPA. 1986. Evaluation of Control Technologies for Hazardous Air Pollutants: Volume 1 - Technical Report. EPA/600/7-86/009a. NTIS PB 86-167020. Volume 2 - Appendices. EPA/600/7-86/009b. NTIS PB 86-167038. Office of Research and Development. Research Triangle Park, N.C. 27711.

If a control device is present on the unit of concern, descriptive and operational characteristics of the unit/control device combination should be reviewed and documented. In many cases, performance testing of these devices has been conducted after their installation on the unit(s). Information from this testing may help to quantify releases to air from the unit(s); however, this testing may not have been performed under a "reasonable worst-case" situation. The conditions under which the testing was performed should be documented.

#### 12.3.2.4 Operational Schedules

Another characteristic which can affect the magnitude of a release to air from a unit is the unit's operational schedule. If the unit is operational on a part time or batch basis, the emission or release rate should be measured during both operational and non-operational periods. In contrast to batch operations, emission or release rates from continuous waste management operations may be measured at any time.

#### 12.3.2.5 Temperature of Operation

Phase changes of liquids and solids to gases is directly related to temperature. Therefore, vapor phase releases to air are directly proportional to process temperature. Thus, it is important to document operational temperature (i.e., waste temperature) and fluctuations to enhance the understanding of releases to air from units. Particular attention should be paid to this parameter in the review of existing data or information regarding the operation of the unit.

The release rate of volatile components also generally increases with temperature. Frequently, the same effect is observed for particulates, because entrainment is enhanced as materials are dried. Thus, the evaporation of any water from solids, which generally increases as temperature increases, will likely increase the emissions of many particulates in the waste streams. Evaporation of water may also serve to concentrate wastes, leading to conditions more conducive to vapor phase releases to air. It should also be noted that the destruction efficiency of incinerators is also a function of temperature (i.e., higher temperatures are generally associated with greater destruction efficiency).

### **12.3.3 Characterization of the Environmental Setting**

Environmental factors can influence not only the rate of a release to air but also the potential for exposure. Significant environmental factors include climate, soil conditions, terrain and location of receptors. These factors are discussed below.

#### **12.3.3.1 Climate**

Wind, atmospheric stability and temperature conditions affect emission rates from area sources as well as atmospheric dispersion conditions for both area and point sources. Historical summaries of climatic factors can provide a basis to assess the long-term potential for air emissions and to characterize long-term ambient concentration patterns for the area. Short-term measurements of these conditions during air monitoring will provide the meteorological data needed to interpret the concurrent air quality data. Meteorological monitoring procedures are discussed in Section 12.8. Available climatic information, on an annual and monthly or seasonal basis, should be collected for the following parameters:

- Wind direction and roses (which affects atmospheric transport, and can be used to determine the direction and dispersion of release migration);
- Mean wind speeds (which affects the potential for dilution of releases to air);
- Atmospheric stability distributions (which affects dispersion conditions);

- Temperature means and extremes (which affects the potential for volatilization, release rate and wind erosion);
- Precipitation means (which affects the potential for wind erosion of particulates);
- Atmospheric pressure means (which affects the potential for air emissions from landfills); and
- Humidity means (which can affect the air collection efficiencies of some adsorbents - see Section 12.8).

The primary source of climate information for the United States is the National Climatic Data Center (Asheville, NC). The National Climatic Data Center can provide climate summaries for the National Weather Service station nearest to the site of interest. Standard references for climatic information include the following:

National Climatic Data Center. Local Climatological Data - Annual Summaries with Comparative Data, published annually. Asheville, NC 28801.

National Climatic Data Center. Climates of the States. 1973. Asheville, NC 28801.

National Climatic Data Center. Weather Atlas of the United States. 1968. Asheville, NC 28801.

The climatological data should be evaluated considering the effects of topography and other local influences that can affect data representativeness.

A meteorological monitoring survey may be conducted prior to ambient air monitoring to establish the local wind flow patterns and for determining the number and locations of sampling stations. The survey results will be used to characterize local prevailing winds and diurnal wind flow patterns (e.g., daytime upslope winds, nighttime downslope winds, sea breeze conditions) at the site. The survey should be conducted for a one-month period and possibly longer to adequately characterize anticipated wind patterns during the air monitoring

program. Inland, flat terrain conditions may not necessitate an onsite meteorological monitoring survey if representative data are available from previous onsite studies or from National Weather Service stations.

The meteorological monitoring data collected during the initial monitoring phase can serve as a basis for the placement of air sampling stations during any subsequent monitoring phases.

#### 12.3.3.2 Soil Conditions

Soil conditions (e.g., soil porosity) can affect air emissions from landfills and the particulate wind erosion potential for contaminated surface soils. Soil conditions pertinent to characterizing the potential for air emissions include the following:

- Soil porosity (which affects the rate of potential gaseous emissions);
- Particle size distribution (which affects the potential for particulate emissions from contaminated soils); and
- Contaminant concentrations in soil (i.e., potential to act as air emission sources).

Soil characterization information is presented in Section 9.

#### 12.3.3.3 Terrain

Terrain features can significantly influence the atmospheric transport of air emissions. Terrain heights relative to release heights will affect groundlevel concentration. Terrain obstacles such as hills and mountains can divert regional winds. Likewise, valleys can channel wind flows and also limit horizontal dispersion. In addition, complex terrain can result in the development of local diurnal wind circulations and affect wind speed, atmospheric turbulence and stability conditions. Topographic maps of the facility and adjacent areas are needed to assess local and regional terrain. Guidance on the appropriate format and sources of topographic and other maps is presented in Section 7 and Appendix A.

#### **12.3.3.4 Receptors**

Information concerning the locations of nearby buildings and the population distribution in the vicinity of the site are needed to identify potential air-pathway receptors. This receptor information provides a basis for determining the need for interim corrective measures. Both environmental and human receptor information is needed to assess potential air-pathway exposures. Such information may include:

- A site boundary map;
- Location of nearest buildings and residences for each of the sixteen 22.5 degree sectors which corresponds to major compass points (e.g., north, north-northwest);
- Location of buildings and residences that correspond to the area of maximum offsite groundlevel concentrations based on preliminary modeling estimates (these locations may not necessarily be near the site boundary for elevated releases); and
- Identification of nearby sensitive receptors (e.g., nursing homes, hospitals, schools, critical habitat of endangered or threatened species).

The above information should be considered in the planning of an air monitoring program. Additional guidance on receptor information is provided in Section 2.

#### **12.3.4 Review of Existing Information**

The review of existing air modeling/monitoring data entails both summarizing the reported air contaminant concentrations as well as evaluating the quality of these data. Air data can be of many varieties and of varying utility to the RFI process. Modeling data should be evaluated based on the applicability of the model used, model accuracy, as well as the quality and representativeness of the input data.



One of the most basic parameters to review in any type of air monitoring data should be the validity of the sampling locations used during the collection of the monitoring data. The results of previous investigations should be assessed with respect to the upwind-downwind pattern around the unit to determine the likelihood that the sampling devices would have measured releases from the unit of concern. For relatively simple sites (e.g., flat terrain, constant wind speed and direction), this determination should be fairly straight-forward; however, for complex sites (e.g., complex terrain, variable winds, multiple sources, etc.), assessing the appropriateness of past sampling locations should consider such factors as potential interferences that may not have been addressed by the sampling scheme.

The most useful monitoring data are compound-specific results which can be associated with the unit being investigated, or, for point sources (such as vent stacks or ventilation system outlets), direct measurements of the exhaust prior to its release into the atmosphere. Because the hazardous properties and health and environmental criteria are compound-specific, general compound category or class data (e.g., hydrocarbon results) are less meaningful. Any existing air data should also be described and documented as to the sampling and analysis methods utilized, the associated detection limits, precision and accuracy, and the results of QA/QC analyses conducted. Results reported as non-detected (i.e., not providing numerical detection limits) are likely to be of no value.

In addition, available upwind and downwind air data should be evaluated to determine if the contamination is due to releases from the unit. If background data are available for the unit of concern, the data will be of much greater use in the planning of additional air monitoring tasks. Upwind data (to characterize ambient air background levels) are important for evaluating if downwind contamination can be attributed to the unit of concern. If background data are not available, the existing downwind air concentration data will be of less value in characterizing a release; however, the lack of background data does not negate the utility of the available monitoring data.

Data may also be available from air monitoring studies that did not focus directly on releases from a unit of concern. Many facilities conduct onsite health and safety programs, including routine monitoring of air quality for purposes of evaluating worker exposure. This type of data may include personnel hygiene

monitoring results from personal sampling systems worn by employees as they perform their jobs, general area monitoring of zones at which hazardous operations are conducted, or actual unit-emission monitoring. The detection limits of these methods (generally in parts per million) are frequently higher than are needed for RFI purposes. However, this type of industrial hygiene monitoring is frequently compound-specific, and can be useful in qualitatively evaluating the air emissions from particular sources.

Indoor air monitoring, generally only applicable to units that are enclosed in a building (e.g., drum handling areas or tanks), often includes flow monitoring of the ventilation system. Monitoring of hoods and ductwork systems may have been conducted to determine exchange time and air circulation rates. These flow determinations could prove to be useful in the evaluation of air emission measurements during the RFI.

Another important aspect of the existing data review is to document any changes in composition of the waste managed in the unit of concern since the air data were collected. Also, changes in operating conditions or system configuration for waste generation and/or unit functions could have major effects on the nature or extent of releases to air. If such operational or waste changes have occurred, they should be summarized and reviewed to determine their role in the evaluation of existing data. This summary and review will not negate the need to take new samples to characterize releases from the unit. However, such information can be useful in the planning of the new air monitoring activities.

#### **12.3.5 Determination of "Reasonable Worst-Case" Exposure Period**

A "reasonable worst-case" exposure period over a 90 day period should be identified if an air monitoring program is to be conducted. Determination of reasonable worst-case exposure conditions will aid in planning the air monitoring program and is dependent on seasonal variations in emission rates and dispersion conditions.

The selection of the "reasonable worst-case" 90-day exposure period for the conduct of air monitoring should account for the following factors:

- For vapor phase releases, wind speed and temperature are the key factors affecting releases from the unit. In general, the higher the temperature and windspeed, the greater the rate of volatilization of constituents of concern from the waste. This process is tempered, however, by the fact that at higher windspeeds, dispersion of the release is generally greater, resulting in lower downwind concentrations at potential exposure points.
- For particulate releases, wind speed is the key meteorological factor. The amount of local precipitation contributing to the degree of moisture of the waste may also be important. In general, the higher the windspeed, and the drier the waste, the greater will be the potential for particulate release. As with vapor phase releases, higher wind speeds may also lead to greater dispersion of the release, resulting in lower downwind concentrations.
- For point source releases, increased wind speeds and unstable atmospheric conditions (e.g., during cloudless days) enhance dispersion but also tend to reduce plume height and can lead to relatively high groundlevel concentrations.
- Constituent concentrations at any downwind sector will also be directly affected by the wind direction and frequency.

Air emission release rate models and atmospheric dispersion models can be used to identify reasonable worst-case exposure conditions (i.e., to quantitatively account for the above factors). For this application, it is recommended that the modeling effort be limited to a screening/sensitivity exercise with the objective of obtaining "relative" results for a variety of source and meteorological scenarios. By comparing results in a relative fashion, only those input meteorological parameters of greatest significance (e.g., temperature, wind speed and stability) need to be considered.

In general, the summer season will be the "reasonable worst-case" exposure period at most sites because of relatively high temperatures and low windspeeds. Spring and fall are also candidate monitoring seasons that should be evaluated on a

site-specific basis. Winter is generally not a prime season for air monitoring due to lower temperatures and higher wind speeds.

## **12.4 Air Emission Modeling**

### **12.4.1 Modeling Applications**

Air emission models can be used to estimate constituent-specific emission rates based on waste/unit input data for many types of waste management units. (An emission rate is defined as the source release rate for the air pathway in terms of mass per unit of time.)

An important application of emission models in the RFI release characterization strategy for air is the conduct of screening assessments. For this application, available waste/unit input data for emission models, in conjunction with dispersion modeling results, are used to estimate concentrations at locations of interest. These results can then be evaluated to determine if adequate information is available for RFI decisionmaking or if monitoring is needed to further reduce the uncertainty associated with characterizing the release. Depending on the degree of uncertainty in the estimated concentrations relative to the differences between the estimated concentrations and the health based levels, modeling results may be sufficient to characterize the release as significant (i.e., implementation of corrective action would be appropriate) or as insignificant (i.e., no further action is warranted).

Emission rate models can also be used to identify potential major air emission sources at a facility (especially multiple-unit facilities). For this type of application, modeling results are used to compare routine long-term emissions from various units to prioritize the need for release characterization at each unit. For example, modeling results may indicate that 90 percent of the volatile organic compound emissions at a facility are attributable to surface impoundment units and only 10 percent to other sources. Therefore, emphasis should be on characterizing releases from the surface impoundments.

Emission modeling is not available for all air-related phenomenon associated with waste management. For example, anaerobic biological activity in surface

impoundments may, in certain instances, contribute to air pollution by emitting constituents not contained in the waste placed in the impoundment and which available models do not adequately address. In such instances, source testing or monitoring may be necessary; based on such monitoring, emission rates can be developed.

#### **12.4.2 Model Selection**

The information gathered during the initial stage of the air investigation should be used to select appropriate models and to estimate unit-specific and constituent-specific emission rates. A thorough understanding of the available models is needed before selecting a model for an atypical emission source. When gathering information on any emission source, it would be useful to obtain a perspective of the potential variability of the waste and unit input data. A sensitivity analysis of this variability relevant to emission rate estimates would help determine the level of confidence associated with the emission modeling results.

Air emission models can be classified into two categories; models which can be used to estimate volatile organic releases, and models which can be used to estimate particulate emissions. These are discussed below.

##### **12.4.2.1 Organic Emissions**

Comprehensive guidance on the application of air emission models for volatile organic releases from various units is presented in the following references:

U.S. EPA. December 1987. Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF) - Air Emission Models. EPA-450/3-87-026. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

U.S. EPA. December 1988 Draft. Procedures for Conducting Air Pathway Analyses for Superfund Applications. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

These references provide modeling guidance for the following units:

- Surface impoundments
  - Storage impoundments
  - Disposal impoundments
  - Mechanically aerated impoundments
  - Diffused air systems
  - Oil film surfaces
- Land treatment
  - Waste application
  - Oil film surfaces
  - Tilling
- Landfills
  - Closed landfills
  - Fixation pits
  - Open landfills
- Waste piles
- Transfer, storage and handling operations
  - Container loading
  - Container storage
  - Container cleaning
  - Stationary tank loading
  - Stationary tank storage
  - Spills
  - Fugitive emissions
  - Vacuum truck loading

Emission factors for various evaporation loss sources (e.g., storage and handling of organic liquids) are provided in the following reference:

U.S. EPA. 1985. (Fourth edition and subsequent supplements) Compilation of Air Pollutant Emission Factors. EPA AP-42. NTIS PB 86-124906. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

An emission factor is generally defined as an average value which relates the quantity of a pollutant released to the atmosphere with the activity associated with the release of the pollutant. However, for estimation of organic releases from storage tanks, the emission factors are presented in terms of empirical formulae which can relate emissions to such variables as tank diameter, liquid temperature, etc.

Selection of an appropriate air emission model will be based primarily on selection of a model which is appropriate for the unit of concern, has technical credibility and is practical to use. Some of the models presented in Hazardous Waste Treatment, Storage and Disposal Facilities (TSDf) - Air Emission Models (U.S. EPA, December 1987), are available on a diskette for use on a microcomputer. Computer-compatible air emission models (referred to as CHEMDAT6 models) are available for the following sources.

- Nonaerated impoundments
- Open tanks
- Aerated impoundments
- Land treatment
- Landfills

These models are prime candidates for RFI air release characterization applications.

#### 12.4.2.2 Particulate Emissions

Guidance on the selection and application of air emission models for particulate releases is presented in the following references:

U.S. EPA. February 1985. Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites. EPA/600-18-85/002. Office of Health and Environmental Research. Washington, D.C. 20460.

U.S. EPA. 1985. (Fourth edition and subsequent supplements) Compilation of Air Pollutant Emission Factors. EPA, AP-42. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

U.S. EPA. 1978. Fugitive Emissions from Integrated Iron and Steel Plants. EPA 600/2-78-050. Washington, D.C. 20460.

U.S. EPA. December 1988 Draft. Procedures for Conducting Air Pathway Analysis for Superfund Applications. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

These references provide modeling guidance for the following particulate sources and associated operations and activities (e.g., vehicular traffic):

- Wastepiles
- Flat, open surfaces

The air emission models for both types of sources should account for both wind erosion potential as well as releases due to mechanical disturbances.

The U.S. EPA-Office of Air Quality Planning and Standards is currently developing guidance regarding particulate emissions from hazardous waste transfer, storage and disposal facilities.

#### **12.4.3 General Modeling Considerations**

Organics in surface impoundments, land treatment facilities, landfills, and wastepiles, can depart through a variety of pathways, including volatilization, biological decomposition, adsorption, photochemical reaction, and hydrolysis. To allow reasonable estimates of organic disappearance, it is necessary to determine which pathways predominate for a given chemical, type of unit, and set of meteorological conditions.

Source variability will significantly influence the relative importance of the pathways. For highly variable sources it may be possible to exclude insignificantly small pathways from consideration. The relative magnitude of these pathways then



can be computed by applying the methodology to a model facility to determine relative differences among various compounds. A summary of typical pathways for air emission sources is presented in Table 12-7.

It is also necessary to consider the variation of waste composition as a function of time as well as other potential variations in source conditions. These variable conditions may necessitate multiple modeling scenarios to adequately characterize representative waste/unit conditions.

## **12.5 Dispersion Modeling**

### **12.5.1 Modeling Applications**

Atmospheric dispersion models can be used to estimate constituent-specific concentrations at locations of interest based on input emission rate and meteorological input data. The major RFI dispersion modeling applications for characterizing releases to air can be summarized as follows:

- **Screening assessments:** Dispersion models can be used to estimate concentrations at locations of interest using input emission rate data based on air emission modeling.
- **Emission monitoring:** Dispersion models can be used to estimate concentrations at locations of interest using input emission rate data based on emission rate monitoring.
- **Confirmatory air monitoring:** Dispersion modeling can be used to assist in designing an air monitoring program (i.e., to determine appropriate monitoring locations and monitoring period) as well as for interpretation and extrapolation of monitoring results.

Atmospheric dispersion models can be used for monitoring program design applications to identify areas of high concentration relative to the facility property boundary or actual receptor locations. High concentration areas which correspond to actual receptors are priority locations for air monitoring stations.

**TABLE 12-7**

**TYPICAL PATHWAYS FOR AREA EMISSION SOURCES<sup>a</sup>**

Pathway	Surface Impoundments	Land Treatment	Landfill
Volatilization	I	I	I
Biodegradation	I	I	S
Photodecomposition	S	N	N
Hydrolysis	S	N	N
Oxidation/reduction	N	N	N
Adsorption	N	N	N
Hydroxyl radical reaction	N	N	N
Migration <sup>b</sup>	N	N	N
Runoff <sup>b</sup>	N	N	N

I = Important

S = Secondary

N = Negligible or not applicable

<sup>a</sup> Individual chemicals in a given site type may have dominant pathways different from the ones shown here.

<sup>b</sup> Water migration and runoff are considered to have negligible effects on ground and surface water in a properly sited, operated, and maintained RCRA-permitted hazardous waste treatment, storage, and disposal facility.

Dispersion models (with input emission rates based on emission models) can also be used to provide seasonal air concentration "patterns" based on available representative historical meteorological data (either onsite or offsite). Comparison of seasonal air concentration patterns can be used to identify the "reasonable worst case" period for monitoring. Air concentration patterns based on modeling results can similarly be used to evaluate the representativeness of the actual data collection period. Representativeness is determined by comparing the air concentration patterns for the actual air monitoring period with historic seasonal air concentration patterns.

The objective of the modeling applications discussed above involves the estimation of long-term (i.e., several months to years) concentration patterns. These long-term patterns do not have the variability associated with short-term (i.e., hours to days, such as a 24-hour event) emission rate and dispersion conditions, and are more conducive to data extrapolation applications. For example, near source and fence line air monitoring results can be used to back calculate an emission rate for the source. This estimated emission rate can be used as dispersion modeling input to estimate offsite air concentrations for the same downwind sector and exposure period as for the air monitoring period.

## **12.5.2 Model Selection**

Guidance on the selection and application of dispersion models is provided in the following references:

U.S. EPA. July 1986. Guidelines on Air Quality Models (Revised). EPA-450/12-78-027R. NTIS PB86-245248. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

U.S. EPA. December 1988 Draft. Procedures for Conducting Air Pathway Analyses for Superfund Applications. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

The following information is based primarily on guidance provided in these references.

### 12.5.2.1 Suitability of Models

The extent to which a specific air quality model is suitable for the evaluation of source impact depends upon several factors. These include: (1) the meteorological and topographic complexities of the area; (2) the level of detail and accuracy needed for the analysis; (3) the technical competence of those undertaking such simulation modeling; (4) the resources available; and (5) the detail and accuracy of the data base, i.e., emissions inventory, meteorological data, and air quality data. Appropriate data should be available before any attempt is made to apply a model. A model that requires detailed, precise, input data should not be used when such data are unavailable. However, assuming the data are adequate, the greater the detail with which a model considers the spatial and temporal variations in emissions and meteorological conditions, the greater the ability to evaluate the source impact and to distinguish the effects of various control strategies.

Air quality models have been applied with the most accuracy or the least degree of uncertainty to simulations of long term averages in areas with relatively simple topography. Areas subject to major topographic influences experience meteorological complexities that are extremely difficult to simulate. Although models are available for such circumstances, they are frequently site-specific and resource intensive. In the absence of a model capable of simulating such complexities, only a preliminary approximation may be feasible until such time as better models and data bases become available.

Models are highly specialized tools. Competent and experienced personnel are an essential prerequisite to the successful application of simulation models. The need for specialists is critical when the more sophisticated models are used or the area being investigated has complicated meteorological or topographic features. A model applied improperly, or with inappropriately chosen data, can lead to serious misjudgments regarding the source impact or the effectiveness of a control strategy.

The resource demands generated by use of air quality models vary widely depending on the specific application. The resources required depend on the nature of the model and its complexity, the detail of the data base, the difficulty of

the application, and the amount and level of expertise required. The costs of manpower and computational facilities may also be important factors in the selection and use of a model for a specific analysis. However, it should be recognized that under some sets of physical circumstances and accuracy requirements, no present model may be appropriate. Thus, consideration of these factors should not lead to selection of an inappropriate model.

#### 12.5.2.2 Classes of Models

Dispersion models can be categorized into four generic classes: Gaussian, numerical, statistical or empirical, and physical. Within these classes, especially Gaussian and numerical models, a large number of individual "computational algorithms" may exist, each with its own specific applications. While each of the algorithms may have the same generic basis, e.g., Gaussian, it is accepted practice to refer to them individually as models. In many cases the only real difference between models within the different classes is the degree of detail considered in the input or output data.

Gaussian models are the most widely used techniques for estimating the impact of nonreactive pollutants. Numerical models may be more appropriate than Gaussian models for area source urban applications that involve reactive pollutants, but they require much more extensive input data bases and resources and therefore are not as widely applied. Statistical or empirical techniques are frequently employed in situations where incomplete scientific understanding of the physical and chemical processes or lack of the required data bases make the use of a Gaussian or numerical model impractical.

Physical modeling, the fourth generic type, involves the use of wind tunnel or other fluid modeling facilities. This class of modeling is a complex process requiring a high level of technical expertise, as well as access to the necessary facilities. Nevertheless, physical modeling may be useful for complex flow situations, such as building, terrain or stack down-wash conditions, plume impact on elevated terrain, diffusion in an urban environment, or diffusion in complex terrain. It is particularly applicable to such situations for a source or group of sources in a geographic area limited to a few square kilometers. The publication "Guideline for Fluid Modeling

of Atmospheric Diffusion" provides information on fluid modeling applications and the limitations of that method (U.S. EPA, 1981).

#### 12.5.2.3 Levels of Sophistication of Models

In addition to the various classes of models, there are two levels of sophistication. The first level consists of general, relatively simple estimation techniques that provide conservative estimates of the air quality impact of a specific source, or source category. These are screening techniques or screening models. The purpose of such techniques is to eliminate the need for further more detailed modeling for those sources that clearly can be characterized and evaluated based on simple screening assessments.

The second level consists of those analytical techniques that provide more detailed treatment of physical and chemical atmospheric processes, require more detailed and precise input data, and provide more specialized concentration estimates. As a result they provide a more refined and, at least theoretically, a more accurate estimate of source impact and the effectiveness of control strategies. These are referred to as refined models.

The use of screening techniques followed by a more refined analysis is always desirable, however, there are situations where the screening techniques are practically and technically the only viable option for estimating source impact. In such cases, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

#### 12.5.2.4 Preferred Models

Guidance on EPA preferred models for screening and refined applications is provided in the following references:

U.S. EPA. July 1986. Guidelines on Air Quality Models (Revised). EPA-450/2-78-027R. NTIS PB86-245248. Office of Air Quality Planning and Standards. Research Triangle Park, N.C. 27711.

U.S. EPA. October 1977. Guidelines for Air Quality Maintenance Planning and Analysis. Vol. 10 (Revised): Procedures for Evaluating Air Quality Impact of New Stationary Sources. EPA-450/4-77-001. NTIS PB274-087. Office of Air Quality Planning and Standards. Research Triangle Park, N.C. 27711.

U.S. EPA. December 1988 Draft. Procedures for Conducting Air Pathway Analyses for Superfund Applications. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

Appropriate dispersion models commensurate with the above guidance and suitable for mainframe computer use are included in the UNAMAP series available from NTIS. Versions of the UNAMAP models suitable for use on a microcomputer are also available from commercial sources.

Alternative screening approaches based on hand calculations are available for point sources located in flat terrain based on the following guidance:

Turner, D.B. 1969. Workbook of Atmospheric Dispersion Estimates. Public Health Service. Cincinnati, OH.

U.S. EPA. March 1988 Draft. A Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

Preferred models for selected applications in simple terrain are identified in Table 12-8. Appropriate dispersion models for complex terrain applications generally need to be determined on a case-by-case basis. Acceptable models may not be available for many complex terrain applications.

The use of the Industrial Source Complex (ISC) Model is recommended as a prime candidate for RFI atmospheric dispersion modeling applications. Applicable ISC source types include stack area and volume sources. Concentration estimates can be based on times of as short as one hour and as long as one year. The model can be used for both flat and rolling terrain. The ISC model can also account for atmospheric deposition (i.e., inter-media transport to soil). The ISC Model (See EPA

TABLE 12-8

## PREFERRED MODELS FOR SELECTED APPLICATIONS IN SIMPLE TERRAIN

Short Term (1-24 hours)	Land Use	Model*
Single Source	Rural Urban	CRSTER RAM
Multiple Source	Rural Urban	MPTER RAM
Complicated Sources**	Rural/Urban	ISC*
Buoyant Industrial Line Sources	Rural	BLP
Long Term (monthly, seasonal or annual)		
Single Source	Rural Urban	CRSTER RAM
Multiple Source	Rural Urban	MPTER CDM 2.0 or RAM***
Complicated Sources**	Rural/Urban	ISC*
Buoyant Industrial Line Sources	Rural	BLP

\* The long-term version of ISC (i.e., ISCLT) is recommended as the preferred dispersion model for RFI applications.

\*\* Complicated sources are sources with special problems such as aerodynamic downwash, particle deposition, volume and area sources, etc.

\*\*\*If only a few sources in an urban area are to be modeled, RAM should be used.



450/4-86-005a and b) is included in the UNAMAP series available through the NTIS (U.S. EPA, June 1986).

Additional guidance on dispersion model selection and application is available from EPA Regional Office and State modeling representatives as well as from the EPA Model Clearinghouse.

If other than preferred models are selected for use, early discussions with the regulatory agency is encouraged. Agreement on the data base to be used, modeling techniques to be applied and the overall technical approach, prior to the actual analyses, helps avoid misunderstandings concerning the final results and may reduce the later need for additional analyses. The preparation (and submittal to the appropriate regulatory agency) of a written modeling protocol is recommended for all RFI atmospheric dispersion modeling applications.

### **12.5.3 General Modeling Considerations**

Dispersion modeling results are limited by the amount, quality and representativeness of the input data. In addition to meteorological and source data modeling input, the following are also important modeling factors:

- Location of facility property boundary
- Dispersion coefficients
- Stability categories
- Plume rise
- Chemical transformation
- Gravitational settling and deposition
- Urban/rural classification

In designing a computational network for modeling, the emphasis should be placed on location with respect to the facility property boundary. The selection of sites should be a case-by-case determination taking into consideration the topography, the climatology, monitor sites, and should be based on the results of the initial screening procedure. Additional locations may be needed in the high concentration location if greater resolution is indicated by terrain or source factors.

Gaussian models used in most applications should employ dispersion coefficients consistent with those contained in the preferred models available in UNAMAP. Factors such as averaging time, urban/rural surroundings, and type of source (point vs. line) may dictate the selection of specific coefficients.

The Pasquill approach to classifying stability is generally required in all preferred models. The Pasquill method, as modified by Turner, was developed for use with commonly observed meteorological data from the National Weather Service (NWS) and is based on cloud cover, insolation and wind speed.

Procedures to determine Pasquill stability categories from other than NWS data are presented in Guidelines on Air Quality Models (Revised) (U.S. EPA, July 1986). Any other method to determine Pasquill stability categories should be justified on a case-by-case basis.

The plume rise methods incorporated in the EPA preferred models are recommended for use in all modeling applications. No provisions in these models are made for fumigation or multi-stack plume rise enhancement or the handling of such special plumes as flares; these problems should be considered on a case-by-case basis.

Where aerodynamic downwash occurs due to the adverse influence of nearby structures, the algorithms included in the ISC model should be used.

Use of models incorporating complex chemical mechanisms should be considered only on a case-by-case basis with proper demonstration of applicability. These are generally regional models not designed for the evaluation of individual sources but used primarily for region-wide evaluations.

An "infinite half-life" should be used for estimates of total suspended particulate concentrations when Gaussian models containing only exponential decay terms for treating settling and deposition are used. Gravitational settling and deposition may be directly included in a model if either is a significant factor. At least one preferred model (ISC) contains settling and deposition algorithms and is recommended for use when particulate matter sources can be quantified and settling and deposition are problems.

The selection of either rural or urban dispersion coefficients in a specific application should follow one of the procedures presented in Guidelines on Air Quality Models (Revised) (U.S. EPA, July 1986). These include a land use classification procedure or a population based procedure to determine whether the character of an area is primarily urban or rural.

## **12.6 Design of a Monitoring Program to Characterize Releases**

Monitoring procedures should be developed based on the information previously described, including determination of reasonable worst-case scenarios as discussed above. This section discusses the recommended monitoring approaches.

Primary elements in designing a monitoring system include:

- Establishing monitoring objectives;
- Determining monitoring constituents of concern;
- Monitoring schedule;
- Monitoring approach; and
- Monitoring locations.

Each of these elements should be addressed to meet the objectives of the initial monitoring phase, and any subsequent monitoring that may be necessary. These elements are described in detail below.

### **12.6.1 Objectives of the Monitoring Program**

The primary goal of the air investigation is to determine concentrations at the facility property boundary as input to the health and environmental assessment process. As discussed previously, the monitoring program may be conducted in a phased approach, using the results of initial monitoring and/or modeling to determine the need for and scope of subsequent monitoring.

Principal components of both the initial and subsequent monitoring phases are:

- Identification or verification of constituents;
- Characterization of long-term air constituent concentrations (based on a "reasonable worst case" exposure period) at:
  - the unit boundary to maximize the potential for release detection
  - the facility property boundary
  - actual offsite receptor locations (for determining the need for interim corrective measures)
  - areas upwind of the release source (to characterize background concentrations); and
- Collection of meteorological data during the monitoring period to aid in evaluating the air monitoring data.

Atmospheric dispersion modeling may also be used to estimate concentrations, if monitoring is not practical, as discussed previously.

Subsequent monitoring may be necessary if initial monitoring and modeling data were not sufficient to characterize long-term ambient constituent concentrations.

#### **12.6.2 Monitoring Constituents and Sampling Considerations**

Sampling and analysis may be conducted for all appropriate Appendix VIII constituents that have an air pathway potential (See Section 3 and Appendix B). An alternative approach is to use unit and waste-specific information to identify constituents that are not expected to be present and thus, reduce the list of target monitoring constituents. For example, the industry specific monitoring constituent lists presented in Appendix B, List 4 can be used to identify appropriate air monitoring constituents for many applications (especially for units that serve only a limited number of industrial categories). The target constituents selected should be

limited to those which may be present in the waste and have health criteria for the air pathway (see Section 8).

Results from screening assessment, emission monitoring, and/or screening sampling phase (as defined later in Section 12.6.4.1) may also be used as a basis for selection of monitoring constituents. These results may confirm/identify appropriate monitoring constituents for the unit of concern.

### **12.6.3 Meteorological Monitoring**

Monitoring of onsite meteorological conditions should be performed in concert with other emission rate and air monitoring activities. Meteorological monitoring results can serve as input for dispersion models, can be used to assure that the air monitoring effort is conducted during the appropriate meteorological conditions (e.g., "reasonable worst case" period for initial monitoring), and to aid in the interpretation of air monitoring data.

#### **12.6.3.1 Meteorological Monitoring Parameters**

The following meteorological parameters should be routinely monitored while collecting ambient air samples:

- Horizontal wind speed and direction;
- Ambient temperature;
- Atmospheric stability (e.g., based on the standard deviation of horizontal wind direction or alternative standard methodologies);
- Precipitation measurements if representative National Weather Service data are not available; and
- Atmospheric pressure (e.g., for landfill sites or contaminated soils) if representative National Weather Service data are not available.

It is recommended that horizontal wind speed and direction, and air temperature be determined onsite with continuous recording equipment. Estimates from offsite monitors are not likely to be representative for all of the conditions at the site. Input parameters for dispersion models, if appropriate, should be reviewed prior to conducting the meteorological data collection phase to ensure that all necessary parameters are included.

Field equipment used to collect meteorological data can range in sophistication from small, portable, battery-operated units with wind speed and direction sensors, to large, permanently mounted, multiple sensor units at varying heights. Individual sensors can collect data on horizontal wind speed and direction, three-dimensional wind speed, air temperature, humidity, dew point, and mixing height. From such data, variables for dispersion models such as wind variability and atmospheric stability can be determined. Additional guidance on meteorological measurements can be obtained from:

U.S. EPA. June 1987. On-Site Meteorological Program Guidance for Regulatory Modeling Applications. EPA-450/4-87-013. Office of Air Quality Planning and Standards. Research Triangle Park, N.C. 27711.

U.S. EPA. February 1983. Quality Assurance handbook for Air Pollution Measurements Systems: Volume IV. Meteorological Measurements. EPA-600/4-82-060. Office of Research and Development. Research Triangle Park, N.C. 27711.

U.S. EPA. July 1986. Guidelines on Air Quality Models (Revised). EPA-405/2-78-027R. NTIS PB 86-245248. Office of Air Quality Planning and Standards. Research Triangle Park, N.C. 27711.

Appropriate performance specifications for monitoring equipment are given in the following document:

U.S. EPA. November 1980. Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD). EPA-450/4-80/012. NTIS PB 81-153231. Office of Air Quality Planning and Standards. Research Triangle Park, N.C. 27711.

### 12.6.3.2 Meteorological Monitor Siting

Careful placement of meteorological monitoring equipment (e.g., sensors) is important in gathering relevant data. The objective of monitoring tower placement is to position sensors to obtain measurements representative of the conditions that determine atmospheric dispersion in the area of interest. The convention for placement of meteorological monitoring equipment is:

- At or above a height of 10 meters above ground; and
- At a horizontal distance of 10 times the obstruction height from any upwind obstructions.

In addition, the recommendations given in Table 12-9 should be followed to avoid effects of terrain on meteorological monitors.

Depending on the complexity of the terrain in the area of interest and the parameters being measured, more than one tower location may be necessary. Complex terrain can greatly influence the transport and diffusion of a contaminant release to air so that one tower may not be able to account for these influences. The monitoring station height may also vary depending on source characteristics and logistics. Heights should be selected to minimize near-ground effects that are not representative of conditions in the atmospheric layer into which a constituent of concern is being released.

A tower designed specifically to mount meteorological instruments should be used. Instruments should be mounted on booms projecting horizontally out from the tower at a minimum distance of twice the tower diameter. Sound engineering practice should be used to assure tower integrity during all meteorologic conditions.

Further guidance on siting meteorological instruments and stations is available in the following publications:

**TABLE 12-9**  
**RECOMMENDED SITING CRITERIA TO AVOID TERRAIN EFFECTS**

Distance from Tower (meters)	Maximum Acceptable Construction or Vegetation Height (meters)
0 - 15	0.3
15 - 30	0.5 - 1.0
30 - 100	3
100 - 300	10



U.S. EPA. November 1980. Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD). EPA-450/4-80-012. NTIS PB 81-153231. Office of Air Quality Planning and Standards. Research Triangle Park, N.C. 27711.

U.S. EPA. June 1987. On-Site Meteorological Program Guidance for Regulatory Modeling Applications. EPA-450/4-87-013. Office of Air Quality Planning and Standards. Research Triangle Park, N.C. 27711.

U.S. EPA. February 1983. Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV. Meteorological Measurements. EPA-600/4-82-060. Office of Research and Development. Research Triangle Park, N.C. 27711.

#### **12.6.4 Monitoring Schedule**

Establishment of a monitoring schedule is an important consideration in developing a monitoring plan. When appropriate, air monitoring should coincide with monitoring of other media (e.g., subsurface gas, soils, and surface water) that have the potential for air emissions. As with all other aspects of the monitoring program, the objectives of monitoring should be considered in establishing a schedule. As indicated previously, monitoring generally consists of screening sampling, emission monitoring, and air monitoring. The monitoring schedule during each of these phases is discussed below.

##### **12.6.4.1 Screening Sampling**

A limited screening sampling effort may be necessary to focus the design of additional monitoring phases. Therefore, screening samples may be warranted during the screening assessment or prior to initiating emission monitoring or air monitoring studies. This screening phase can also be used to supplement modeling and emission monitoring results as available, to verify the existence of a release to air, and to prioritize the major release sources at the facility.

Screening sampling should be used to characterize air emissions (e.g., by using total hydrocarbon measurements as an indicator), and to confirm/identify the presence of candidate constituents. Screening samples should generally consist of

source emissions measurements or ambient air samples collected at or in close proximity to the source. This approach will provide the best opportunity for detection of air emission constituents. (A discussion of available screening methods is presented in Section 12.8.) An alternative screening approach involves collection of a limited number of air samples to facilitate the analysis of a wide range of constituents (e.g., collection via Tenax adsorption tubes or whole air sampling with analysis by GC/MS - see Section 12.8).

The screening study should generally involve collection of a limited number of grab or time-integrated samples (several minutes to 24 hours) for a limited time period (e.g., one to five days). Sampling should be conducted during emission/dispersion conditions that are expected to result in relatively high concentrations, as discussed previously. Screening results should be interpreted considering the representativeness of the waste and unit operations during the sampling, and the detection capabilities of the screening methodology used.

#### 12.6.4.2 Emission Monitoring

Emission rate monitoring may be necessary to characterize a release if screening assessment results are not conclusive. This approach involves stack or vent emission monitoring for point sources. Point source monitoring is not dependent on meteorological conditions. However, emission rate monitoring for both point and area sources should be conducted during typical or "reasonable worst case" emission rate conditions. Therefore, emission monitoring should be conducted when source conditions (e.g., unit operations and waste concentrations) as well as meteorological conditions are conducive to "reasonable worst case" emission rate conditions. Emission rate monitoring for area sources should not be conducted during or immediately following precipitation or if hourly average wind speeds are greater than 15 miles per hour. It should also be noted that soil or cover material (if present) should be allowed to dry prior to continuing monitoring operations, as volatilization decreases under saturated soil conditions. In these cases, the monitoring should be interrupted and resumed as soon as possible after the unfavorable conditions pass. Similarly, operational interruptions such as unit shutdown should also be factored into the source sampling schedule.

Point source emission sampling generally requires only a few hours of sampling and occurs during a more limited time (e.g., one to three days). Guidance on point-source sampling schedules is presented in the following:

U.S. EPA. November 1985. Practical Guide - Trial Burns for Hazardous Waste Incinerators. NTIS PB 86-190246. Office of Research and Development. Cincinnati, OH 45268.

U.S. EPA. Code of Federal Regulations. 40 CFR Part 60: Appendix A: Reference Methods. Office of the Federal Register. Washington, D.C.

U.S. EPA. 1978. Stack Sampling Technical Information, A Collection of Monographs and Papers, Volumes I-III. EPA-450/2-78-042a,b,c. NTIS PB 80-161672, 80-161680, 80-161698. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

U.S. EPA. February 1985. Modified Method 5 Train and Source Assessment Sampling System Operators Manual. EPA-600/8-85-003. NTIS PB 85-169878. Office of Research and Development. Research Triangle Park, NC 27711.

U.S. EPA. March 1984. Protocol for the Collection and Analysis of Volatile POHCs Using VOST. EPA-600/8-84-007. NTIS PB 84-170042. Office of Research and Development. Research Triangle Park, NC 27711.

U.S. EPA. February 1984. Sampling and Analysis Methods for Hazardous Waste Combustion. EPA-600/8-84-002. NTIS PB 84-155845. Washington, D.C. 20460.

U.S. EPA. 1981. Source Sampling and Analysis of Gaseous Pollutants. EPA-APTI Course Manual 468. Air Pollution Control Institute. Research Triangle Park, NC 27711.

U.S. EPA. 1979. Source Sampling for Particulate Pollutants. EPA-APTI Course Manual 450. NTIS PB 80-188840, 80-182439, 80-174360. Air Pollution Control Institute. Research Triangle Park, NC 27711.

U.S. EPA. 1986. Test Methods for Evaluating Solid Waste. 3rd Edition. Office of Solid Waste. EPA/SW-846. GPO No. 955-001-00000-1. Washington, D.C. 20460.

Emission rate monitoring should be conducted during a 1 to 3 day period representative of "reasonable worst case" source emission conditions. The worst case short-term emission rate conditions should be determined by parametric analyses (i.e., by modeling a wide range of source operational conditions and associated waste concentrations as well as meteorological conditions for parameters such as wind speed and temperature). Historical meteorological data representative of the site should be reviewed to determine the season and time of day associated with worst case emission conditions. These results should be used to select and schedule (along with meteorological forecasts for local conditions and expected source operational and waste concentration) the emission monitoring period.

Emission rate monitoring results based on measurements during worst-case conditions should be initially used as dispersion modeling input. If these initial results exceed health criteria then the emission monitoring results should be scaled to represent long term (i.e., annual) conditions. The scaling factor should be based on the ratio of emission rate modeling results (using meteorological conditions during the monitoring period as input) compared to modeling results based on typical (annual) meteorological conditions.

Guidance on area source emission rate monitoring is provided in the following:

U.S. EPA. 1986. Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber: User's Guide. EPA/600/8-86/008. NTIS PB86-223161. Environmental Monitoring Systems Laboratory. Las Vegas, NV 89114.

U.S. EPA. December 1988 Draft. Procedures for Conducting Air Pathway Analyses for Superfund Applications. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

The primary objective of confirmatory monitoring is to characterize long-term exposures that may be associated with air emissions from the unit under reasonable worst-case conditions. A schedule should be proposed that will provide an adequate degree of confidence that those compounds that may be released will be detected (i.e., by sampling during the season associated with the highest air concentrations as determined based on modeling). Laboratory analytical costs typically range from \$200 to over \$1,000 per air monitoring station for one 24-hour integrated sample (the actual cost depends on the number and type of target constituents). Recent advances in applied technology have facilitated the use of field gas chromatographs (GCs) to automatically obtain analytical results for many organics (i.e., offsite laboratory analyses may not be necessary for some air monitoring programs). The cost for this equipment typically range from \$20,000 to over \$50,000 and one GC can generally service multiple sampling stations.

An example sampling schedule (e.g., for flat terrain sites with minimal variability of dispersion and source conditions) for meeting this objective is given below:

- Meteorological monitoring - 90 days continuous monitoring.
- Initial air monitoring (Alternative 1) -90 days:
  - Analysis of 24-hour time integrated samples for target constituents every day during the 90-day period (total of 90 samples)
- Additional monitoring - as necessary to supplement initial air monitoring results in order to adequately characterize the release.

The 90-day monitoring program will facilitate collecting samples over a wide range of emission and dispersion conditions. The 90-day period should be selected, as previously discussed, to coincide with the expected season of highest ambient concentrations. Meteorological monitoring should be continuous and concurrent with this 90-day period to adequately characterize dispersion conditions at the site and to provide meteorological data to support interpretation of the air-quality monitoring data.

The collection of a time-integrated sample based on continuous monitoring for several days can result in technical difficulties (e.g., poor collection efficiencies for volatile constituents or large sample volumes). The application of five-day composite samples at each station, or intermittent sampling during the five days, results in continuous monitoring coverage during the 90-day period and facilitates the characterization of long-term exposure levels.

Although there are some limitations associated with composite/intermittent sampling (e.g., the potential for sample degradation), the 24-hour samples collected every sixth day will provide a second data set for characterizing ambient concentrations. Although the results of the two data sets should not be directly combined (because of the different sampling periods) they provide a comprehensive technical basis by which to evaluate long-term exposure conditions.

#### **12.6.4.4 Subsequent Monitoring**

Subsequent monitoring may be necessary if initial monitoring data were not sufficient to estimate "reasonable worst case" long-term concentrations (e.g., data recovery was not sufficient or additional monitoring stations are needed).

The same schedule specified for the initial monitoring phase is also applicable to subsequent monitoring. However, when evaluating the results of subsequent monitoring and comparing them to previously collected data, potential differences in emission/dispersion conditions and other data representativeness factors should be accounted for.

#### **12.6.5 Monitoring Approach**

The RFI air release characterization strategy may involve source emission monitoring and/or air monitoring. The strategy which defines the process for selection and application of these alternative monitoring approaches has been discussed previously. A summary of applicable air monitoring strategies related to source type is presented in Table 12-10.

**TABLE 12-10**  
**APPLICABLE AIR RELEASE SAMPLING STRATEGIES BY SOURCE TYPE**

Unit Type/Expected Emission	Air Release Sampling Strategy		
	Air Monitoring	Emissions Monitoring	
		Vent/Stack Sampling	Isolation Flux Chambers
<b>AREA SOURCES WITH LIQUID SURFACES</b>			
Surface Impoundments			
Vapor Phase	X		X
Particulates	X		
Open Roof Storage/Treatment Tanks			
Vapor Phase	X	X	X
<b>AREA SOURCES WITH SOLID SURFACES</b>			
Waste Piles			
Vapor Phase	X		X
Particulates	X		
Landfill Surface			
Vapor Phase	X		X
Particulates	X		
Land Treatment			
Vapor Phase	X		X
Particulates	X		
<b>POINT SOURCES</b>			
Vents from container Handling Units			
Vapor Phase	X	X	
Landfill Vents			
Vapor Phase	X	X	X
Storage/Treatment Tank Vents			
Vapor Phase	X	X	
Incinerators			
Vapor Phase	X	X	
Particulates	X	X	

#### 12.6.5.1 Source Emissions Monitoring

Monitoring at the source to measure a rate of emission for the constituents of concern may, in many cases, offer a practical approach to characterizing air emissions. Using this technique, the emission rate is then input into a mathematical dispersion model for estimation of downwind concentrations. Monitoring interferences from sources close to the unit are eliminated because the source is isolated from the ambient atmosphere for monitoring purposes. Source monitoring techniques are also advantageous because they do not require the level of sensitivity required by air monitors. Concentrations of airborne constituents at the source are generally higher than at downwind locations due to the lack of dispersion of the constituent over a wide area. The concentrations expected in the air (generally part-per-billion levels) may be at or near the limit of detectability of the methods used. Methods for source emissions monitoring for various constituent classes are discussed in Section 12.8.

Area sources (such as landfills, land treatment units, and surface impoundments) can be monitored using the isolation flux chamber approach. This method involves isolating a small area of contamination under a flux chamber, and passing a known amount of a zero hydrocarbon carrier gas through the chamber, thereby picking up any organic emissions in the effluent gas stream from the flux chamber. Samples of this effluent stream are collected in inert sampling containers, usually stainless steel canisters under vacuum, and removed to the laboratory for subsequent analysis. The analytical results of the identified analytes can be converted through a series of calculations to direct emission rates from the source. These emission rates can be used to evaluate downwind concentrations by application of dispersion models. Multiple emission tests should be conducted to account for temporal and spatial variability of source conditions. More information on use of the isolation flux chamber and test design is provided in the following references:

U.S. EPA. 1986. Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber: User's Guide. EPA/600/8-86/008. NTIS PB 86-223161. Washington, D.C. 20460.



U.S. EPA. December 1988 Draft. Procedures for Conducting Air Pathway Analyses for Superfund Applications. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

Some area source units may not be amenable to the source sampling approach, however. A unit in which the source cannot be isolated and viable measurements taken of the parameters of concern is one example. This includes active areas of landfills and land-treatment areas, as well as aerated surface impoundments. Also, area sources in which particulate emissions are of concern cannot be measured using an isolation flux chamber due to technical limitations in the technique. For these applications, only an upwind/downwind monitoring approach should be used.

#### 12.6.5.2 Air Monitoring

Use of an upwind/downwind network of monitors or sample collection devices is the primary air monitoring approach recommended to determine release and background concentrations of the constituents of concern. Upwind/downwind air monitoring networks provide concentrations of the constituents of concern at the point of monitoring, whether at the unit boundary, facility property boundary, or at a receptor point. The upwind/downwind approach involves the placement of monitors or sample collection devices at various points around the unit of concern. Each air sample collected is classified as upwind or downwind based on the wind conditions for the sampling period. Downwind concentrations are compared to those measured at upwind points to determine the relative contribution of the unit to air concentrations of toxic compounds. This is generally accomplished by subtracting the upwind concentration (which represents background conditions) from the concurrent downwind concentrations. Applicable field methods for air monitoring are discussed in Section 12.8 as well as in Procedures for Conducting Air Pathway Analyses for Superfund Applications (U.S. EPA, December 1988). Downwind air concentrations at the facility can be extrapolated to other locations by using dispersion modeling results. This is accomplished by obtaining initial modeling results based on meteorological conditions for the monitoring period and an arbitrary emission rate. These initial dispersion modeling results along with monitoring results at the site perimeter are used to back calculate an emission rate such that modeling results can be adjusted to be equivalent to monitoring results at

the onsite monitoring station. This estimated emission rate is then used as dispersion modeling input to predict offsite concentrations.

#### **12.6.6 Monitoring Locations**

As with other factors associated with air monitoring, siting of the monitors should reflect the primary objective of characterizing concentrations at the facility property boundary. This section discusses monitoring locations for both upwind/downwind approaches and source monitoring techniques.

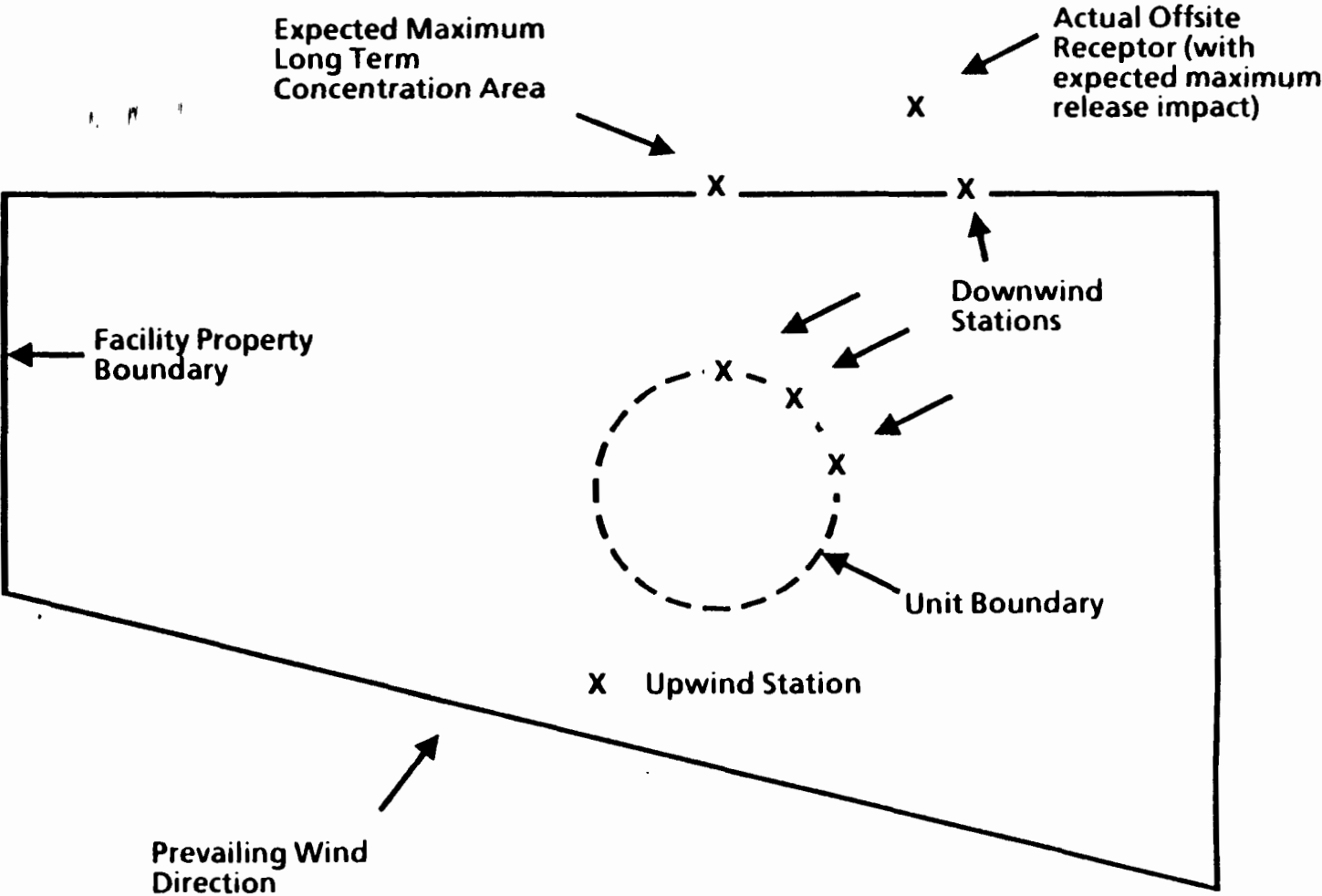
##### **12.6.6.1 Upwind/Downwind Monitoring Locations**

The air monitoring network design should provide adequate coverage to characterize both upwind (background) and downwind concentrations. Therefore, four air monitoring zones are generally necessary for initial monitoring. Multiple monitoring stations per zone will frequently be required to adequately characterize the release. An upwind zone is used to define background concentration levels. Downwind zones at the unit boundary, at the facility property boundary and beyond the facility property boundary, if appropriate, are used to define potential offsite exposure.

The location of air monitoring stations should be based on local wind patterns. Air monitoring stations should be placed at strategic locations, as illustrated in the following example (see Figure 12-6).

- Upwind (based on the expected prevailing wind flow during the 90-day monitoring period) of the unit and near the facility property boundary to characterize background air concentration levels. There should be no air emission source between the upwind monitoring station and the unit boundary.
- Downwind (based on the expected prevailing wind flow during the 90-day monitoring period) at the unit boundary plus stations at adjacent sectors also at the unit boundary (the separation distance of air monitoring stations at the unit boundary should be 30° or 50 feet, whichever is greater).

FIGURE 12-6. EXAMPLE AIR MONITORING NETWORK



- Downwind (based on the expected prevailing wind flow during the 90-day monitoring period) at the facility property boundary (this station may not be required if the site perimeter is within 100 meters of the unit boundary).
- Downwind (at the area expected to have the highest average concentration levels during the 90-day monitoring period) at the facility property boundary, if appropriate.
- Downwind at actual offsite receptor locations (if appropriate).
- Additional locations at complex terrain and coastal sites associated with pronounced secondary air flow paths (e.g., downwind of the unit near the facility property boundary for both primary daytime and nighttime flow paths).

The above locations should be selected prior to initial monitoring based on the onsite meteorological survey and on evaluation of available representative offsite meteorological data. This analysis should provide an estimate of expected wind conditions during the 90-day initial monitoring period. If sufficient representative data are available, dispersion modeling can be used to identify the area of maximum long term concentration levels at the facility property boundary and, if appropriate, at actual offsite receptors. If not, the facility property boundary sector nearest to the unit of concern should be selected for initial monitoring.

The network design defined above will provide an adequate basis to define long-term concentrations based on continuous monitoring during the 90-day initial monitoring period. The monitoring stations at the unit boundary should increase the potential for release detection. The facility property boundary air monitoring stations should provide data (with the aid of dispersion modeling, if appropriate) to perform health and environmental assessment, and if appropriate, characterize offsite concentrations.

Air monitoring at offsite receptors (if deemed to be appropriate) may be impractical in many cases, because analytical detection limits may not be low

enough at offsite receptor locations to measure the release. Also, a 90-day offsite monitoring program can be problematic. Factors such as vandalism, erroneous readings due to public tampering with the equipment, public relations problems in setting up the equipment, and legal access problems may preclude the use of offsite air monitoring stations. For these cases, dispersion models may be used to extrapolate monitoring data collected at the facility to actual offsite receptor locations. This is accomplished by obtaining initial modeling results based on meteorological conditions for the monitoring period and an arbitrary emission rate. These initial dispersion modeling results along with monitoring results at the site perimeter are used to back calculate an emission rate such that modeling results can be adjusted to be equivalent to monitoring results at the onsite monitoring station. This estimated emission rate is then used as dispersion modeling input to predict offsite concentrations for the same downwind sector and exposure period as for this monitoring period.

If additional monitoring is required, a similar network design to that illustrated in Figure 12-6 will generally be appropriate. Evaluation of the meteorological monitoring data collected during the initial phase should provide an improved basis to identify local prevailing and diurnal wind flow paths. Also, the site meteorological data will provide dispersion modeling input. These modeling results should provide dilution patterns that can be used to identify areas with expected relatively high concentration levels. However, these results should account for seasonal meteorological differences between initial and additional monitoring periods.

Wind-directionally controlled air monitoring stations can also be used at sites with highly variable wind directions. These wind-directionally controlled stations should be collocated with the fixed monitoring stations. This approach facilitates determination of the unit source contribution to total constituent levels in the local area. These automated stations will only sample for a user-defined range of wind directions (e.g., downwind stations would only sample if winds were blowing from the source towards the station). Interpretation of results from wind-directionally controlled air monitoring stations should account for the lower sampling volumes (and therefore, the possibility that not enough sample would be collected for analysis) generally associated with this approach.

The inlet exposure height of the air monitors should be 2 to 15 meters to be representative of potential inhalation exposure but not unduly biased by road dust and natural wind erosion phenomena. Further guidance on air monitoring network design and station exposure criteria (e.g., sampling height and proximity to structures and air emission sources) is provided in the following reference:

U.S. EPA. September 1984. Network Design and Site Exposure Criteria for Selected Non-criteria Air Pollutants. EPA-450/4-84-022. Office of Air Quality Planning and Standards. Research Triangle Park, N.C.

The above referenced document recommends the use of dispersion models to identify potential relatively high concentration areas as a basis for network design. This topic is also discussed in the following document:

U.S. EPA. July 1986. Guidelines on Air Quality Models (Revised). EPA-450/2-78-027R. NTIS PB 86-245248. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

Uniformity among the sampling sites should be achieved to the greatest degree possible. Descriptions should be prepared for all sampling sites. The description should include the type of ground surface, and the direction, distance, and approximate height with respect to the source of the release. Location should also be described on a facility map.

#### 12.6.6.2 Stack/Vent Emission Monitoring

Point source measurements should be taken in the vent. Both the VOST and Modified Method 5 methodologies describe the exact placement in the stack for the sampler inlet. (See Section 12.8.3). If warranted, an upwind/downwind monitoring network can be used to supplement the release rate data.

#### 12.6.6.3 Isolation Flux Chambers

Monitor placement using flux chambers (discussed earlier) is similar to conducting a characterization of any area source. Section 3 of this guidance discusses establishment of a grid network for sampling. Such a grid should be

established for an area source, with sampling points established within the grids, as appropriate. It is suggested that a minimum of six points be chosen for each monitoring effort. Once these areas are sampled, the results can be temporally and spatially averaged to provide an overall compound specific emission rate for the plot. Additional guidance on monitoring locations for isolation flux chambers is presented in Section 3.6 and in the following references:

U.S. EPA. 1986. Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber: User's Guide. EPA/600/8-86/008. NTIS PB86-223161. Environmental Monitoring Systems Laboratory. Las Vegas, NV 89114.

U.S. EPA. December 1988 Draft. Procedures for Conducting Air Pathway Analyses for Superfund Applications. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

## **12.7 Data Presentation**

As discussed in Section 5, progress reports will be required by the regulatory agency at periodic intervals during the investigation. The following data presentation formats are suggested for the various phases of the air investigation in order to adequately characterize concentrations at actual offsite receptors.

### **12.7.1 Waste and Unit Characterization**

Waste and unit characteristics should be presented as:

- Tables of waste constituents and concentrations;
- Tables of relevant physical/chemical properties for potential air emission constituents;
- Tables and narratives describing unit dimensions and special operating conditions and operating schedules concurrent with the air monitoring program;

- Narrative description of unit operations; and
- Identification of “reasonable worst case” emission conditions that occurred during the monitoring period.

#### **12.7.2 Environmental Setting Characterization**

Environmental characteristics should be presented as follows:

- Climate (historical summaries from available onsite and offsite sources):
  - Annual and monthly or seasonal wind roses;
  - Annual and monthly or seasonal tabular summaries of mean wind speeds and atmospheric stability distributions; and
  - Annual and monthly or seasonal tabular summaries of temperature and precipitation.
- Meteorological survey results:
  - Hourly listing of all meteorological parameters for the entire monitoring period;
  - Daytime wind rose (at coastal or complex terrain sites);
  - Nighttime wind rose (at coastal or complex terrain sites);
  - Summary wind rose for all hours;
  - Summary of dispersion conditions for the monitoring period (joint frequency distributions of wind direction versus wind speed category and stability class frequencies); and
  - Tabular summaries of means and extremes for temperature and other meteorological parameters.



- Definition of soil conditions (if appropriate):
  - Narrative of soil characteristics (e.g., temperature, porosity and organic matter content); and
  - Characterization of soil contamination conditions (e.g., in land treatment units, etc.).
- Definition of site-specific terrain and nearby receptors:
  - Topographic map of the site area with identification of the units, meteorological and air monitoring stations, and facility property boundary;
  - Topographic map of 10-kilometer radius from site (U.S. Geological Survey 7.5 minute quadrangle sheets are acceptable); and
  - Maps which indicate location of nearest residence for each of sixteen 22.5 degree sectors which correspond to major compass points (e.g., north, north-northwest, etc.), nearest population centers and sensitive receptors (e.g., schools, hospitals and nursing homes).
- Maps showing the topography of the area, location of the unit(s) of concern, and the location of meteorological monitoring equipment.
- A narrative description of the meteorological conditions during the air sampling periods, including qualitative descriptions of weather events and precipitation which are needed for data interpretation.

### **12.7.3 Characterization of the Release**

Characteristics of the release should be presented as follows:

- Screening sampling:

- Identification of sampling and analytical methodology;
  - Map which identifies sampling locations;
  - Listing of measured concentrations indicating collection time period and locations;
  - Prioritization of units as air release sources which warrant monitoring based on screening results;
  - Discussion of QA/QC results; and
  - Listing and discussion of meteorological data during the sampling period.
- Initial and additional monitoring results:
    - Identification of monitoring constituents;
    - Discussion of sampling and analytical methodology as well as equipment and specifications;
    - Identification of monitoring zones as defined in Section 12.6.6.1;
    - Map which identifies monitoring locations relative to units;
    - Discussion of QA/QC results;
    - Listing of concentrations measured by station and monitoring period indicating concentrations of all constituents for which monitoring was conducted. Listings should indicate detection limits if a constituent is not detected;
    - Summary tables of concentration measured indicating maximum and mean concentration values for each monitoring station;

- Discussion of meteorological station locations selection, sensor height, local terrain, nearby obstructions and equipment specifications;
- Listing of all meteorological parameters concurrent with the air sampling periods;
- Daytime wind rose (only for coastal or complex terrain areas);
- Nighttime wind rose (only for coastal or complex terrain areas);
- Summary wind rose based on all wind direction observations for the sampling period;
- Summary of dispersion conditions for the sampling period (joint frequency distributions of wind direction versus wind speed category and stability class frequencies based on guidance presented in Guidelines on Air Quality Models (Revised), (U.S. EPA, July 1986));
- Tabular summaries of means and extremes for temperature and other meteorological parameters;
- A narrative discussion of sampling results, indicating problems encountered, relationship of the sampling activity to unit operating conditions and meteorological conditions, sampling periods and times, background levels and identification of other air emission sources and interferences which may complicate data interpretation;
- Presentation and discussion of models used (if any), modeling input data and modeling output data (e.g., dilution or dispersion patterns based on modeling results); and

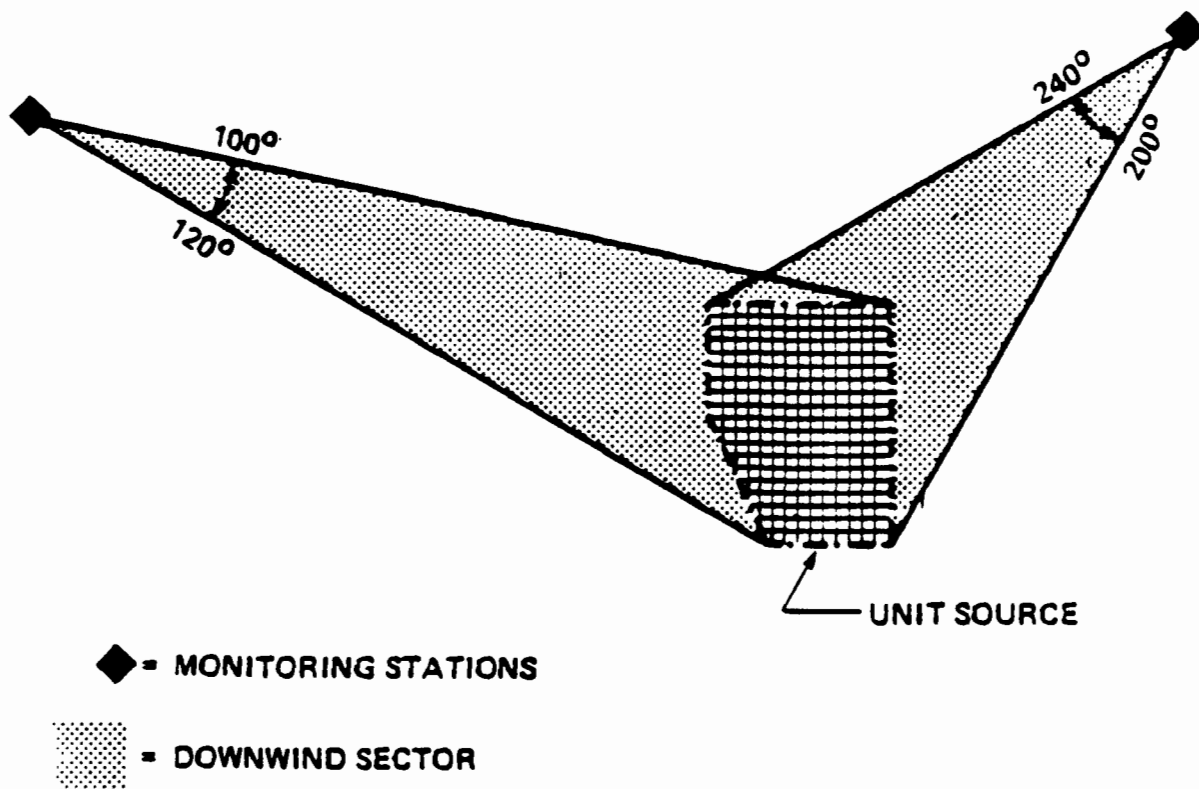
- Concentrations based on monitoring and/or modeling for actual offsite receptor locations.

Interpretation of air monitoring results should also account for additional factors such as complex terrain, variable winds, multiple contaminant sources and intermittent or irregular releases. The key to data interpretation for these cases is to evaluate monitoring results as a function of wind direction.

Terrain factors can alter wind flow trajectories especially during stable nighttime conditions. Therefore, straightline wind trajectories may not occur during these conditions if there is intervening terrain between the source and the air monitoring station. For these cases wind flows will be directed around large obstacles (such as hills) or channeled (for flows within valleys). Therefore, it is necessary to determine the representativeness of the data from the meteorological stations as a function of wind direction, wind speed and stability conditions. Based on this assessment, and results from the meteorological survey, upwind and downwind sectors (i.e., a range of wind direction as measured at the meteorological station) should be defined for each air monitoring station to aid in data interpretation. Figure 12-7 illustrates an example which classifies a range of wind directions during which the air monitoring stations will be downwind of an air emission source. Therefore, concentrations measured during upwind conditions can be used to characterize background conditions and concentrations measured during downwind conditions can be used to evaluate the air-quality impact of the release.

Complex terrain sites and coastal sites frequently have very pronounced diurnal wind patterns. Therefore, as previously discussed, the air monitoring network at these sites may involve coverage for multiple wind direction sectors and use of wind-directionally controlled air samplers. This monitoring approach is also appropriate for sites with highly variable wind conditions. Comparing results from two collocated air monitoring stations (i.e., one station which samples continuously and a second station at the same location which is wind-directionally controlled on an automated basis), facilitates determination of source contributions to ambient air concentrations.

FIGURE 12-7  
EXAMPLE OF DOWNWIND EXPOSURES AT AIR MONITORING STATIONS



Comparison of results from collocated (continuous versus wind-directionally controlled) air monitoring stations can also be used to assist in data interpretation at sites with multiple air emission sources or with intermittent/irregular releases. For some situations, the consistent appearance of certain air emission constituents can be used to "fingerprint" the source. Therefore, the air monitoring results can be classified based on these "fingerprint" patterns. These results can then be summarized as two separate data sets to assess background versus source contributions to ambient concentrations.

The use of collocated (continuous and wind-directionally controlled) air monitoring stations is a preferred approach to data interpretation for complex terrain, variable wind, multiple source and intermittent release sites. An alternative data interpretation approach involves reviewing the hourly meteorological data for each air sampling period. Based on this review, the results from each sampling period (generally a 24-hour period) for each station are classified in terms of downwind frequency. The downwind frequency is defined as the number of hours winds were blowing from the source towards the air monitoring station divided by the total number of hours in the sampling period. These data can then be processed (by plotting scattergrams) to determine the relationship of downwind frequency to measured concentrations.

Data interpretation should also take into account the potential for deposition, degradation and transformation of the monitoring constituents. These mechanisms can affect ambient concentrations as well as air sample chemistry (during storage). Therefore, standard technical references on chemical properties, as well as the monitoring guidance previously cited, should be consulted to determine the importance of degradation and transformation for the monitoring constituents of concern.

## **12.8 Field Methods**

This section describes field methods which can be used during initial or subsequent monitoring phases. Methods are classified according to source type and area. Guidance on meteorological monitoring methods is also provided in this section.

### 12.8.1 Meteorological Monitoring

Meteorological monitoring generally should employ a 10-meter tower equipped with wind direction, wind speed, temperature and atmospheric stability instrumentation. Wind direction and wind speed monitors should exhibit a starting threshold of less than 0.5 meters per second (m/s). Wind speed monitors should be accurate above the starting threshold to within 0.25 m/s at speeds less than or equal to 5 m/s. At higher speeds the error should not exceed 5 percent of the wind speed. Wind direction monitor errors should not exceed 5 degrees. Errors in temperature should not exceed 0.5°C during normal operating conditions.

The meteorological station should be installed at a location which is representative of overall site terrain and wind conditions. Multiple meteorological station locations may be required at coastal and complex terrain sites.

Additional guidance on equipment performance specifications, station location, sensor exposure criteria, and field methods for meteorological monitoring are provided in the following references:

U.S. EPA. February 1983. Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV, Meteorological Measurement. EPA-600-4-82-060. Office of Research and Development. Research Triangle Park, NC 27711.

U.S. EPA. November 1980. Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD). EPA-450/4-80-012. NTIS PB 81-153231. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

U.S. EPA. July 1986. Guidelines on Air Quality Models (Revised). EP-450/2-78-027R. NTIS PB 86-245248. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711.

### 12.8.2 Air Monitoring

Selection of methods for monitoring air contaminants should consider a number of factors, including the compounds to be detected, the purpose of the

method (e.g., screening or quantification), the detection limits, and sampling rates and duration required for the investigation.

Organic and inorganic constituents require different analytical methods. Within these two groups, different methods may also be required depending on the constituent and its physical/chemical properties. Another condition that affects the choice of monitoring technique is whether the compound is primarily in the gaseous phase or is found adsorbed to solid particles or aerosols.

Screening for the presence of air constituents involves techniques and equipment that are rapid, portable, and can provide "real-time" monitoring data. Air contamination screening will generally be used to confirm the presence of a release, or to establish the extent of contamination during the screening phase of the investigation. Quantification of individual components is not as important during screening as during initial and additional air monitoring, however the technique must have sufficient specificity to differentiate hazardous constituents of concern from potential interferences, even when the latter are present in higher concentrations. Detection limits for screening devices are often higher than for quantitative methods.

Laboratory analytical techniques must provide positive identification of the components, and accurate and precise measurement of concentrations. This generally means that preconcentration and/or storage of air samples will be required. Therefore, methods chosen for quantification usually involve a longer analytical time-period, more sophisticated equipment, and more rigorous quality assurance procedures.

The following list of references provides guidance on air monitoring methodologies:

U.S. EPA. June 1983. Technical Assistance Document for Sampling and Analysis of Toxic Organic Compounds in Ambient Air. EPA-600/4-83-027. NTIS PB 83-239020. Office of Research and Development. Research Triangle Park, NC 27711.



U.S. EPA. April 1984. Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air. EPA-600/4-84-041. Office of Research and Development. Research Triangle Park, NC 27711.

NIOSH. February 1984. NIOSH Manual of Analytical Methods. NTIS PB 85-179018. National Institute for Occupational Safety and Health. Cincinnati, OH.

U.S. EPA. September 1983. Characterization of Hazardous Waste Sites - A Methods Manual: Volume II, Available Sampling Methods. EPA-600/4-83-040. NTIS PB 84-126929. Office of Solid Waste. Washington, D.C. 20460.

U.S. EPA. September 1983. Characterization of Hazardous Waste Sites - A Methods Manual: Volume III, Available Laboratory Analytical Methods. EPA-600/4-83-040. NTIS PB 84-126929. Office of Solid Waste. Washington, D.C. 20460.

U.S. EPA. 1986. Test Methods for Evaluating Solid Waste. 3rd Edition. EPA SW-846. GPO No 955-001-00000-1. Office of Solid Waste. Washington, D.C. 20460.

ASTM. 1982. Toxic Materials in the Atmosphere. ASTM, STP 786. Philadelphia, PA.

ASTM. 1980. Sampling and Analysis of Toxic Organics in the Atmosphere. ASTM, STP 721. Philadelphia, PA.

ASTM. 1974. Instrumentation for Monitoring Air Quality. ASTM, STP 555. Philadelphia, PA.

APHA. 1977. Methods of Air Sampling and Analysis. American Public Health Association. Cincinnati, OH.

ACGIH. 1983. Air Sampling Instruments for Evaluation of Atmospheric Contaminants. American Conference of Governmental Industrial Hygienists. Washington, D.C.

U.S. EPA. December 1988 Draft. Procedures for Conducting Air Pathway Analyses for Superfund Applications. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711. -

#### 12.8.2.1 Screening Methods

Screening techniques for vapor-phase constituents fall into two main categories. (1) organic and non-organic compound-specific indicators, and (2) general organic detectors. Table 12-11 presents a summary of commercially available screening methods for these compounds.

Indicator tubes and other colorimetric methods--Indicator tubes, also known as gas detector or Draeger tubes, are small glass tubes filled with a reagent-coated material which changes color when exposed to a particular chemical. Air is pulled through the tube with a low-volume pump. Tubes are available for 40 organic gases, and for 8 hour or 15 minute exposure periods. Indicator tubes were designed for use in occupational settings, where high levels of relatively pure gases are likely to occur. Therefore, they have only limited usefulness for ambient air sampling, where part-per-billion levels are often of concern. However, because they are convenient to use and available for a wide range of compounds, detector tubes may be useful in some screening/sampling situations.

Other colorimetric methods, such as continuous flow and tape monitor techniques, were developed to provide real-time monitoring capability with indicator methods. The disadvantages of these systems are similar to those of indicator tubes.

Instrument detection screening methods--More commonly used for volatile organic surveys, portable instrument detection methods include flame ionization detectors (FID), photoionization detectors (PID), electron capture detectors (ECD), and infrared detectors (ID). Also in use are detectors that respond to specific chemical classes such as sulfur- and nitrogen-containing organics. These instruments are used to indicate levels of total organic vapors and for identification of "hot zones" downwind of the release source(s). They can be used as real-time non-specific monitors or, by adding a gas chromatograph, can provide concentration estimates and tentative identification of pollutants.

**TABLE 12-11**  
**TYPICAL COMMERCIALLY AVAILABLE SCREENING TECHNIQUES FOR ORGANICS IN AIR (FROM RIGGIN, 1983)**

Technique	Manufacturers	Compounds Detected	Approximate Detection Limit	Comments
Gas Detection Tubes	Draeger Matheson Kitagawa	Various organics and inorganics	0.1 to 1 ppmv	Sensitivity and selectivity highly dependent on component of interest.
Continuous Flow Colorimeter	CEA Instruments, Inc.	Acrylonitrile, formaldehyde, phosgene, and various organics	0.05 to 0.5 ppmv	Sensitivity and selectivity similar to detector tubes.
Colorimetric Tape Monitor	KHDA Scientific	Toluene, diisocyanate, dinitro toluene, phosgene, and various inorganics	0.05-0.5 ppmv	Same as above.
Infrared Analysis	Foxboro/Wilkes	Most organics	1-10 ppmv	Some inorganic gases (H <sub>2</sub> O, CO) will be detected and therefore are potential interferences.
FID (Total Hydrocarbon Analyzer)	Beckman HSA, Inc. AID, Inc.	Most organics	0.5 ppmv	Responds uniformly to most organic compounds on a carbon basis.
GC/FID (portable)	Foxboro/Century AID, Inc.	Same as above except that polar compounds may not elute from the column.	0.5 ppmv	Qualitative as well as quantitative information obtained.
PID and GC/PID (portable)	HNU, Inc. AID, Inc. Photovac, Inc.	Most organic compounds can be detected with the exception of methane	0.1 to 100 ppbv	Selectivity can be adjusted by selection of lamp energy. Aromatics most readily detected.
GC/ECD (portable)	AID, Inc.	Halogenated and nitro-substituted compounds	0.1 to 100 ppbv	Response varies widely from compound to compound.
GC/FPD (portable)	AID, Inc.	Sulfur or phosphorus-containing compounds	10-100 ppbv	Both inorganic and organic sulfur or phosphorus compounds will be detected.
Chemiluminescent Nitrogen Detector	Antek, Inc.	Nitrogen-containing compounds	0.1 ppmv (as N)	Inorganic nitrogen compounds will interfere.

Of the available detectors, those that are the most applicable to an RFI are the FID and PID. Table 12-12 summarizes four instruments (two FID and two PID versions) which are adequate for the purposes of the screening phase.

Flame Ionization Detectors--The Century OVA 100 series and AID Model 550 utilize a FID to determine the presence of vapor phase organics. The detector responds to the total of all organics present in the air at any given moment. Flame ionization detectors will respond to most organics, but are most sensitive to hydrocarbons (i.e., those chemicals which contain only carbon and hydrogen molecules such as benzene and propane). FIDs are somewhat less sensitive to compounds containing chlorine, nitrogen, oxygen, and sulfur molecules. The response is calibrated against a reference gas, usually methane. FID response is often termed "total hydrocarbons"; however, this is misleading because particulate hydrocarbons are not detected. FID detection without gas chromatography is not useful for quantification of individual compounds, but provides a useful tool for general assessment purposes. Detection limits using a FID detector alone are about 1 ppm. Addition of a gas chromatograph (GC) lowers the detection limit to ppb levels, but increases the analysis time significantly.

Photoionization Detectors--Portable photoionization detectors such as the HNU Model PI-101 and the Photovac 10A10 operate by applying UV ionizing radiation to the contaminant molecules. Some selectivity over the types of organic compounds detected can be obtained by varying energy of the ionizing beam. In the screening mode this feature can be used to distinguish between aliphatic and aromatic hydrocarbons and to exclude background gases from the instrument's response. The HNU and Photovac can be used either in the survey mode (PID only), or with GC. Sensitivity with PID alone is about 1 ppm, but can go down to as low as 0.1 ppb when a GC is used.

PI and FI detectors used in the GC mode can be used for semiquantitative analysis of compounds in ambient air. However, in areas where numerous contaminants are present, identification of peaks in a complex matrix may be tentative at best.

TABLE 12-12

## SUMMARY OF SELECTED ONSITE ORGANIC SCREENING METHODOLOGIES

Instrument or detector	Measurable parameters	Low range of detection	Comments
Century Series 100 or AID Model 550 (survey mode)	Volatile organic species	Low ppm	Uses Flame Ionization Detector (FID)
HNU Model PI-101	Volatile organic species	Low ppm	Photo-ionization (PI) detector-provides especially good sensitivity to low molecular weight aromatic compounds (i.e., benzene, toluene)
Century Systems OVA-128 (GC mode)	Volatile organic species	Low ppm	Uses GC column for possible specific compound identification
Photo Vac 10A10	Volatile organic species	Low ppm	Uses PI detector. Especially sensitive to aromatic species. May be used for compound identification if interferences are not present

Another method which can be used as a survey technique is mobile mass spectrometry. Ambient air is drawn through a probe directly into the instrument, which is usually mounted in a van. Particularly in the MS/MS configuration this is a powerful technique which can provide positive identification and semiquantitative measurement of an extremely wide range of organic and inorganic gaseous contaminants.

#### **12.8.2.2 Quantitative Methods**

Laboratory analysis of hazardous constituents in air includes the following standard steps:

- Preconcentration of organics (as necessary to achieve detection limit goals);
- Transfer to a gas chromatograph or HPLC (High Pressure Liquid Chromatography); and
- Quantification and/or identification with a detector.

Broad-spectrum methods applicable to most common air contaminants are discussed below.

##### **12.8.2.2.1 Monitoring Organic Compounds in Air**

Due to the large number of organic compounds that may be present in air, and their wide range in chemical and physical properties, no single monitoring technique is applicable to all organic air contaminants. Numerous techniques have been developed, and continue to be developed, to monitor for specific compound classes, individual chemicals, or to address a wide range of hazardous contaminants. This last approach may be the most efficient approach to monitoring at units where a wide range of chemicals are likely to be present. Therefore, methods that apply to a broad range of compounds are recommended. In cases where specific compounds of concern are not adequately measured by broad-spectrum methods, compound-specific techniques are described or referenced.

#### 12.8.2.2.1.1 Vapor-Phase Organics

The majority of hazardous constituents of concern can be classified as gaseous or (vapor-phase) organics. These constituents include most petroleum-related hydrocarbons, organic solvents, and many pesticides, and other semivolatile organic compounds. Methods to monitor these compounds generally include on-site analysis (making use of onsite concentration techniques, where necessary), or require storage in a tightly sealed non-reactive container.

Techniques for volatile and semivolatile organics measurement include:

- Adsorption of the sample on a solid sorbent with subsequent desorption (thermal or chemical), followed by gas chromatographic analysis using a variety of detectors.
- Collection of whole air (grab) samples in an evacuated flask or in Tedlar or Teflon bags, with direct injection of the sample into a GC using high sensitivity and/or constituent-specific detectors. This analysis may or may not be preceded by a preconcentration step.
- Cryogenic trapping of samples in the field with subsequent instrumental analysis.
- Bubbling ambient air through a liquid-filled impinger, containing a chemical that will absorb or react with specific compounds to form more stable products for GC analysis.
- Direct introduction of the air into a MS/MS or other detector.

Tables 12-13 (A and B), 12-14, and 12-15 summarize sampling and analytical techniques that are applicable to a wide range of vapor phase organics, have been widely tested and validated in the literature, and make use of equipment that is readily available. A discussion of general types of techniques is given below.

TABLE 12-13A. SUMMARY OF CANDIDATE METHODOLOGIES FOR QUANTIFICATION OF VAPOR PHASE ORGANICS

Collection Technique	Analytical Technique	Applicability (See Table 12-15B)	Positive Aspects	Negative Aspects
I. Sorption onto Tenax-GC or carbon molecular sieve packed cartridges using low-volume pump	Thermal Desorption into GC or GC/MS	I	<ul style="list-style-type: none"> <li>adequate QA/QC data base</li> <li>widely used on investigations around uncontrolled waste sites</li> <li>wide range of applicability</li> <li><math>\mu\text{m}^3</math> detection limits</li> <li>practical for field use</li> </ul>	<ul style="list-style-type: none"> <li>possibility of contamination</li> <li>artifact formation problems</li> <li>rigorous cleanup needed</li> <li>no possibility of multiple analysis</li> <li>low breakthrough volumes for some compounds</li> </ul>
II. Sorption onto charcoal packed cartridges using low-volume pump	Resorption with solvent-analysis by GC or GC/MS	II	<ul style="list-style-type: none"> <li>large data base for various compounds</li> <li>wide use in industrial applications</li> <li>practical for field use</li> </ul>	<ul style="list-style-type: none"> <li>problems with irreversible adsorption of some compounds</li> <li>high (<math>\text{mg}/\text{m}^3</math>) detection limits</li> <li>artifact formation problems</li> <li>high humidity reduces retention efficiency</li> </ul>
III. Sorption onto polyurethane foam (PUF) using low-volume or high-volume pump	Solvent extraction of PUF; analysis by GC/MS	I, II, III	<ul style="list-style-type: none"> <li>wide range of applicability</li> <li>easy to preclean and extract</li> <li>very low blanks</li> <li>excellent collection and retention efficiencies</li> <li>reusable up to 10 times</li> </ul>	<ul style="list-style-type: none"> <li>possibility of contamination</li> <li>losses of more volatile compounds may occur during storage</li> </ul>
IV. Sorption on passive dosimeters using Tenax or charcoal as adsorbing medium	Analysis by chemical or thermal desorption following by GC or GC/MS	I or II	<ul style="list-style-type: none"> <li>samplers are small, portable, require no pumps</li> <li>makes use of analytical procedures of known precision and accuracy for a broad range of compounds</li> <li><math>\text{pg}/\text{m}^3</math> detection limits</li> </ul>	<ul style="list-style-type: none"> <li>problems associated with sampling using sorbents</li> <li>uncertainty in volume of air sampled makes concentration calculations difficult</li> <li>requires minimum external air flow rate</li> </ul>



TABLE 12-13A (Continued)

Collection Technique	Analytical Technique	Applicability (see Table 12-15B)	Positive Aspects	Negative Aspects
V. Cryogenic trapping of analytes in the field	Desorption into GC	II, III	<ul style="list-style-type: none"> <li>• applicable to a wide range of compounds</li> <li>• artifact formation minimized</li> <li>• low blanks</li> </ul>	<ul style="list-style-type: none"> <li>• requires field use of liquid nitrogen or oxygen</li> <li>• sample is totally used in one analysis - no reanalysis possible</li> <li>• samplers easily clogged with water vapor</li> <li>• no large data base on precision or recoveries</li> </ul>
VI. Whole air sample taken in glass or stainless steel bottles	Cryogenic trapping or direct injection into GC or GC/MS (onsite or laboratory analysis)	II, III	<ul style="list-style-type: none"> <li>• useful for grab sampling</li> <li>• large data base</li> <li>• excellent long-term storage</li> <li>• wide applicability</li> <li>• allows multiple analyses</li> </ul>	<ul style="list-style-type: none"> <li>• difficult to obtain integrated samples</li> <li>• low sensitivity if preconcentration is not used</li> </ul>
VII. Whole air sample taken in Tedlar <sup>®</sup> Bag	Cryogenic trapping or direct injection into GC or GC/MS (onsite or laboratory)	II, III	<ul style="list-style-type: none"> <li>• grab or integrated sampling</li> <li>• wide applicability</li> <li>• allows multiple analyses</li> </ul>	<ul style="list-style-type: none"> <li>• long-term stability uncertain</li> <li>• low sensitivity if preconcentration is not used</li> <li>• adequate cleaning of containers between samples may be difficult</li> </ul>
IX. Dinitrophenyl - hydrazine Liquid Impinger sampling using a Low-Volume Pump	HPLC/UV analysis	IV	<ul style="list-style-type: none"> <li>• specific to aldehydes and ketones</li> <li>• good stability for derivatized compounds</li> <li>• low detection limits</li> </ul>	<ul style="list-style-type: none"> <li>• fragile equipment</li> <li>• sensitivity limited by reagent impurities</li> <li>• problems with solvent evaporation when long-term sampling is performed</li> </ul>
X. Direct introduction by probe	Mobile MS/MS	I, II, III, IV	<ul style="list-style-type: none"> <li>• immediate results</li> <li>• field identification of air contaminants</li> <li>• allows "real-time" monitoring</li> <li>• widest applicability of any analytical method</li> </ul>	<ul style="list-style-type: none"> <li>• high instrument cost</li> <li>• requires highly trained operators</li> <li>• grab samples only</li> <li>• no large data base on precision or accuracy</li> </ul>

TABLE 12-13B. LIST OF COMPOUND CLASSES REFERENCED IN TABLE 12-13A

Category	Types of Compound
I	Volatile, nonpolar organics (e.g., aromatic hydrocarbons, chlorinated hydrocarbons) having boiling points in the range of 80 to 200°C.
II	Highly volatile, nonpolar organics (e.g., vinyl chloride, vinylidene chloride, benzene, toluene) having boiling points in the range of -15 to + 120°C.
III	Semivolatile organic chemicals (e.g., organochlorine pesticides and PCBs).
IV	Aldehydes and ketones.

**TABLE 12-14. SAMPLING AND ANALYSIS TECHNIQUES APPLICABLE TO  
VAPOR PHASE ORGANICS**

Compound Name	Whole Air	Tenax Cartridge TO-1	Carbon MS Cartridge TO-2	Cryogenic Trapping TO-3	Hi-Vol PUF TO-4	Liquid Impinger TO-5	NIOSH Method Number	Comments/Others
Acetophenone	X	X						
Acrolein	X					X		
Acrylonitrile	X		X	X				
Aniline	X			X			2002	
Arsenic and compounds							7900	Solid, use Std. Hi-Vol
Benzene	X	X	X	X				
Bis(2-ethylhexyl)phalate							5020	
Bromomethane	X		NP	X			2520	
Cadmium and compounds							7048	Solid, use Std. Hi-Vol
Carbon disulfide	X		NP	X			1600	
Carbon tetrachloride	X	B	X	X			1003	
Chlordane	X			X	X			
Chloroaniline (p)	NP			NP				No validated Method
Chlorobenzene	X	X		X			1003	
Chloroform	X	B	X	X			1003	
Chloromethane (methyl chloride)	X	B	NP		NP			
Chlorophenol								Needs XAD-2 Backup
Chloroprene (Neoprene)	X	X	NP	X			1002	
Chromium and compounds							7024	Solid, use Std. Hi-Vol
Copper cyanide							7029	Solid, use Std. Hi-Vol.

TABLE 12-14 (continued)

Compound Name	Whole Air	Tenax Cartridge TO-1	Carbon MS Cartridge TO-2	Cryogenic Trapping TO-3	Hi-Vol PUF TO-4	Liquid Impinger TO-5	NIOSH Method Number	Comments/Others
Cresol (o)							2001	Syn: methylphenol
Cresol (p)							2001	Syn: methylphenol
Cyanide	X						7904	
Dichloro-2-butene (1,4)	X	X		X				
Dichloro benzene (1,2)	X	X		X			1003	
Dichloro benzene (1,4)	X	X		X			1003	
Dichlorodifluoromethane	X	NP	NP					NIOSH 1012 should work
Dichloroethane (1,1) [ethylidene chloride]	X	X	NP	X			1003	
Dichlorophenoxyacetic acid (2,4)	X				NP		5001	Syn: 2,4-D
Dichloropropane (1,2)	X	X		X			1013	Method 1003 may be used
Dichloropropene (1,3)	X	NP		X				
Diethyl phthalate								No method identified
Dinitrotoluene (2,4)								Yellow crystals, use Hi-Vol
Dioxane (1,4)	X	X		X			1602	
Diphenylhydrazine (1,2)								No method identified
Ethylene dibromide	X	B		X			1008	Syn: 1,2-dibromoethane
Ethylene dichloride	X	B		X			1003	Syn: 1,2-dichloroethane
Fluorides							7902	Std. Hi-Vol for particulate fraction
Heptachlor								Waxy solid, use Std Hi-Vol
Hexachlorobutadiene	X							

Compound Name	Whole Air	Tenax Cartridge TO-1	Carbon MS Cartridge TO-2	Cryogenic Trapping TO-3	Hi-Vol PUF TO-4	Liquid Impinger TO-5	NIOSH Method Number	Comments/Others
Hexachloroethane		NP		X			1003	Syn: perchloroethane
Isobutanol		NP		X			1401	Syn: isobutyl alcohol
Lead and compounds							7802	Mostly particulate, use Hi-Vol
Mercury and compounds							7300	Mostly particulate, use Hi-Vol
Methacrylonitrile	X		NP	X				
Methyl ethyl ketone	X	X					2500	Syn: 2-butanone
Methyl methacrylate	X	NP		X				
Methylene chloride		B	X	X			1005	Syn: dichloromethane
Naphthalene	X				X		5515	Method TO-4 needs XAD-2
Nickel and compounds							7300	Mostly particulate, use Hi-Vol
Nitrobenzene	X	X		X			2005	
Nitrophenol	X	NP		X				
Parathion					NP		5012	
Pentachlorobenzene	X	NP		X				
Pentachloroethane	X	X		X				
Pentachlorophenol	X	NP						
Perchloroethylene	X	X		X				Syn. Tetrachloroethylene
Phenol	X	X		X			3502	
Phorate	X			X				
Pyridine	X							
Resorcinol	X							
Styrene	X	NP		X			1501	Syn. Polystyrene

TABLE 12-14. (continued)

Compound Name	Whole Air	Tenax Cartridge TO-1	Carbon MS Cartridge TO-2	Cryogenic Trapping TO-3	Hi-Vol PUF TO-4	Liquid Impinger TO-5	NIOSH Method Number	Comments/Others
TCDD (2,3,7,8)					X			
Toluene	X	X	X	X			1501	
Toxaphene	X				NP			Syn: Chlorinated camphene
Trichlorobenzene	X	NP		NP				
Trichloroethane (1,1,1)	X	B	X	X			1003	Syn: Methyl Chloroform
Trichloroethylene	X	X	X	X				
Trichloropropane (1,2,3)	X	X		X				
Vanadium pentoxide								Mostly particulate, use Hi-Vol
Vinyl acetate	X			X				
Vinyl chloride	X		X	X			1007	Syn: 1,1-dichloroethene
Vinylidene chloride (1,1 dichloroethylene)	X		X	X				
Xylene (m, o, p)	X	X		X			1501	Syn: dimethylbenzene
Zinc oxide							7530 and 7502	Solid, use Std. Hi-Vol

- Blank spaces indicate that the method is inappropriate for that compound
- B = small breakthrough volume for adsorbent
- NP = not proven for this adsorbent, but may work
- X = acceptable media for collection

**TABLE 12-15**

**COMPOUNDS MONITORED USING EMSL-RTP  
TENAX SAMPLING PROTOCOLS**

2-Chloropropane	1-Bromo-3-chloropropane
1,1-Dichloroethene	Ethylbenzene
Bromoethane	Bromoform
1-Chloropropane	Ethenylbenzene
Bromochloromethane	o-Xylene
Chloroform	1,1,2,2-Tetrachloroethane
Tetrahydrofuran	Bromobenzene
1,2-Dichloroethane	Benzaldehyde
1,1,1-Trichloroethane	Pentachloroethane
Benzene	4-Chlorostyrene
Carbon tetrachloride	3-Chloro-1-propene
Dibromomethane	1,4-Dichlorobutane
1,2-Dichloropropane	1,2,3-Trichloropropane
Trichloroethene	1,1-Dichloroethane
1,1,2-Trichloroethane	2-Chlorobutane
2,3-Dichlorobutane	2-Chloroethyl vinyl ether
Bromotrichloromethane	1,1,1,2-Tetrachloroethane
Toluene	p-Dioxane
1,3-Dichloropropane	Epichlorobutane
1,2-Dibromomethane	1,3-Dichlorobutane
Tetrachloroethene	p-Dichlorobenzene
Chlorobenzene	cis-1,4-Dichloro-2-butene
1,2-Dibromopropane	n-Butyl benzene
Nitrobenzene	3,4-Dichloro-1-butene
Acetophenone	1,3,5-Trimethyl benzene
Benzonitrite	
Isopropylbenzene	
p-Isopropyltoluene	

Sorbent techniques--A very common technique used to sample vapor-phase organics involves sorption onto a solid medium. Methods of this type usually employ a low- or high-volume pump to pull air through a glass tube containing the sorbent material. Organic compounds are trapped (removed from the air) by chemical attraction to the surface of the adsorbent material. After a predetermined volume of air has been pulled through the trap, the tube is capped and returned to the laboratory for analysis. Adsorbed organics are then thermally or chemically desorbed from the trap prior to GC or GC/MS analysis.

Thermal desorption is accomplished by rapidly heating the sorbent tube while a stream of inert gas flushes desorbed organics directly onto the GC column. Generally a secondary trap (either another sorbent or a cryogenically cooled loop) is used to hold the organics until injection into the GC column, but this step precludes multiple analyses of the sample.

Chemical desorption involves flushing the sorbent tube with an organic solvent, and analysis of the desorbed organics by GC or GC/MS. Since only a portion of the solvent is injected into the GC, sensitivity is lower than with thermal adsorption. However, reanalysis of samples is possible. The most common application of chemical desorption is for analysis of workplace air samples, where relatively high concentrations of organics are expected.

The primary advantages of sorbent techniques are their ease of use and ability to sample large volumes of air. Sorbent cartridges are commercially available for many applications, and can easily be adapted to portable monitoring pumps or personal samplers. A wide variety of sorbent materials are available, and sorbent traps can be used singly or in series for maximum retention of airborne pollutants. Sorbent methods are especially applicable to integrated or long-term sampling, because large volumes of air can be passed through the sampling tube before breakthrough occurs.

In choosing a sorbent method, the advantages and limitations of specific methods should be considered along with general limitations of sorbents. Some important considerations are discussed below.



- Sorbents can be easily contaminated during manufacturing, shipping or storage. Extensive preparation (cleaning) procedures are generally needed to insure that the sorbent is free from interfering compounds prior to sampling. Tenax, for example, is often contaminated with benzene and toluene from the manufacturing process, requiring extensive solvent extraction and thermal conditioning before it is used. Once prepared, sampling cartridges must be protected from contamination before and after sampling.
- No single adsorbent exists that will retain all vapor phase organics. The efficiency of retention of a compound on a sorbent depends on the chemical properties of both compound and sorbent. Generally, a sorbent that works well for nonpolar organics such as benzene will perform poorly with polar organics such as methanol, and vice versa. Highly volatile compounds such as vinyl chloride will not be retained on weakly adsorbing materials such as Tenax, while less volatile compounds will be irreversibly retained on strong adsorbents such as charcoal. The optimal approach involves use of a sorbent that will retain a wide range of compounds with good efficiency, supplemented by techniques specifically directed towards "problem" compounds.
- Tenax-GC is a synthetic polymeric resin which is highly effective for volatile nonpolar organics such as aliphatic and aromatic hydrocarbons, and chlorinated organic solvents. Table 12-15 lists compounds that have been successfully monitored using a Tenax sorption protocol. Tenax has the important advantage that it does not retain water. Large amounts of water vapor condensing on a sorbent reduces collection efficiency and interferes with GC and GC/MS analysis. Another advantage of this material is the ease of thermal or chemical desorption.

The major limitation of Tenax is that certain highly volatile or polar compounds are poorly retained (e.g., vinyl chloride, methanol). Formation of artifacts (i.e., degradation products from the air contaminant sample collected due to hydrolysis, oxidation, photolysis or other processes) on Tenax has also been noted, especially the oxidation

of amines to form nitrosamines, yielding false positive results for the latter compounds.

Carbon sorbents include activated carbon, carbon molecular sieves, and carbonaceous polymeric resins. The major advantage of these materials is their strong affinity for volatile organics, making them useful for highly volatile compounds such as vinyl chloride. The strength of their sorptive properties is also the major disadvantage of carbon sorbents because some organic compounds may become irreversibly adsorbed on the carbon. Thermal desorption of compounds with boiling points above approximately 80°C is not feasible due to the high temperature (400°C) required. Carbon adsorbents will retain some water, and therefore may not be useful in high humidity conditions.

In addition to the Tenax and carbon tube sampling methods shown above, passive sorption devices for ambient monitoring can be used. These passive samplers consist of a portion of Tenax or carbon held within a stainless steel mesh holder. Organics diffuse into the sampler and are retained on the sorbent material. The sampling device is designed to fit within a specially constructed oven for thermal desorption. Results from these passive samplers were reported to compare favorably with pump-based sorbent techniques. Because of the difficulty of determining the volume of air sampled via passive sampling, these devices would appear to be mainly applicable for screening purposes.

- Polyurethane foam (PUF) has been used extensively and effectively for collection of semivolatile organics from ambient air. Semivolatiles include PCBs and pesticides. Such compounds are often of concern even at very low concentrations. A significant advantage of PUF is its ability to perform at high flow rates, typically in excess of 500 liters per minute (l/m). This minimizes sampling times.

PUF has been shown to be effective for collection of a wide range of semivolatile compounds. Tables 12-16 and 12-17 list compounds that have been successfully quantified in ambient air with PUF. Compounds

TABLE 12-10. SUMMARY LISTING OF ORGANIC COMPOUNDS SUGGESTED FOR COLLECTION WITH A LOW VOLUME POLYURETHANE FOAM SAMPLER AND SUBSEQUENT ANALYSIS WITH AN ELECTRON CAPTURE DETECTOR (GC/ECD)<sup>a</sup>

<u>Polychlorinated Biphenyls (PCBs)</u>	<u>p, p'-DDT<sup>a</sup></u>	<u>Chlorinated Phenols</u>
Aroclor 1221 <sup>c</sup>	Endosulfan 1 <sup>a</sup>	2,3-Dichlorophenol <sup>b</sup>
Aroclor 1232 <sup>d</sup>	Heptachlor <sup>d</sup>	2,4-Dichlorophenol <sup>b</sup>
Aroclor 1242 <sup>a</sup>	Aldrin <sup>a</sup>	2,5-Dichlorophenol <sup>b</sup>
Aroclor 1016 <sup>c</sup>		2,6-Dichlorophenol <sup>b</sup>
Aroclor 1248 <sup>d</sup>	<u>Polychlorinated Naphthalenes (PCNs)</u>	3,4-Dichlorophenol <sup>b</sup>
Aroclor 1254 <sup>a</sup>		3,5-Dichlorophenol <sup>b</sup>
Aroclor 1260 <sup>a</sup>	Halowax 1001 <sup>c</sup>	2,3,4-Trichlorophenol <sup>d</sup>
	Halowax 1013 <sup>c</sup>	2,3,5-Trichlorophenol <sup>d</sup>
		2,3,6-Trichlorophenol <sup>d</sup>
<u>Chlorinated Pesticides</u>		2,4,5-Trichlorophenol <sup>a</sup>
	<u>Chlorinated Benzene</u>	2,4,6-Trichlorophenol <sup>d</sup>
α-chlordane <sup>a</sup>	1,2,3-Trichlorobenzene <sup>a</sup>	3,4,5-Trichlorophenol <sup>d</sup>
γ-chlordane <sup>a</sup>	1,2,4-Trichlorobenzene <sup>d</sup>	2,3,4,5-Tetrachlorophenol <sup>d</sup>
<u>Chlordane (technical)<sup>a</sup></u>	1,3,5-Trichlorobenzene <sup>d</sup>	2,3,4,6-Tetrachlorophenol <sup>d</sup>
<u>Mirex<sup>a</sup></u>	1,2,3,4-Tetrachlorobenzene <sup>a</sup>	2,3,5,6-Tetrachlorophenol <sup>d</sup>
α-BHC <sup>a</sup>	1,2,3,5-Tetrachlorobenzene <sup>d</sup>	Pentachlorophenol <sup>a</sup>
β-BHC <sup>d</sup>	1,2,4,5-Tetrachlorobenzene <sup>d</sup>	
-BHC (Lindane) <sup>a</sup>	Pentachlorobenzene <sup>a</sup>	
-BHC <sup>d</sup>	Hexachlorobenzene <sup>a</sup>	
p,p'-DDDD <sup>d</sup>	Pentachloronitrobenzene <sup>a</sup>	
p,p'-DDE <sup>a</sup>		

- <sup>a</sup> Method validation data for all components, unless otherwise noted, are available in the literature. This includes collection efficiency data and/or retention efficiency data, method recovery data, and in some cases, storage stability data on selected isomers from this compound class.
- <sup>b</sup> Method validation data not presently available in the literature for either a low or high volume sampling procedure. Dichlorophenols, however, are amenable to the same analytical protocols suggested for the higher molecular weight chlorophenol isomers (trichloro, tetrachloro, and pentachloro). Users are cautioned that sample collection efficiencies may not be as high for dichlorophenols as for the higher molecular weight chlorophenols. Collection/retention efficiency data should be generated for each specific program.
- <sup>c</sup> Validation data employing low volume sampling conditions not presently available in literature. Component has, however, been evaluated using high volume PUF sampler.
- <sup>d</sup> Actual validation data for isomer(s) employing low volume PUF sampler not available in literature. Behavior under low volume sample conditions should be similar to other structural isomers listed. Component is amenable to analytical scheme employing GC/ECD

**TABLE 12-17. SUMMARY LISTING OF ADDITIONAL ORGANIC COMPOUNDS SUGGESTED FOR COLLECTION WITH A LOW VOLUME POLYURETHANE FOAM SAMPLER**

<u>Polynuclear Aromatic Hydrocarbons<sup>a</sup></u>	<u>Herbicide Esters</u>	<u>Urea Pesticides</u>
Napthalene	2,4-D Esters, isopropyl <sup>c</sup>	Monuron <sup>c</sup>
Biphenyl	2,4-D Esters, butyl <sup>c</sup>	Diuron <sup>c</sup>
Fluorene	2,4-D Esters, isobutyl <sup>c</sup>	Linuron <sup>c</sup>
Dibenzothiophene	2,4-D Esters, isooctyl <sup>c</sup>	Terbuthiuron <sup>c</sup>
Phenanthrene		Fluometuron <sup>c</sup>
Anthracene	<u>Organophosphorous Pesticides</u>	Chlorotoluron <sup>c</sup>
Carbazole		
2-Methylanthracene	Mevinphos <sup>b</sup>	<u>Triazine Pesticides</u>
1-Methylphenanthrene	Dichlorvos <sup>c</sup>	
Fluoranthene	Ronnel <sup>c</sup>	Simazine <sup>c</sup>
Pyrene	Chlorpyrifos <sup>c</sup>	Atrazine <sup>c</sup>
Benzo(a)fluorene	Diazinon <sup>c</sup>	Propazine <sup>c</sup>
Benzo(b)fluorene	Methyl parathion <sup>c</sup>	
Benzo(a)anthracene	Ethyl parathion <sup>c</sup>	<u>Pyrethrin Pesticides</u>
Chrysene/triphenylene		
Benzo(b)fluoranthene	<u>Carbamate Pesticides</u>	Pyrethrin I <sup>c</sup>
Benzo(e)pyrene		Pyrethrin II <sup>c</sup>
Benzo(a)pyrene	Propoxur <sup>c</sup>	Allethrin <sup>c</sup>
Perylene	Carbofuran <sup>c</sup>	d-trans-Allethrin <sup>c</sup>
o-Phenylene pyrene	Bendiocarb <sup>c</sup>	Dicrotophos <sup>c</sup>
Dibenzo(ac)/(ah)anthracene	Mexacarbate <sup>c</sup>	Resmethrin <sup>c</sup>
Benzo(g,h,i)perylene	Carbaryl <sup>c</sup>	Fenvalerate <sup>c</sup>
Coronene		

- <sup>a</sup> These components have been reported in the literature using polyurethane foam samplers. Users are cautioned that this listing is provided solely as a working reference. Method validation studies including collection efficiencies, retention efficiencies, etc., employing the sampling procedures cited in this document have not been conducted. Procedures other than those noted in this document may be more applicable in routine use.
- <sup>b</sup> Validation data employing low volume sampling conditions not presently available in literature. Component, however, has been evaluated using high volume PUF sampler.
- <sup>c</sup> sample evaluation data for these compound classes using a low volume PUF sampler contained in the literature.

that have shown poor retention or storage behavior with PUF include hexachlorocyclohexane, dimethyl and diethylphthalates, mono- and dichlorophenols, and trichloro- and tetrachlorobenzenes. These compounds have higher vapor pressures, and may be collected more effectively with Tenax or with resin sorbents such as XAD-2.

PUF is easy to handle, pre-treat, and extract. Blanks with very low contaminant concentrations can be obtained, as long as precautions are taken against contamination after pretreatment. Samples have been shown to remain stable on PUF during holding times of up to 30 days. PUF concentration methods have shown excellent collection efficiency and recovery of sorbed compounds from the material.

Most PUF methods specify the use of a filter ahead of the PUF cartridge, to retain particulates. The filter prevents plugging of the PUF which would reduce air flow through the sorbent. Some methods recommend extracting the filter separately to obtain a value for particulate organics. However, because most semivolatile compounds have sufficient vapor pressure to volatilize from the filter during the collection period, particulate measurements may not be representative of true particulate concentrations. Therefore, results from the PUF analyses may overestimate gaseous concentrations of semi-volatile compounds due to volatilization of semi-volatiles originally collected on the sampler inlet filter and subsequently collected by the PUF cartridge.

- Cryogenic methods for capturing and collecting volatile organics involve pulling air through a stainless steel or nickel U-tube immersed in liquid oxygen or liquid argon. After sampling, the tube is sealed, stored in a coolant, and returned to the laboratory for analysis. The trap is connected to a GC, rapidly heated, and flushed into a GC or GC/MS for analysis.

The major advantage of cryogenic concentration is that all vapor phase organics, except the most volatile, are concentrated. This is a distinct advantage over sorbent concentration, which is especially selective for particular chemical

classes. Contamination problems are minimal with cryogenic methods because a collection media is not required.

Several disadvantages limit the current usefulness of cryogenic methods, including:

- Samplers rapidly become plugged with ice in high humidity conditions. This limits the volume of air that can be sampled.
- The entire sample is analyzed at once, enhancing sensitivity but making multiple analyses of a sample impossible.
- The necessity of handling and transporting cryogenic liquids makes this method cumbersome for many sampling applications.
- There is a possibility of chemical reactions between compounds in the cryogenic trap.

Whole air sampling--Air may be collected without preconcentration for later use in direct GC analysis or for other treatment. Samples may be collected in glass or stainless steel containers, or in inert flexible containers such as Tedler bags. Rigid containers are generally used for collection of grab samples, while flexible containers or rigid containers may be used to obtain integrated samples. Using a flexible container to collect whole air samples requires the use of a sampling pump with flow rate controls. Sampling with rigid containers is performed either by evacuating the container and allowing ambient air to enter, or by having both inlet and outlet valves remain open while pumping air through the container until equilibrium is achieved.

Whole air sampling is generally simple and efficient. Multiple analyses are possible on samples, allowing for good quality control. This method also has the ability to be used for widely differing analyses on a single sample. The method has been widely used, and a substantial data base has been developed.

Problems may occur using this method due to decomposition of compounds during storage and loss of some organics by adsorption to the container walls.

Sample stability is generally much greater in stainless steel containers than in glass or plastic. Whole-air sampling is limited to relatively small volumes of air (generally up to 20 liters due to the impracticality of handling larger sample collection containers), and has higher detection limits than some sorbent techniques.

Impinger collection--Impinger collection involves passing the air stream through an organic solvent. Organics in the air are dissolved in the solvent, which can then be analyzed by GC/MS. Large volumes of air sampled cause the collection solvent to evaporate. In addition, collection efficiency is dependent on flow rate of the gas, and on the gas-liquid partition coefficients of the individual compounds. However, there are certain specialized applications of impinger sampling that have been found to be preferable to alternate collection techniques (e.g., sampling for aldehydes and ketones).

Certain compounds of interest are highly unstable or reactive, and will decompose during collection or storage. To concentrate and analyze these compounds, they must be chemically altered (derivatized) to more stable forms. Another common reason for derivatization is to improve the chromatographic behavior of certain classes of compounds (e.g., phenols). Addition of the derivatization reagent to impinger solvent is a convenient way to accomplish the necessary reaction.

A widely used method for analysis of aldehydes and ketones is a DNPH (dinitrophenylhydrazine) impinger technique. Easily oxidized aldehydes and ketones react with DNPH to form more stable hydrazone derivatives, which are analyzed by high performance liquid chromatography (HPLC) with a UV detector. This method is applicable to formaldehyde as well as less volatile aldehydes and ketones.

Direct analysis--A method not requiring preconcentration or separation of air components is highly desirable, because it avoids component degradation or loss during storage. Air is drawn through an inert tube or probe directly into the instrument detector. Several portable instruments exist that can provide direct air analysis, including infrared spectrophotometers, mobile MS instruments, and portable FID detectors. Some of these instruments have been discussed in the section on screening methods.

Mobile mass spectrometry has been used to compare upwind and downwind concentrations of organic pollutants at hazardous waste management facilities. The advantage of the multiple mass spectrometer configuration (MS/MS or triple MS) over a single MS system is that multiple systems can identify compounds in complex mixtures without pre-separation by gas chromatography. Major limitations of MS/MS methods are low sensitivity and high instrument cost.

In summary, of the methods described in this subsection, the majority of vapor-phase organics can be monitored by use of the following sampling methods:

- Concentration on Tenax or carbon adsorbents, followed by chemical or thermal desorption onto GC or GC/MS.
- Sorption on polyurethane foam (PUF) cartridges, followed by solvent extraction.
- Cryogenic trapping in the field.
- Whole-air sampling.

#### 12.8.2.2.1.2 Particulate Organics

Certain hazardous organic compounds of concern in ambient air are primarily associated with airborne particles, rather than in the vapor phase. Such compounds include dioxins, organochlorine pesticides, and polyaromatic hydrocarbons. Therefore, to measure these compounds accurately, it is necessary to monitor particulate emissions from units of concern.

Measurement of particulate organics is complicated because even relatively nonvolatile organics exhibit some vapor pressure, and will volatilize to a certain extent during sampling. The partitioning of a compound between solid and gaseous phases is highly dependent on the sampling conditions (e.g., sampling flow rate, temperature). Particulate sampling methods generally include a gas phase collection device after the particulate collector to trap those organics that become desorbed during sampling.



The most common methods used for collection of particles from ambient air are:

- Filtration
  - Cellulose Fiber
  - Glass or Quartz Fiber
  - Teflon Coated Glass Fiber
  - Membranes
- Centrifugal Collection (e.g., cyclones)
- Impaction
- Electrostatic Precipitation

The standard sampling method for particulates is filtration. Teflon-coated glass membranes generally give the best retention without problems with separating the particulates sampled from the filter. Problems, however, may be caused by desorption of organics from the filter, by chemical transformation of organics collected on the filter, and with chemical transformation of organics due to reaction with atmospheric gases such as oxides of nitrogen and ozone. These problems are magnified by the large volumes of air that must be sampled to obtain sufficient particulate material to meet analytical requirements. For example, to obtain 50 milligrams of particulates from a typical air sample, 1000 cubic meters of air must be sampled, involving about 20 hours of sampling time with a high-volume sampling pump.

Despite the drawbacks mentioned above, filtration is currently the simplest and most thoroughly tested method of collecting particulates for organic analysis. Other methods, such as electrostatic precipitation, make use of electrical charge or mechanical acceleration of the particles. The effect of these procedures on compound stability is poorly understood.

## 12.8.2.2.2 Monitoring Inorganic Compounds in Ambient Air

### 12.8.2.2.2.1 Particulate Metals

Metals in ambient air can occur as particulates or can be adsorbed on other particulate material. Metals associated with particulate releases are effectively collected by use of filter media allowing for the collection of adequate samples for analysis of a number of particulate contaminants.

Collection on filter media--Sampling methods for particulate metals are generally based on capture of the particulate on filter media. For the most part, glass fiber filters are used; however, organic and membrane filters such as cellulose ester and Teflon can also be used. These membrane filters demonstrate greater uniformity of pore size and, in many cases, lower contamination levels of trace metals than are found in glass fiber filters. Analytical procedures described in the following reference can be utilized to analyze particulate samples.

U.S. EPA. 1986. Test Methods for Evaluating Solid Waste. 3rd Edition. EPA SW-846. GPO No. 955-001-00000-1. Office of Solid Waste. Washington, D.C. 20460.

Hi-Vol collection devices--The basic ambient air sampler is the high volume sampler which can collect a 2000 cubic meter sample over a 24-hour period and capture particulates on an 8 x 10 inch filter (glass fiber) as described in 40 CFR Part 50. It has a nominal cut point of 100 $\mu$ m for the maximum diameter particle size captured. A recent modification involves the addition of a cyclone ahead of the filter to separate respirable and non-respirable particulate matter. Health criteria for particulate air contaminants are based on respirable particulate matter.

Personnel samplers--Another particulate sampling method involves the use of personnel samplers according to NIOSH methods (NIOSH, 1984). The NIOSH methods are intended to measure worker exposure to particulate metals for comparison to OSHA standards. A 500-liter air volume is sampled at approximately 2 liters per minute. This method is most efficient when less than 2 mg total particulate weight are captured. Capture of more than 2 mg may lead to sample

TABLE 12-18. SAMPLING AND ANALYSIS METHODS FOR VOLATILE MERCURY

Method/Reference	Species measured	Procedures summary	Advantages	Disadvantages
*NIOSH P&CAM 6000	Particulate, organic and elemental mercury	Sampling train consists of membrane filter to capture particulate Hg, followed by Carbosieve B to trap organic Hg, and then silver coated Chromosorb P (CP) to collect elemental Hg. Each section is analyzed separately by thermal desorption into a flameless AA. Filters are acid digested, reduced to Hg and amalgamated on Ag CP prior to the AA analysis step.	<ul style="list-style-type: none"> <li>- Standard method</li> <li>- Permits measurement of all three types of mercury</li> <li>- Method selective to mercury</li> </ul>	<ul style="list-style-type: none"> <li>- Requires use of complex desorption unit</li> <li>- <math>\text{Cl}_2</math> interferes with sampling</li> <li>- Separation of organic and metallic mercury is uncertain at 0.001 Hg/total Hg</li> <li>- Requires preparation of special sorbents</li> </ul>
NIOSH SCP-5342	Organic mercury	Filter to separate particulate; adsorb organic Hg on Carbosieve B; thermally desorb into flameless AA unit	<ul style="list-style-type: none"> <li>- Standard method</li> <li>- Option to P&amp;CAM 175 if organic mercury is only concern</li> <li>- Range is 20-80 <math>\mu\text{g}/\text{m}^3</math> with a 3 liter sample volume</li> </ul>	<ul style="list-style-type: none"> <li>- Requires complex thermal desorption unit</li> </ul>
EPA Method 101	Particulate and vaporous mercury	Collection in acidified 0.1 N HCl impinger solution; analysis by NAA or optionally by cold vapor AA	<ul style="list-style-type: none"> <li>- Standard method</li> <li>- Detection limit of 1 <math>\mu\text{g}/\text{m}^3</math></li> <li>- Fairly stable reagent</li> <li>- Same reagent has been used for volatile Pb (Ref. 572)</li> </ul>	<ul style="list-style-type: none"> <li>- NAA expensive and not routinely available</li> <li>- Ice interferes with cold vapor AA method at low concentrations of Hg</li> <li>- Instability of collected Hg compounds in solution has been reported</li> </ul>
Canadian EPS Standard Method	Particulate and vaporous mercury	Collection in impinger solution of 10% $\text{H}_2\text{SO}_4$ /2% $\text{KMnO}_4$ ; analysis by cold vapor AA	<ul style="list-style-type: none"> <li>- Standard method</li> <li>- Collection efficiency <math>\geq 90\%</math></li> <li>- <math>\text{KMnO}_4</math> and AA compatible</li> <li>- AA costs <math>\approx \\$30/\text{sample}</math></li> <li>- Reagent gives low blank levels</li> </ul>	<ul style="list-style-type: none"> <li>- <math>\text{KMnO}_4</math> reagent must be prepared within 12 hours of use</li> <li>- Short sample holding time</li> <li>- Reagent can be easily expended in oxidizing and organic matrices</li> </ul>

losses during handling of the sample. The preferred filter medium is cellulose ester (47 mm diameter) which will dissolve during the standard acid digestion.

The NIOSH method, however, is not recommended for the RFI for several reasons. The NIOSH analytical methods (and good QA/QC practices) require several aliquots of the sample to be prepared for best analytical results. The 47 mm filter is too small for aliquoting; therefore, use of the NIOSH method would require the simultaneous operation of several sampling systems. More importantly, the 500 liter sample volume generally does not provide sufficient particulate matter for the analytical methods to detect trace ambient levels of metals. The method is best suited for industrial hygiene applications.

Dichotomous Samplers--Dichotomous samplers (virtual impactors) have been developed for particle sizing with various limit cutpoints for use in EPA ambient monitoring programs. These samplers collect two particulate fractions on separate 37 mm diameter filters from a total air volume of about 20 cubic meters. The standard sampling period is 24 hours. Teflon filters are generally recommended by sampler manufacturers because they exhibit negligible particle penetration and result in a low pressure drop during the sampling period. However, glass fiber and cellulose filters are also acceptable.

The need for multiple extractions would require multiple sampling trains. If the two filters are combined to form one aliquot and extracted together, they will provide sufficient sensitivity for some but not all analytical procedures and defeat the purpose of fractioning the sample. The use of the dichotomous sampler is, therefore, limited.

#### 12.8.2.2.2 Vapor Phase Metals

Most metallic elements and compounds have very low volatilities at ambient temperatures. Those that are relatively volatile, however, require a different sampling method than used for collection of particulate forms, although analytical techniques may be similar. For the purpose of ambient monitoring, vapor-phase metals are defined as all elements or compounds that are not effectively captured by standard filter sampling procedures. Available methods for the measurement of vapor phase metals are presented in Tables 12-18 and 12-19. These available

TABLE 12-18. (continued)

Method/Reference	Species measured	Procedures summary	Advantages	Disadvantages
Environment Canada	Vaporous mercury or particulate mercury	Vaporous mercury is collected by amalgamation on silver. Particulate is collected on microquartz filters. Both are analyzed by thermal desorption and/or pyrolysis with re-amalgamation; then thermal desorption for determination by UV absorption at 253.7	<ul style="list-style-type: none"> <li>- Standard method for ambient air</li> <li>- Used in range of 4-22 mg/m<sup>3</sup></li> <li>- Claimed to be "inexpensive"</li> </ul>	<ul style="list-style-type: none"> <li>- Complex desorption/amalgamation unit</li> </ul>
3M Badge	Elemental Hg vapor	Passive device-diffusion of Hg through membrane, amalgamation on gold, analysis of badges performed by 3M	<ul style="list-style-type: none"> <li>- Very simple and mercury specific method</li> <li>- Requires no analysis to be performed by users</li> <li>- Gives 8-hour time weighted average and concentrations of up to 20 µg/m<sup>3</sup></li> </ul>	<ul style="list-style-type: none"> <li>- Cl<sub>2</sub> interferes with sampling efficiency</li> <li>- High H<sub>2</sub>S and SO<sub>2</sub> also interfere</li> <li>- Temperature variations affect diffusion rates and must be corrected for</li> </ul>
MSA Method	Elemental and organic mercury	Adsorb mercury on iodine impregnated charcoal; place in tantalum boat and volatilize	<ul style="list-style-type: none"> <li>- Simple equipment requirements</li> <li>- Range of 50-200 µg/m<sup>3</sup> tested</li> </ul>	<ul style="list-style-type: none"> <li>- Large coefficient of variation</li> <li>- Quality of results are very much operator dependent</li> <li>- Only works well at 200 µg/m<sup>3</sup></li> </ul>
Hopcalite Method	Elemental and organic mercury	Adsorb on hopcalite; dissolve sorbent and mercury in HNO <sub>3</sub> + HCl; analyze by cold vapor AA	<ul style="list-style-type: none"> <li>- Simple equipment requirement</li> <li>- Evaluated in range of 50-200 µg/m<sup>3</sup></li> </ul>	<ul style="list-style-type: none"> <li>- Does not provide for analysis of particulate mercury</li> <li>- Insufficient performance data in available literature</li> </ul>

TABLE 12-18 (continued)

Method/Reference	Species measured	Procedures summary	Advantages	Disadvantages
*Silver amalgamation and APHA	Vaporous elemental mercury	Amalgamation on silver wool or silver gauge; thermal desorption with analysis by flameless AA or UV absorption	<ul style="list-style-type: none"> <li>- Substantial information on the method; interferences provided in the references</li> <li>- Ag wool-24 hour sample can be used with 15 ng-10 pg/m<sup>3</sup> levels</li> <li>- Ag gauge ≤ 2 hour sample can give concentrations of 5 ng-100 µg/m<sup>3</sup></li> </ul>	<ul style="list-style-type: none"> <li>- Collection efficiency for organic mercury is in question</li> <li>- Oxidants could interfere with sampling procedure unless removed before reaching silver</li> </ul>
Impinger/Dithizone	Organic, particulate and vaporous mercury	Collect in impinger solution of 0.1 NiCl and 0.5 m HCl; analyze by the dithizone colorimetric method	<ul style="list-style-type: none"> <li>- Efficient capture of all three types of volatile mercury</li> </ul>	<ul style="list-style-type: none"> <li>- Dithizone method suffers from high blanks, interference from SO<sub>2</sub> and interference from several other metals</li> <li>- Mercury compounds collected in HCl are unstable</li> </ul>
Jerome Instrument Corp., Model 411, Gold Film Hg Vapor Analyzer	Elemental mercury	Onsite monitor-amalgamation of Hg on gold, measure concentration by change in gold foil resistance	<ul style="list-style-type: none"> <li>- Selective for mercury</li> <li>- Direct reading eliminates sample transport and analysis</li> <li>- Concentration range from µg/m<sup>3</sup> to mg/m<sup>3</sup></li> </ul>	<ul style="list-style-type: none"> <li>- Monitor costs \$3500-\$4000</li> <li>- May suffer interference from oxidants as noted for 3M badges</li> </ul>

\* Recommended methods

TABLE 12-19. SAMPLING AND ANALYSIS OF VAPOR STATE TRACE METALS (EXCEPT MERCURY)

Element	Reference(s)	Species measured	Procedures summary	Advantages	Disadvantages
Antimony	NIOSH S243	Stibine ( $\text{SbH}_3$ )	Adsorb on mercuric chloride impregnated silica gel; extract with concentration HCl; oxidize Sb(III) to Sb(V) with ceric sulfate; colorimetric analysis by Rhodamine	- Standard method	- Range only 0.1-1.0 $\text{ng/m}^3$ using a 20-liter sample - Analytical interferences by Pb(III), Tl(I), and Sb(II)
Arsenic	NIOSH P&CAM 6001	Arsine ( $\text{AsH}_3$ )	Adsorb on charcoal; desorb with $\text{HNO}_3$ ; analyze by furnace AA	- Standard method	- Possible breakthrough at high concentrations
	NIOSH S229 NIOSH 7900	Arsine ( $\text{AsH}_3$ )	Same as P&CAM 265 except that $\text{HNO}_3$ desorption is performed with 10 ml rather than 1 ml	- Standard method - Working range 0.09-0.1 $\text{mg/m}^3$	- Possible breakthrough at high concentrations - Earlier version of P&CAM 265
		$\text{As}_2\text{O}_3$ and others	Absorb in dilute NaOH solution; analytical procedure not specified but it may be suitable to use arsine generation or furnace AA	- Only method proposed for $\text{As}_2\text{O}_3$ in available literature - Relatively simple	- No supporting data available
*Lead	NIOSH S383 and S384	Tetraethyl lead and tetramethyl lead	Adsorb on XAD-2; desorb with pentane; analysis by GC	- Standard method - Permits separation of the various alkyl lead compounds - Range 0.045-0.20 $\text{ng/m}^3$ (as Pb) - Can alter GC conditions to remove interferences with analysis	- Compound identification only by GC retention times; must verify
		Alkyl lead compounds	Collect in HCl/NiCl impinger solution; analyze by dithizone colorimetric method when 8-hour sampling period or by AA for 24 hour sample	- Near 100% collection efficiency - Dithizone detection limit - 10 $\mu\text{g/m}^3$ - AA detection limit - 0.2 - 10 $\mu\text{g/m}^3$	- Very little information in literature - Dithizone method may have same problems noted elsewhere for other elements

TABLE 21-19. (continued)

Element	Reference(s)	Species measured	Procedures summary	Advantages	Disadvantages
		Alkyl lead compounds	Adsorb on activated carbon; digest with $\text{HNO}_3 + \text{HClO}_4$ ; analyze by dithizone method	<ul style="list-style-type: none"> <li>- Good collection efficiency</li> <li>- Low detection limits possible</li> </ul>	<ul style="list-style-type: none"> <li>- No data available</li> <li>- Dithizone method may have interferences as noted above</li> </ul>
Nickel	NIOSH P&CM 344	Nickel tetracarbonyl ( $\text{Ni}(\text{CO})_4$ )	Adsorb on charcoal; desorb with dilute $\text{HNO}_3$ ; analyze by furnace AA	<ul style="list-style-type: none"> <li>- Standard method</li> <li>- AA specific for Nickel</li> <li>- Range 2-60 <math>\mu\text{g}/\text{m}^3</math></li> </ul>	<ul style="list-style-type: none"> <li>- Sorbent capacity limits upper concentration</li> </ul>
	Ref. 120, 142	Nickel tetracarbonyl ( $\text{Ni}(\text{CO})_4$ )	Absorb in 3% $\text{HCl}$ impinger solution; analyze by colorimetric method in which color development in chloroform phase is measured	<ul style="list-style-type: none"> <li>- Detection limit - 0.001 ppm</li> </ul>	<ul style="list-style-type: none"> <li>- Not a standard method</li> <li>- Interference may occur from other Nickel compounds, Cu, Pb, Cr, Se and V</li> </ul>
Selenium		$\text{SeO}_2$ , $\text{H}_2\text{SeO}_3$	Collect in impinger with aqueous solution of $\text{Na}_2\text{SO}_3$ , $\text{Na}_2\text{S}$ , or $\text{NaOH}$ , analyze by NAA, AA, GC, colorimetry, fluorimetry, ring oven techniques, or catalytic methods	<ul style="list-style-type: none"> <li>- Only method suggested in literature for volatile Se</li> </ul>	<ul style="list-style-type: none"> <li>- No data to support this method</li> </ul>



methods are generally developed for industrial hygiene applications by NIOSH.

The methods for measuring vapor-phase metals presented in Tables 12-18 and 12-19 have undergone limited testing for precision and accuracy and have had matrix interferences documented. Therefore, they should be used in lieu of any methods which have no supporting data.

Several methods are suitable for quantification of vapor-phase mercury. If elemental mercury is to be measured, the silver amalgamation technique with thermal desorption and flameless AA (atomic absorption) analysis is recommended. This technique is presented in American Public Health Association (APHA) Method 317, which can achieve nanogram per cubic meter detection limits. If organic and/or particulate mercury are also to be determined, NIOSH methods (NIOSH, 1984) are recommended. These methods can measure all three airborne mercury species, but require a complex two stage thermal desorption apparatus.

#### 12.8.2.2.2.3 Monitoring Acids and Other Compounds in Air

Monitoring for acids and other inorganic/non-metal compounds (e.g., hydrogen sulfide) in the ambient air will generally require application of industrial hygiene technologies. Applicable methods have been compiled in the following references:

NIOSH. February 1984. NIOSH Manual of Analytical Methods. NTIS PB 85-179108. National Institute for Occupational Safety and Health. Cincinnati, OH.

ASTM. 1981. Toxic Materials in the Atmosphere. ASTM, STP 786. Philadelphia, PA.

APHA. 1977. Methods of Air Sampling and Analysis. American Public Health Association.

ACGIH. 1983. Air Sampling Instruments for Evaluation of Atmospheric Contamination. American Conference of Governmental Industrial Hygienists. Cincinnati, OH.

### 12.8.3 Stack/Vent Emission Sampling

EPA methods for source-sampling and analysis are documented in the following reference:

Code of Federal Regulations. 40 CFR Part 60, Appendix A: Reference Methods. Office of the Federal Register, Washington, D.C.

Additional guidance is available in the following references:

U.S. EPA. 1978. Stack Sampling Technical Information, A Collection of Monographs and Papers, Volumes I-III. EPA-450/2-78-042 a, b, c. NTIS PB 80-161672, 80-1616680, 80-161698. Office of Air Quality Planning and Standards Research Triangle Park, NC 27711.

U.S. EPA. February 1985. Modified Method 5 Train and Source Assessment Sampling System Operators Manual. EPA-600/8-85-003. NTIS PB 85-169878. Office of Research and Development. Research Triangle Park, NC 27711.

U.S. EPA March 1984. Protocol for the Collection and Analysis of Volatile POHC's Using VOST. EPA-600/8-84-007. NTIS PB 84-177799. Office of Research and Development. Research Triangle Park, NC 27711.

U.S. EPA. February 1984. Sampling and Analysis Methods for Hazardous Waste Combustion. EPA-600/8-84-002. NTIS PB 84-155845. Washington, D.C. 20460.

U.S. EPA. November 1985. Practical Guide - Trial Burns for Hazardous Waste Incinerators. NTIS PB 86-190246. Office of Research and Development. Cincinnati, OH 45268.

U.S. EPA. 1981. Source Sampling and Analysis of Gaseous Pollutants. EPA-APTI Course Manual 468. Air Pollution Control Institute. Research Triangle Park, NC 27711.

U.S. EPA. 1979. Source Sampling for Particulate Pollutants. EPA-APTI Course Manual 450. NTIS PB 80-188840, 80-174360, 80-182439. Air Pollution Control Institute. Research Triangle Park, NC 27711.

U.S. EPA. 1986. Test Methods for Evaluating Solid Waste. 3rd Edition. EPA/SW-846. GPO No. 955-001-00000-1. Office of Solid Waste. Washington, D.C. 20460.

#### 12.8.3.1 Vapor-Phase and Particulate Associated Organics

Generally, point source vapor-phase samples are obtained from the process vents and effluent streams either by a grab sample technique or by an integrated sampling train. Careful planning is necessary to insure that sampling and analytical techniques provide accurate quantitative and qualitative data for measurement of vapor-phase organics. Considerations such as need for real-time (continuous) versus instantaneous or short-term data, compatibility with other compounds/parameters to be measured, and the need for onsite versus offsite analysis may all be important in the selection process.

Monitoring for complex organic compounds generally requires detailed methods and procedures for the collection, recovery, identification, and quantification of these compounds. The selection of appropriate sampling and analytical methods depends on a number of important considerations, including source type and the compounds/parameters of interest. Table 12-20 lists several sampling methods for various applications and compound classes (applicable to combustion sources). The first three methods listed are fixed-volume, grab-sampling methods. Grab sampling is generally the simplest technique to obtain organic emission samples.

Sample collection by the bag and canister sampling methods can be used to collect time-integrated samples. These methods also allow for a choice of sample volumes due to a range of available bag sizes (6, 12, and 20 liter capacities are typical). Bags of various materials are available, including relatively inert and noncontaminating materials such as Teflon, Tedlar, and Mylar. All sample collection bag types may have some sample loss due to adsorption of the contaminants collected to container walls. The bag sample is collected by inserting the bag into

TABLE 12-20. SAMPLING METHODS FOR TOXIC AND HAZARDOUS ORGANIC MATERIALS FROM POINT SOURCES

Sampling Method	Description	Applicable Source Type	Applicable Compound Type	Applicable Analytical Method(s)	Sampling Method Limitations
Syringe Flow-through bottle Evacuated canister Tedlar bag (EPA Method 3)	Instantaneous grab Instantaneous grab  Integrated grab  Integrated grab	Non-combustion (storage tanks spray booths paint bake ovens, etc.) Low moisture content combustion emissions (boilers, incinerators, etc.).	Volatiles, C <sub>1</sub> -C <sub>10</sub>  Volatiles, C <sub>1</sub> -C <sub>10</sub>  Volatiles, C <sub>1</sub> -C <sub>10</sub> Volatiles, C <sub>1</sub> -C <sub>10</sub>	GC-FID <sup>a</sup>  GC-MS <sup>b</sup> or  GC-PID <sup>c</sup>	Sample size and therefore detectable concentration are limited by container size; $\geq 1$ ppm.  Bag samples are subject to absorptive losses of sample components.
EPA method 25	Two stage integrated grab train consisting of cold trap followed by evacuated S.S. tank.	Non-combustion and low moisture content combustion emissions as above.	Volatiles and semi-volatiles, C <sub>1</sub> -C <sub>16</sub>	Oxidation/reduction followed by GC/FID.	Sample size is limited by tank volume. CO <sub>2</sub> and H <sub>2</sub> O can produce significant interferences. System is complex/cumbersome.
-VOST <sup>d</sup>	Water-cooled sample gas, including condensate, is passed through dual in-series sorbent traps. Tenax GC in first tube followed by Tenax GC backed-up by charcoal in second tube.	Combustion emissions (boilers, hazardous waste incinerators, etc.).	Volatiles and semi volatiles, C <sub>1</sub> -C <sub>16</sub> , C <sub>1</sub> -C <sub>10</sub>	GC-MS GC-ECD GC-PID	Sample size is limited to 20 liters per pair of sorbent tubes. Sorbent tubes are susceptible to contamination from organics in ambient air during installation and removal from train.

Sampling Method	Description	Applicable Source Type	Applicable Compound Type	Applicable Analytical Method(s)	Sampling Method Limitations
Modified Method 5	Water-cooled sample gas, with condensate is passed through single sorbent trap. Sorbent type dependent on compound(s) of interest. <sup>e</sup>	Combustion emission as for VOST.	Semi-volatiles, PCB's, other halogenated organics, C <sub>7</sub> -C <sub>16</sub> , C <sub>1</sub> -C <sub>10</sub>	GC-ECD, GC-HECD, GC-MS	Single trap system does not provide check for breakthrough. Flow rate limited to approximately 1 cpm.
High Volume Modified Method 5	Sample gas is passed through condensers where moisture is removed before passing through two sorbent traps, primary followed by back-up. Flow rates of up to 5 cpm are achievable. Sorbent type dependent on compounds of interest. <sup>e</sup>	Combustion emissions.	Semi-volatiles, PCBs, other halogenated organics, C <sub>7</sub> -C <sub>16</sub> , C <sub>1</sub> -C <sub>10</sub>	GC-ECD, GC-HECD, GC-MS	High flow rate results in high sampling train pressure drop requiring large pump capacity.
SASS Train	Sample gas passes through a cold trap followed by an XAD-2 sorbent trap. Train is all stainless steel construction.	Combustion emissions (boilers, hazardous waste incinerators).	Semi-volatiles, and other, non-halogenated organics, C <sub>7</sub> -C <sub>16</sub>	GC-ECD, GC-HECD, GC-MS	System is complex, large and cumbersome. Recovery of organics from cold trap can be difficult. S.S. construction makes train components highly susceptible to corrosion from acidic gases especially HCl

a GC-FID - gas chromatography with flame ionization detector.

b GC-MS - gas chromatography-mass spectrometry.

c GC-PID - gas chromatography-photoionization detector.

d VOST - volatile organic sampling train.

e Sorbents include Florisil, XAD-2 resin, and Tenax-GC among the most commonly used.

Source: Hazardous Waste Management, Vol. 35, No. 1, January 1985

an airtight, rigid container (lung) and evacuating the container. The sample is drawn into the bag because reduced pressure in the container provides adequate suction to fill the bag. This procedure is presented in detail in 40 CFR Part 60, Appendix A (Method 3).

Evacuated canisters are conventionally constructed of high grade polished stainless steel. There are many versions available ranging from units with torque limiting needle valves, purge free assemblies, internal electropolished surfaces and versions utilizing stainless steel beakers with custom designed tops and fittings. Also, different container materials may react differently with the sample. Therefore, sample storage time or sample recovery studies to determine or verify inertness of the sampling canister should be considered.

Canisters are generally used to collect samples by slowly opening the sample valve, allowing the vacuum to draw in the sample gas. In less than a minute, the container should equilibrate with the ambient atmospheric pressure. At that time, the sample valve is closed to retain the sample. To collect composite samples over longer intervals, small calibrated orifices can be inserted before the inlet valve to extend the time required for equilibration of pressure once the sample valve is opened.

The sample collection procedure for EPA Method 5 (U.S. EPA, 1981) is similar in principle to that for the evacuated canister. The train consists of a polished stainless steel canister with a cold condensate trap in series and prior to the canister to collect a higher boiling point organic fraction. This two fraction apparatus provides for separate collection of two concentration ranges of volatile organic compounds based on boiling point.

The following four sampling methods utilize sample concentration techniques using one or more sorbent traps. The advantages of these methods is an enhanced limit of detection for many toxic and hazardous organic compounds. These techniques are preferred due to their lower detection limit. The Modified Method 5 (MM5) sampling train (U.S. EPA, 1981) is used to sample gaseous effluents for vapor-phase organic compounds that exhibit vapor pressures of less than 2 mm Hg (at 20°C). This system is a modification of the conventional EPA Method 5 particulate sampling train. The modified system consists of a probe, a high efficiency glass or

quartz fiber filter, a sorbent module, impingers, and related control hardware. The sample gas is passed through a single sorbent trap, containing XAD-2. The MM5 train is limited due to the single sorbent trap design that does not provide a backup for breakthrough. This is especially important when large volumes of sample are collected.

To minimize the potential for breakthrough, the MM5 train can be modified to provide a backup trap. However, this dual trap modification increases the pressure drop across the train, reducing the range of flow rates possible for sample collection. To overcome this pressure drop and maintain the desired flow rate, the high-volume MM5 train utilizes a much larger capacity pump.

The Source Assessment Sampling System (SASS) train is another comprehensive sampling train, consisting of a probe that connects to three cyclones and a filter in a heated oven module, a gas treatment section, and a series of impingers to provide large collection capacities for particulate matter, semivolatiles, and other lower volatility organics. The materials of construction are all stainless steel making the system very heavy and cumbersome. The stainless steel construction is also very susceptible to corrosion. This system can, however, be used to collect and concentrate large sample volumes, providing for a much lower detection limit. Because of the sorbents used (generally XAD-2), its use is limited to the same class of lower volatility organics and metals as the MM5 train.

The Volatile Organic Sampling Train (VOST) has proven to be a reliable and accurate method for collection of the broad range of organic compounds. By using a dual sorbent and dual in-series trap design, the VOST train can supplement either the MM5 or SASS methods allowing for collection of more volatile species. However, VOST has several limitations, including a maximum sample flow rate of 1.0 liter/minute, and a total sample volume of 20 liters per trap pair. Therefore, frequent changes of the trap pairs are required for test periods that exceed 20 minutes. The frequent change of traps makes the samples more susceptible to contamination.

Any of the point source monitoring techniques described above can be adapted for use with the isolation flux chamber techniques described previously. For point sources where particulate emissions are of concern, the Modified Method

5 or SASS train (originally designed to measure particle emissions from combustion effluents) are also applicable and proven technologies.

Analytical methodologies for the techniques discussed above will vary with the technique used. While certain techniques will offer advantages over others in the measurement of specific contaminants, the investigator is advised to utilize standard methodologies whenever possible in performing the RFI. For example, use of the VOST and/or the MM5 train, and their associated analytical methodologies is recommended for point source monitoring of the applicable compounds. Descriptions for both of these methods are included in the 3rd Edition of "Test Methods for Evaluating Solid Waste" (EPA SW-846), 1986 (GPO No. 955-001-00000-1). Although these methods are designed for the evaluation of incinerator efficiencies, they are essentially point-source monitoring methods which can be adapted to most point sources.

#### 12.8.3.2 Metals

Although the emission of metallic contaminants is primarily associated with particulate emission from area sources caused by the transfer of material to and from different locations, wind erosion, or general maintenance and traffic activities at the unit, point source emission of particulate or vapor-phase metals can exist. Metallic constituents may exist in the atmosphere as solid particulate matter, as dissolved or suspended constituents of liquid droplets (mists), and as vapors.

Metals specified as hazardous constituents in 40 CFR Part 261, Appendix VIII are generally noted as the element and compounds "not otherwise specified (NOS)", as shown in Table 12-21, indicating that measurement of the total content of that element in the sample is required.

Vapor phase metals--For the purpose of point-source monitoring, vapor-phase metals will be defined as all elements or compounds thereof, that are not quantitatively captured by standard filter sampling procedures. These include volatile forms of metals such as elemental and alkyl mercury, arsine, antimony, alkyl lead compounds, and nickel carybonyl.



Table 12-21.

**RCRA APPENDIX VIII HAZARDOUS METALS AND  
METAL COMPOUNDS**

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Antimony and compounds NOS<sup>a</sup>  
Arsenic and compounds NOS<sup>b</sup>  
Barium and compounds NOS<sup>b</sup>  
Beryllium and compounds NOS  
Cadmium and compounds NOS  
Chromium and compounds NOS  
Lead and compounds NOS  
Mercury and compounds NOS<sup>b</sup>  
Nickel and compounds NOS<sup>b</sup>  
Selenium and compounds NOS<sup>b</sup>  
Silver and compounds NOS<sup>b</sup>  
Thallium and compounds NOS<sup>b</sup>

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<sup>a</sup> NOS = not otherwise specified.

<sup>b</sup> Additional specific compound(s) listed for this element.

The sampling of point sources for vapor phase metals has not been a common or frequent activity for the investigation of air releases from solid waste management units. If a point source of vapor-phase metals is identified, the sampling approach should identify the best available monitoring techniques, considering that many have been developed which are specific to single species rather than multiple species of many different metal elements. The primary references for identifying available techniques include National Institute of Occupational Safety and Health (NIOSH, 1984) methods, EPA methods such as those presented in SW-846 and in the Federal Register under the National Emissions Standards for Hazardous Air Pollutants (NESHAPs), and American Public Health Association (APHA, 1977) methods. The basic monitoring techniques include collection on sorbents and in impinger solutions. The particular sorbent or impinger solution utilized should be selected based on the specific metal species under investigation.

Particulate Metals--Point-source releases to air could also require investigation of particulate metals. Source sampling particulate procedures such as the Modified Method 5 or SASS methods previously discussed are appropriate for this activity. EPA Modified Method 5 is the recommended approach. Modification of this basic technique involving the collection of particulate material on a filter with subsequent analysis of the collected particulate material on a filter for the metals of concern, could include higher or lower flow rates and the use of alternate filter media. Such modifications may be proposed when standard techniques prove to be inadequate. Several important particulate metal sampling methods are available in the NIOSH methods manuals (NIOSH, 1984); however, these methods were designed for ambient or indoor applications and may require modification if used on point sources.

## **12.9 Site Remediation**

Although the RFI Guidance is not intended to provide detailed guidance on site remediation, it should be recognized that certain data collection activities that may be necessary for a Corrective Measures Study may be collected during the RFI. EPA has developed a practical guide for assessing and remediating contaminated sites that directs users toward technical support, potential data requirements and

technologies that may be applicable to EPA programs such as RCRA and CERCLA. The reference for this guide is provided below.

U.S. EPA. 1988. Practical Guide for Assessing and Remediating Contaminated Sites. Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

The guide is designed to address releases to ground water as well as soil, surface water and air. A short description of the guide is provided in Section 1.2 (Overall RCRA Corrective Action Process), under the discussion of Corrective Measures Study.

**12.10 Checklist**

**RFI CHECKLIST - AIR**

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Site Name/Location

Type of Unit

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1. Does waste characterization include the following information? (Y/N)

- Physical form of the waste
- Identification of waste components
- Concentrations of constituents of concern
- Chemical and physical properties of constituents of concern

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2. Does unit characterization include the following information? (Y/N)

- Type of unit
- Types and efficiencies of control devices
- Operational schedules
- Operating logs
- Dimensions of the unit
- Quantities of waste managed
- Locations and spatial distribution/  
variation of waste in the unit
- Past odor complaints from neighbors
- Existing air monitoring data
- Flow rates from vents

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3. Does environmental setting characterization include the following information? (Y/N)

- Definition of regional climate
- Definition of site-specific meteorological conditions
- Definition of soil conditions

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- Definition of site-specific terrain \_\_\_\_\_
- Identification of potential release receptors \_\_\_\_\_

4. Have the following data on the initial phase of the release characterization been collected? (Y/N)

- Conceptual model of release developed \_\_\_\_\_
- Concentrations of released constituent at unit, facility property boundary and, if appropriate, at nearby offsite receptors (based on screening assessment or available modeling/monitoring data) \_\_\_\_\_
- Screening monitoring data (as warranted) \_\_\_\_\_
- Additional waste/unit data (as warranted) \_\_\_\_\_

5. Have the following data on the subsequent phase(s) of the release characterization been collected? (Y/N)

- Identification of "reasonable worst case" conditions \_\_\_\_\_
- Meteorological conditions during monitoring \_\_\_\_\_
- Release source conditions during monitoring \_\_\_\_\_
- Basis for selection of monitoring constituents \_\_\_\_\_
- Concentrations of released constituents at unit, facility property boundary and, if appropriate, at nearby offsite receptors (based on monitoring or modeling and representative of reasonable "worst case" conditions) \_\_\_\_\_

## 12.11 References

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## **SECTION 13**

### **SURFACE WATER**

#### **13.1 Overview**

The objective of an investigation of a release to surface water is to characterize the nature, extent, and rate of migration of the release to this medium. This section provides the following:

- An example strategy for characterizing releases to the surface water system (e.g., water column, bottom sediments, and biota), which includes characterization of the source and the environmental setting of the release, and conducting a monitoring program that will characterize the release;
- A discussion of waste and unit source characteristics and operative release mechanisms;
- A strategy for the design and conduct of monitoring programs considering specific requirements of different wastes, release characteristics, and receiving water bodies;
- Formats for data organization and presentation;
- Appropriate field and other methods that may be used in the investigation; and
- A checklist of information that may be needed for release characterization.

The exact type and amount of information required for sufficient release characterization will be facility and site-specific and should be determined through interactions between the regulatory agency and the facility owner or operator during the RFI process. This guidance does not define the specific data needed in all

instances; however, it identifies the information that is likely to be needed to perform release characterizations and identifies methods for obtaining this information. The RFI Checklist, presented at the end of this section, provides a tool for planning and tracking information collection for release characterization. This list is not a list of requirements for all releases to surface water. Some releases will involve the collection of only a subset of the items listed, while others will involve the collection of additional data.

Case Study Numbers 27, 28, 29, 30 and 31 in Volume IV (Case Study Examples) illustrate various aspects of surface water investigations which are described below.

## **13.2 Approach for Characterizing Releases to Surface Water**

### **13.2.1 General Approach**

A conceptual model of the release should be formulated using all available information on the waste, unit characteristics, environmental setting, and any existing monitoring data. This model (not a computer or numerical simulation model) should provide a working hypothesis of the release mechanism, transport pathway/mechanism, and exposure route (if any). The model should be testable/verifiable and flexible enough to be modified as new data become available. For surface water investigations, this model should account for the release mechanism (e.g., overtopping of an impoundment), the nature of the source area (e.g., point or non-point), waste type and degradability, climatic factors (e.g., history of floods), hydrologic factors (e.g., stream flow conditions), and fate and transport factors (e.g., ability for a contaminant to accumulate in stream bottom sediments). The conceptual model should also address the potential for the transfer of contaminants in surface water to other environmental media (e.g., soil contamination as a result of flooding of a contaminated creek on the facility property).

An example strategy for characterization of releases to surface waters is summarized in Table 13-1. These steps outline a phased approach, beginning with evaluation of existing data and proceeding to design and implementation of a monitoring program, revised over time, as necessary, based on findings of the previous phase. Each of these steps is discussed briefly below.

TABLE 13-1

EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO SURFACE WATER\*

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INITIAL PHASE

1. Collect and review existing information on:
  - Waste
  - Unit
  - Environmental setting
  - Contaminant releases, including inter-media transport
2. Identify any additional information necessary to fully characterize release:
  - Waste
  - Unit
  - Environmental setting
  - Contaminant releases, including inter-media transport
3. Develop monitoring procedures:
  - Formulate conceptual model of release
  - Determine monitoring program objectives
  - Select monitoring constituents and indicator parameters
  - Select monitoring locations
  - Determine monitoring frequency
  - Incorporate hydrologic monitoring as necessary
  - Determine role of biomonitoring and sediment monitoring
4. Conduct initial monitoring:
  - Collect samples under initial monitoring phase procedures and complete field analyses
  - Analyze samples for selected parameters and constituents
5. Collect, evaluate, and report results:
  - Compare analytical and other monitoring procedure results to health and environmental criteria and identify and respond to emergency situations and identify priority situations that may warrant interim corrective measures - Notify regulatory agency
  - Summarize and present data in appropriate format
  - Determine if monitoring program objectives were met
  - Determine if monitoring locations, constituents and frequency were adequate to characterize release (nature, extent, and rate)
  - Report results to regulatory agency

TABLE 13-1 (continued)

EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO SURFACE WATER\*

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SUBSEQUENT PHASES (If necessary)

1. Identify additional information necessary to characterize release:
  - Identify additional information needs
  - Determine need to include or expand hydrologic, and sediment and bio-monitoring
  - Evaluate potential role of inter-media transport
2. Expand initial monitoring as necessary:
  - Relocate, decrease, or increase number of monitoring locations
  - Add or delete constituents and parameters of concern
  - Increase or decrease monitoring frequency
  - Delete, expand, or include hydrologic, sediment or bio-monitoring
3. Conduct subsequent monitoring phases:
  - Collect samples under revised monitoring procedures and complete field analyses
  - Analyze samples for selected parameters and constituents
4. Collect, evaluate and report results/identify additional information necessary to characterize release:
  - Compare analytical and other monitoring procedure results to health and environmental criteria and identify and respond to emergency situations and identify priority situations that may warrant interim corrective measures - Notify regulatory agency
  - Determine if monitoring program objectives were met
  - Determine if monitoring locations, constituents, and frequency were adequate to characterize release (nature, extent, and rate)
  - Identify additional information needs
  - Determine need to include or expand hydrologic, sediment, or bio-monitoring
  - Evaluate potential role of inter-media transport
  - Report results to regulatory agency

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\* Surface water system is subject to inter-media transport. Monitoring program should incorporate the necessary procedures to characterize the relationship, if any, with ground water, sediment deposition, fugitive dust and other potential release migration pathways.

The first step in the general approach is the collection and review of available information on the contaminant source and the environmental setting. Some information on the contaminant source will be available from several reports and other documents. The RCRA permit, compliance order, or RFA report will provide a summary of information regarding actual or suspected releases from the various units. The facility owner or operator should be familiar with this information as a basis for further characterization of the release(s) in the RFI. In addition, a thorough understanding of the environmental setting is essential to an adequate determination of the nature and extent of releases to surface waters. Monitoring data should also be reviewed focusing on the quality of the data. If the quality is determined to be acceptable, then the data may be used in the design of the monitoring program. Guidance on obtaining and evaluating the necessary information on the contaminant source and the environmental setting is given in Section 13.3.

During the initial investigation particular attention should be given to sampling run-off from contaminated areas, leachate seeps and other similar sources of surface water contamination, as these are the primary overland release pathways for surface water. Releases to surface water via ground-water discharge should be addressed as part of the ground-water investigation, which should be coordinated with surface water investigations, for greater efficiency.

Based on the collection and review of existing information, the design of the monitoring program is the next major step in the general approach. The monitoring program should include clear objectives, monitoring constituents and indicator parameters, monitoring locations, frequency of monitoring, and provisions for hydrologic monitoring. In addition to conventional water quality and hydrologic monitoring, sediment monitoring and biomonitoring may also have a role in the surface water evaluation for a given RFI. Guidance on the design of the monitoring program is given in Section 13.4.

Implementation of the monitoring program is the next major step in the general strategy for characterizing releases to surface water. The program may be implemented in a phased manner that allows for modifications to the program in subsequent phases. For example, initial monitoring results may indicate that

downstream monitoring locations have been placed either too close to or too far from the contaminant source to accurately define the complete extent of downstream contamination. In this case, the program should be modified to relocate monitoring stations for subsequent monitoring phases. Similarly, initial monitoring may indicate that biomonitoring of aquatic organisms is needed in the next phase. Guidance on methods that can be used in the implementation of the program is given in Section 13.6.

Finally, the results of the characterization of releases to surface waters must be evaluated and presented in conformance with the requirements of the RFI. Section 13.5 provides guidance on data presentation. Table 13-2 summarizes techniques and data-presentation methods for the key characterization tasks.

As monitoring data become available, both within and at the conclusion of discrete investigation phases, they should be reported to the regulatory agency as directed. The regulatory agency will compare the monitoring data to applicable health and environmental criteria to determine the need for (1) interim corrective measures; and/or (2) a Corrective Measures Study. In addition, the regulatory agency will evaluate the monitoring data with respect to adequacy and completeness to determine the need for any additional monitoring efforts. The health and environmental criteria and a general discussion of how the regulatory agency will apply them are supplied in Section 8. A flow diagram illustrating RFI decision points is provided in Section 3 (See Figure 3-2).

Notwithstanding the above process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For these situations, the owner or operator is directed to follow the RCRA Contingency Plan requirements under 40 CFR Part 264, Subpart D and Part 265, Subpart D.



**TABLE 13-2**  
**RELEASE CHARACTERIZATION TASKS FOR SURFACE WATER**

Investigatory Tasks	Investigatory Techniques	Data Presentation Formats/Outputs
<b>1. Waste/Unit Characterization</b> <ul style="list-style-type: none"> <li>- Waste Composition and Analysis</li> <li>- Unit or Facility Operations</li> <li>- Release Mechanisms</li> </ul>	<ul style="list-style-type: none"> <li>- See Section 13.3.1</li> <li>- Review waste handling and disposal practices and schedules</li> <li>- Review environmental control strategies</li> <li>- See Section 13.3.1, Review operational information</li> </ul>	<ul style="list-style-type: none"> <li>- Data Tables</li> <li>- Schematic diagrams of flow paths, narrative</li> <li>- Site-specific diagrams, maps, narrative</li> </ul>
<b>2. Environmental Setting Characterization</b> <ul style="list-style-type: none"> <li>- Geographic Description</li> <li>- Classification of Surface Water and Receptors</li> <li>- Define Hydrologic Factors</li> </ul>	<ul style="list-style-type: none"> <li>- Review topographic, soil and geologic setting information</li> <li>- See Section 13.3.3.1</li> <li>- See Section 13.3.3.1</li> </ul>	<ul style="list-style-type: none"> <li>- Maps, Tables, Narrative</li> <li>- Maps, Cross Sections, Narrative</li> <li>- Tables, Graphs, Map</li> </ul>
<b>3. Release Characterization</b> <ul style="list-style-type: none"> <li>- Delineate Areal Extent of Contamination</li> <li>- Define Distribution Between Sediment, Biota and Water Column</li> <li>- Determine Rate of Migration</li> <li>- Describe Seasonal Effects</li> </ul>	<ul style="list-style-type: none"> <li>- Sampling and Analysis</li> <li>- Sampling and Analysis</li> <li>- Flow Monitoring</li> <li>- Repetitive Monitoring</li> </ul>	<ul style="list-style-type: none"> <li>- Tables of Results, Contour Maps, Maps of Sampling Locations</li> <li>- Graphs and Tables</li> <li>- Graphs and Tables</li> <li>- Graphs and Tables</li> </ul>

### **13.2.2 Inter-media Transport**

Surface waters are subject to inter-media transport, both as a receptor of contamination and as a migration pathway. For example, surface waters are generally engaged in a continual dynamic relationship with ground water. Ground water may discharge to a surface water body that may, in turn, recharge an aquifer. Hence, contamination may be transported from ground water to surface water and from surface water to ground water. Release of contaminants from a receiving water body to soil can also occur through deposition of the contaminants in floodplain sediments. These sediments may be exposed to wind erosion and become distributed through fugitive dust. Sediments may be exposed to air during periods of low flow of water in streams and lakes and when sediments are deposited by overland flow during rainfall-runoff events. Contaminants may also enter the air from surface water through volatilization.

## **13.3 Characterization of the Contaminant Source and Environmental Setting**

The initial step in developing an effective monitoring program for a release to surface waters is to investigate the unit(s) that is the subject of the RFI, the waste within the unit(s), the constituents within the waste, the operative release mechanisms and migration pathways to surface water bodies, and the surface water receptors. From this information, a conceptual model of the release can be developed for use in designing a monitoring program to characterize the release.

### **13.3.1 Waste Characterization**

Knowledge of the general types of wastes involved is an important consideration in the development of an effective monitoring program. The chemical and physical properties of a waste and the waste constituents are major factors in determining the likelihood that a substance will be released. These waste properties may also be important initially in selecting monitoring constituents and indicator parameters. Furthermore, once the wastes are released, these properties play a major role in controlling the constituent's migration through the environment and its fate. Table 13-3 lists some of the significant properties in evaluating environmental fate and transport in a surface water system. Without data on the wastes, the investigator may have to implement a sampling program

**TABLE13-3**

**IMPORTANT WASTE AND CONSTITUENT PROPERTIES  
AFFECTING FATE AND TRANSPORT IN A SURFACE WATER ENVIRONMENT**

**Bulk waste properties affecting mobility<sup>a</sup>**

- Physical state (solid, liquid, gas) of waste
- Chemical nature (e.g., aqueous vs non-aqueous) of waste
- Density (liquid)
- Viscosity (liquid)
- Interfacial tension (with water and minerals) (liquid)

**Properties to assess mobility of constituents<sup>b</sup>**

- Solubility
- Vapor pressure
- Henry's law constant (or vapor pressure and water solubility)
- Bioconcentration factor
- Soil adsorption coefficient
- Diffusion coefficient (in air and water)
- Acid dissociation constant
- Octanol-water partition coefficient
- Activity coefficient
- Mass transfer coefficients (and/or rate constants) for intermedia transfer
- Boiling point
- Melting point

**Properties to assess persistence<sup>c</sup>**

- Rate of biodegradation (aerobic and anaerobic)
- Rate of hydrolysis
- Rate of oxidation or reduction
- Rate of photolysis

<sup>a</sup> These waste properties will be important when it is known or suspected that the waste itself has migrated into the environment (e.g., due to a spill).

<sup>b</sup> These properties are important in assessing the mobility of constituents present in low concentrations in the environment.

<sup>c</sup> For these properties, it is generally important to know (1) the effects of key parameters on the rate constants (e.g., temperature, concentration, pH) and (2) the identity of the reaction products.

Sources of values for these and other parameters include Mabey, Smith, and Podall, (1982), and Callahan, et al. (1979). Parameter estimation methods are described by Lyman, Riehl, and Rosenblatt, (1982), and Neely and Blau (1985).

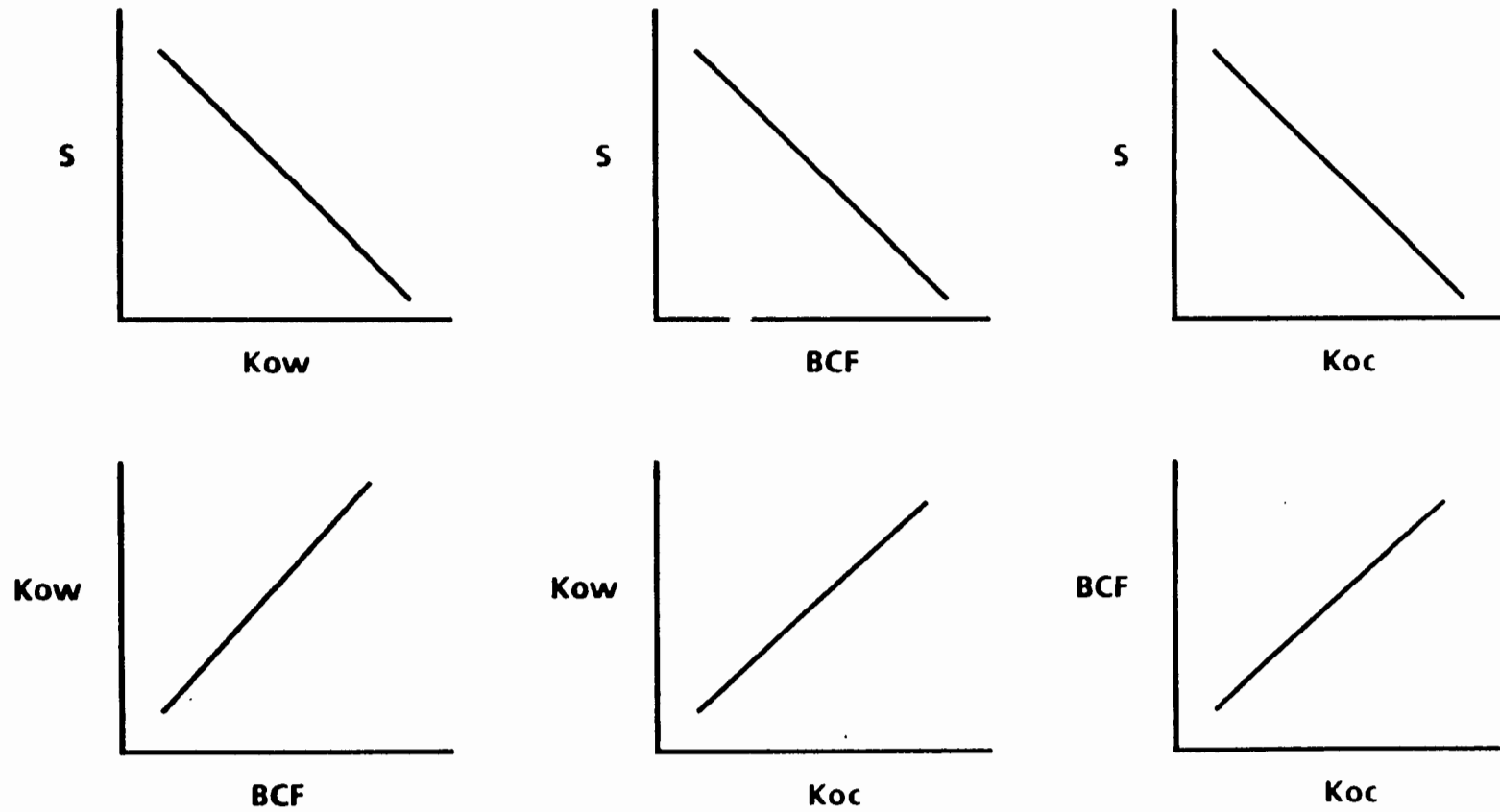
involving many constituents to ensure that all potential constituents have been addressed. General guidance on defining physical and chemical properties and identifying possible monitoring constituents and indicator parameters is provided in Sections 3 and 7.

Below are brief synopses of several of the key release, mobility, and fate parameters summarized in Table 13-3. Figure 13-1 shows the qualitative relationship between various environmental partitioning parameters. Neely and Blau (1985) provide a description of environmental partitioning effects of constituents and application of partition coefficients.

- **Physical State:**  
Solid wastes would appear to be less susceptible to release and migration than liquids. However, processes such as dissolution (i.e., as a result of leaching or runoff), and physical transport of waste particulates can act as significant release mechanisms.
- **Water Solubility:**  
Solubility is an important factor affecting a constituent's release and subsequent migration and fate in the surface water environment. Highly soluble contaminants (e.g., methanol at  $4.4 \times 10^6$  mg/L at 77°F) are easily and quickly distributed within the hydrologic cycle. These contaminants tend to have relatively low adsorption coefficients for soils and sediments and relatively low bioconcentration factors in aquatic life. An example of a less soluble constituent is tetrachloroethylene at 100 mg/L at 77°F.
- **Henry's Law Constant:**  
Henry's Law Constant indicates the relative tendency of a constituent to volatilize from aqueous solution to the atmosphere based on the competition between its vapor pressure and water solubility. Contaminants with low Henry's Law Constant values (e.g., methanol,  $1.10 \times 10^{-6}$  atm-m<sup>3</sup>/mole at 77°F) will tend to favor the aqueous phase

FIGURE 13-1

QUALITATIVE RELATIONSHIP BETWEEN VARIOUS PARTITIONING PARAMETERS



S: Solubility

Kow: Octanol/water partition coefficient

BCF: Bioconcentration factor

Koc: Soil/sediment adsorption coefficient

and volatilize to the atmosphere more slowly than constituents with high values (e.g., carbon tetrachloride,  $2.3 \times 10^{-2}$  atm-m<sup>3</sup>/mole at 77°F). This parameter is important in determining the potential for inter-media transport to the air media.

- **Octanol/Water Partition Coefficient ( $K_{ow}$ ):**

The octanol/water partition coefficient ( $K_{ow}$ ) is defined as the ratio of an organic constituent's concentration in the octanol phase (organic) to its concentration in the aqueous phase in a two-phase octanol/water system. Values of  $K_{ow}$  carry no units.  $K_{ow}$  can be used to predict the magnitude of an organic constituent's tendency to partition between the aqueous and organic phases of a two phase system such as surface water and aquatic organisms. The higher the value of  $K_{ow}$ , the greater the tendency of an organic constituent to adsorb to soil or waste matrices containing appreciable organic carbon or to accumulate in biota. Generally, constituents with  $K_{ow}$  values greater than or equal to 2.3 are considered potentially bioaccumulative (Veith, et al., 1980).

- **Soil-Water Partition Coefficient ( $K_d$ ):**

The mobility of contaminants in soil depends not only on properties related to the physical structure of the soil, but also on the extent to which the soil material will retain, or adsorb, the hazardous constituents. The extent to which a constituent is adsorbed depends on chemical properties of the constituent and of the soil. Therefore, the sorptive capacity must be determined with reference to a particular constituent and soil pair. The soil-water partition coefficient ( $K_d$ ) is generally used to quantify soil sorption.  $K_d$  is the ratio of the adsorbed contaminant concentration to the dissolved concentration, at equilibrium.

- **Bioconcentration Factor (BCF):**

The bioconcentration factor is the ratio of the concentration of the constituent in an organism or whole body (e.g., a fish) or specific tissue (e.g., fat) to the concentration in water. Ranges of BCFs for various constituents and organisms are reported in the literature (Callahan, et al., 1979) and these values can be used to predict the potential for

bioaccumulation, and therefore to determine whether sampling of the biota may be necessary. Another source of BCFs for constituents is contained in EPA's Ambient Water Quality Criteria (for priority pollutants). BCFs can also be predicted by structure-activity relationships. Constituents exhibiting a BCF greater than 1.0 are potentially bioaccumulative. Generally, constituents exhibiting a BCF greater than 100 cause the greatest concern.

- **The Organic Carbon Adsorption Coefficient ( $K_{oc}$ ):**  
The extent to which an organic constituent partitions between the solid and solution phases of a saturated or unsaturated soil, or between runoff water and sediment, is determined by the physical and chemical properties of both the constituent and the soil (or sediment). The tendency of a constituent to be adsorbed to soil is dependent on its properties and on the organic carbon content of the soil or sediment.  $K_{oc}$  is the ratio of the amount of constituent adsorbed per unit weight of organic carbon in the soil or sediment to the concentration of the constituent in aqueous solution at equilibrium.  $K_{oc}$  can be used to determine the partitioning of a constituent between the water column and the sediment. When constituents have a high  $K_{oc}$ , they have a tendency to partition to the soil or sediment. In such cases, sediment sampling would be appropriate.
- **Other Equilibrium Constants:**  
Equilibrium constants are important predictors of a compound's chemical state in solution. In general, a constituent which is dissociated (ionized) in solution will be more soluble and therefore more likely to be released to the environment and more likely to migrate in a surface water body. Many inorganic constituents, such as heavy metals and mineral acids, can occur as different ionized species depending on pH. Organic acids, such as the phenolic compounds, exhibit similar behavior. It should also be noted that ionic metallic species present in the release may have a tendency to bind to particulate matter, if present in a surface water body, and settle out to the sediment over time and distance. Metallic species also generally exhibit bioaccumulative properties. When metallic

species are present in a release, both sediment and biota sampling would be appropriate.

- **Biodegradation:**

Biodegradation results from the enzyme-catalyzed transformation of organic constituents, primarily from microorganisms. The ultimate fate of a constituent introduced into a surface water or other environmental system (e.g., soil), could be a constituent or compound other than the species originally released. Biodegradation potential should therefore be considered in designing monitoring programs. Section 9.3 (Soils) presents additional information on biodegradation.

- **Photolysis:**

Photodegradation or photolysis of constituents dissolved in aquatic systems can also occur. Similar to biodegradation, photolysis may cause the ultimate fate of a constituent introduced into a surface water or other environmental system (e.g., soil) to be different from the constituent originally released. Hence, photodegradation potential should also be considered in designing sampling and analysis programs.

- **Chemical Degradation (Hydrolysis and Oxidation/Reduction):**

Similar to photodegradation and biodegradation, chemical degradation, primarily through hydrolysis and oxidation/reduction (REDOX) reactions, can also act to change constituent species once they are introduced to the environment. Hydrolysis of organic compounds usually results in the introduction of a hydroxyl group (-OH) into a chemical structure. Hydrated metal ions, particularly those with a valence of 3 or more, tend to form ions in aqueous solution, thereby enhancing species solubility. Mabey and Mill (1978) provide a critical review of the hydrolysis of organic compounds in water under environmental conditions. Stumm and Morgan (1982) discuss the hydrolysis of metals in aqueous systems. Oxidation may occur as a result of oxidants being formed during photochemical processes in natural waters. Similarly, in some surface water environments (primarily those with low oxygen levels) reduction of constituents may take place.



Degradation, whether biological, physical or chemical, is often reported in the literature as a half-life, which is usually measured in days. It is usually expressed as the time it takes for one half of a given quantity of a compound to be degraded. Long half-lives (e.g., greater than a month or a year) are characteristic of persistent constituents. It should be noted that actual half-life can vary significantly over reported values based on site-specific conditions. For example, the absence of certain microorganisms at a site, or the number of microorganisms, can influence the rate of biodegradation, and therefore, half-life. Other conditions (e.g., temperature) may also affect degradation and change the half-life. As such, half-life values should be used only as general indications of a chemical's persistence.

In addition to the above, reactions between constituents present in a release may also occur. The owner or operator should be aware of potential transformation processes, based on the constituents' physical, chemical and biological properties, and account for such transformations in the design of monitoring procedures and in the selection of analytical methods.

Table 13-4 provides an application of the concepts discussed above in assessing the behavior of waste material with respect to release, migration, and fate. The table gives general qualitative descriptors of the significance of some of the more important properties and environmental processes for the major classes of organic compounds likely to be encountered.

Table 13-4 can be used to illustrate several important relationships.

- Generally, water solubility varies inversely with sorption, bioconcentration, and to a lesser extent, volatilization.
- Oxidation is a significant fate process for some classes of constituents which can volatilize from the aqueous phase.
- Variations in properties and environmental processes occur within classes as indicated by the pesticides, monocyclic aromatics, polycyclic aromatics, and the nitrosamines and other nitrogen-containing compounds.

TABLE 13-4

**GENERAL SIGNIFICANCE OF PROPERTIES AND ENVIRONMENTAL PROCESSES FOR  
CLASSES OF ORGANIC CHEMICALS UNDER ENVIRONMENTAL CONDITIONS**

Chemical Class	Solubility	Sorption	Bioconcentration	Volatilization	Photolysis	Oxidation	Hydrolysis
<b>Pesticides</b>							
Organochlorines	Low	High	High	High	Moderate	Low	Low
Organophosphates	Moderate	Moderate	Low	Low	High	High	Moderate-High
Carbamates	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate
<b>Polychlorinated Biphenyls</b>	Low	High	High	Moderate	Low	Low	Low
<b>Halogenated Aliphatics</b>	Moderate	Low	Low	High	Low	High*	Low
<b>Halogenated Ethers</b>	High	Low	Low	Low	Low	High*	High
<b>Monocyclic Aromatics</b>							
Toluene	Moderate	Moderate	Low	High	Low	High*	Low
Phenol	High	Low	Low	Low-Moderate	Moderate	Moderate	Low
<b>Phthalate Esters</b>	Low	High	High	Low	Low	Low	Low
<b>Polycyclic Aromatics</b>							
Naphthalene	Moderate	High	Low	Moderate	High**	Low	Low
Benzo(K)Fluoranthene	Low	High	Low	Low	High**	Low	Low
<b>Nitrosamines and other Nitrogen - Containing Compounds</b>							
Benzedine	Moderate-High	High	Low	Low	High	High	Low
Di-n-propylnitrosamine	High	Low	Low	Low	High	Low	Low

\* Atmospheric oxidation (volatile organic chemicals).

\*\* Dissolved portion only.

Table entries are qualitative only and based on a typical chemical within the class. Variations are observed within each class.

Characterizing the environmental processes and properties of inorganic waste constituents takes a similar approach to that shown on Table 13-4 for organics. However, characterizing the metals on a class-by-class basis is not advisable because of the complex nature of each metal and the many species in which the metals generally occur. The interaction of each metal species with the surface water environment is generally a function of many parameters including pH, REDOX potential, and ionic strength. See Stumm and Morgan (1982) for additional discussions on this subject. Generally, however, when metal species are present in a release, it is advisable to monitor the sediment and biota, in addition to the water column. This is due to likely deposition of metals as particulate matter, and to potential bioaccumulation.

### **13.3.2 Unit Characterization**

The relationship between unit characteristics and migration pathways provides the framework in this section for a general discussion of release mechanisms from units of concern to surface waters.

#### **13.3.2.1 Unit Characteristics**

Information on design and operating characteristics of a unit can be helpful in characterizing a release. Unsound unit design and operating practices can allow waste to migrate from a unit and possibly mix with runoff. Examples include surface impoundments with insufficient freeboard, allowing for periodic overtopping; leaking tanks or containers; or land-based units above shallow, low-permeability materials which, if not properly designed and operated, can fill with water and spill over. In addition, precipitation falling on exposed wastes can dissolve and thereby mobilize hazardous constituents. For example, at uncapped active or inactive waste piles and landfills, precipitation and leachate are likely to mix at the toe of the active face or the low point of the trench floor. Runoff may then flow into surface water through drainage pathways.

### 13.3.2.2 Frequency of Release

Releases to surface waters may be intermittent, continuous, or a past occurrence. It is important to consider the anticipated frequency of a release to establish an effective monitoring program.

Most direct releases to surface waters are intermittent. Intermittent discharges may be periodic, but may occur more often in a non-periodic manner, for example, in response to rainfall runoff. Other common factors affecting intermittent releases include fluctuations in water levels and flow rates, seasonal conditions (e.g., snow melt), factors affecting mass stability (e.g., waste pile mass migration), basin configuration, quantity/quality of vegetation, engineering control practices, integrity of the unit, and process activities.

Erosion of contaminated materials from a unit (e.g., a landfill) is generally intermittent, and is generally associated with rainfall-runoff events. Similarly, breaches in a dike are generally short-term occurrences when they are quickly corrected following discovery. Leaks, while still predominantly intermittent in nature, may occur over longer spans of time and are dependent on the rate of release and the quantity of material available.

Direct placement of wastes within surface waters (e.g., due to movement of an unstable waste pile) has the potential to continuously contribute waste constituents until the wastes have been removed or the waste constituents exhausted. Direct placement is usually easily documented by physical presence of wastes within the surface water body.

The frequency of sample collection should be considered in the design of the monitoring program. For example, intermittent releases not associated with precipitation runoff may require more frequent or even continuous sample collection to obtain representative data on the receiving water body. Continuous monitoring is generally feasible only for the limited number of constituents and indicator parameters for which reliable automatic sampling/recording equipment is available. Intermittent releases that are associated with precipitation runoff may require event sample collection. With event sampling, water level or flow-activated automatic sampling/recording equipment can be used. For continuous releases, less

frequent sample collection is generally adequate to obtain representative data on the receiving water body.

Previous intermittent releases may be identified through the analysis of bottom sediments, and whole body or tissue analyses of relatively sessile and long-lived macroinvertebrates (e.g., clams), or other species, such as fish. These analyses may identify constituents that may have adsorbed onto particulates and settled to the sediment, as well as bioaccumulative contaminants. In addition, intermittent releases may be detected through the use of in situ bioassays. Using these procedures, the test specie(s) is held within the effluent or stream flow and periodically checked for survival and condition.

#### **13.3.2.3 Form of Release**

Releases to surface waters may be generally categorized as point sources or non-point sources. Point sources are those that enter the receiving water at a definable location, such as piped discharges. Non-point source discharges are all other discharges, and generally cover large areas.

In general, most unit releases to surface waters are likely to be of a point source nature. Most spills, leaks, seeps, overtopping episodes, and breaches occur within an area which can be easily defined. Even erosion of contaminated soil and subsequent deposition to surface water can usually be identified in terms of point of introduction to the surface water body, through the use of information on drainage patterns, for example. However, the potential for both point and non-point sources should be recognized, as monitoring programs designed to characterize these types of releases can be different. For example, the generally larger and sometimes unknown areal extent of non-point source discharges may require an increase in the number of monitoring locations from that routinely required for point source discharges. The number of monitoring locations must be carefully chosen to ensure representative monitoring results.

#### **13.3.3 Characterization of the Environmental Setting**

The environmental setting includes the surface water bodies and the physical and biological environment. This section provides a general classification scheme for surface waters and discusses collection of hydrologic data that may be important in their characterization. Collection of specific geographical and climatological

data are also discussed. Characterization of the biotic environment is treated in Section 13.4.

Note that individual states have developed water quality standards for surface waters pursuant to the Clean Water Act. These standards identify the designated uses (e.g., drinking, recreation, etc.) of a surface water and a maximum contaminant level to support the use. If applicable, the owner or operator should report such standards.

#### 13.3.3.1 Characterization of Surface Waters

Surface waters can be classified into one of the following categories. These are obviously not pure classifications; intergrades are common.

- Streams and rivers;
- Lakes and impoundments;
- Wetlands; and
- Marine environments.

##### 13.3.3.1.1 Streams and Rivers

Streams and rivers are conduits of surface water flow having defined beds and banks. The physical characteristics of streams and rivers greatly influence their reaction to contaminant releases and natural purification (i.e., assimilative capacity). An understanding of the nature of these influences is important to effective planning and execution of a monitoring program. Important characteristics include depth, velocity, turbulence, slope, changes in direction and in cross sections, and the nature of the bottom.

The effects of some of these factors are so interrelated that it is difficult to assign greater or lesser importance to them. For example, slope and roughness of the channel influence depth and velocity of flow, which together control turbulence. Turbulence, in turn, affects rates of contaminant dispersion,

reaeration, sedimentation, and rates of natural purification. The nature of contaminant dispersion is especially critical in the location of monitoring stations. All these factors may be of greater or lesser importance for specific sites. It should also be noted that these factors may differ at the same site depending on when the release occurred. For example, differences between winter and summer flow may greatly influence the nature of contaminant dispersion.

Of further relevance to a surface water investigation are the distinctions between ephemeral, intermittent, and perennial streams, defined as follows:

- Ephemeral streams are those that flow only in response to precipitation in the immediate watershed or in response to snow melt. The channel bottom of an ephemeral stream is always above the local water table.
- Intermittent streams are those that usually drain watersheds of at least one square mile and/or receive some of their flow from baseflow recharge from ground water during at least part of the year, but do not flow continually.
- Perennial streams flow throughout the year in response to ground water discharge and/or surface water runoff.

The distinction between ephemeral, intermittent and perennial streams will also influence the selection of monitoring frequency, monitoring locations and possibly other monitoring program design factors. For example, the frequency of monitoring for ephemeral streams, and to a lesser extent intermittent streams, will depend on rainfall runoff. For perennial-stream monitoring, the role of rainfall runoff in monitoring frequency may be of less importance under similar release situations.

The location of ephemeral and intermittent streams may not be apparent to the owner or operator during periods of little or no precipitation. Generally, intermittent and ephemeral streams may be associated with topographic depressions in which surface water runoff is conveyed to receiving waters. In addition to topography, a high density of vegetation in such areas may be an indicator of the presence of ephemeral or intermittent drainage.

Perennial streams and rivers are continually engaged in a dynamic relationship with ground water, either receiving ground-water discharge (gaining stream) or recharging the ground water (losing stream) over any given stream reach. These characteristics should be considered in the evaluation of contaminant transport and fate.

The Ecology of Running Waters (Hynes 1970) and Introduction to Hydrology (Viessman et al., 1977) may be reviewed for basic discussions of surface water hydrology.

#### 13.3.3.1.2 Lakes and Impoundments

Lakes are typically considered natural, while impoundments may be man-made. The source for lakes and impoundments may be either surface water or ground water, or both. Impoundments may be either incised into the ground surface or may be created via the placement of a dam or embankment. As with streams and rivers, the physical characteristics of lakes and impoundments influence the transport and fate of contaminant releases and therefore the design of the monitoring program. The physical characteristics that should be evaluated include dimensions (e.g., length, width, shoreline, and depth), temperature distribution, and flow pathways.

Especially in the case of larger lakes and impoundments, flow paths are not clearcut from inlet to outlet. Not only is the horizontal component of flow in question, but as depth of the water body increases in the open water zone, chemical and more commonly physical (i.e., temperature) phenomena create a vertical stratification or zonation. Figure 13-2 provides a typical lake cross section, showing the various zones of a stratified lake.

Because of stratification, deeper water bodies can be considered to be comprised of three lakes. The upper lake, or epilimnion, is characterized by good light penetration, higher levels of dissolved oxygen, greater overall mixing due to wave action, and elevated biological activity. The lower lake, or hypolimnion, is the opposite of the epilimnion. Lying between these is what has been termed the



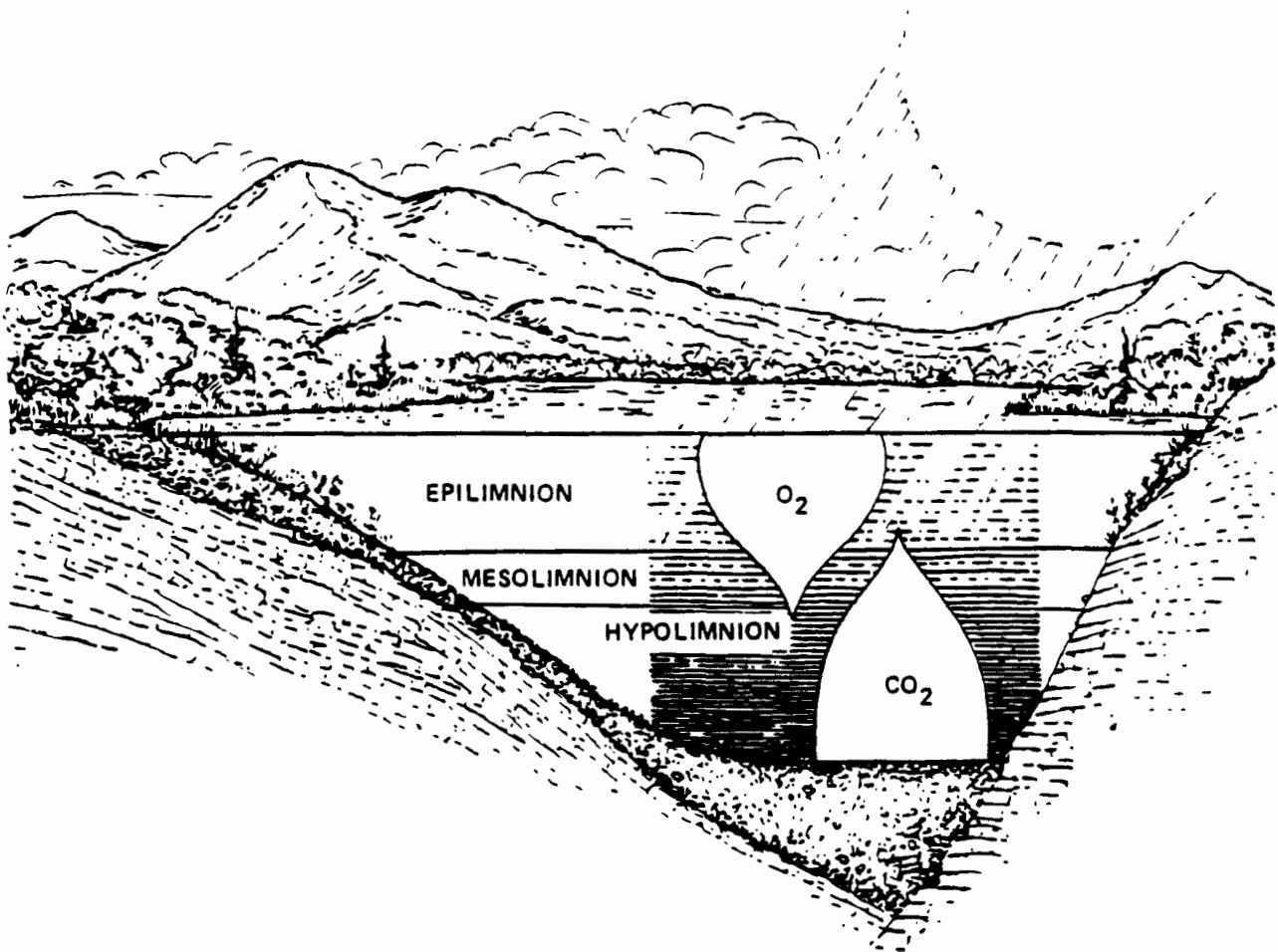


FIGURE 13-2. TYPICAL LAKE CROSS SECTION

(Source: Adapted from Cole, 1975).

middle lake or mesolimnion, characterized by a rapid decrease in temperature with depth. Were it not for the phenomenon of lake overturn, or mixing, contaminants with specific gravities greater than water might be confined to the lowermost lake strata, where they might remain for some time. Due to the potential importance of lake mixing to contaminant transport, it is discussed below.

Temperatures within the epilimnion are relatively uniform because of the mixing that occurs there. Water is most dense at 4° Centigrade (C); above and below 4°C its density decreases. In temperate climates, lake mixing is a seasonal occurrence. As the surface of the epilimnion cools rapidly in the fall, it becomes denser than the underlying strata. At some point, the underlying strata can no longer support the denser water and an "overturn" occurs, resulting in lake mixing. A similar phenomenon occurs in the spring as the surface waters warm to 4°C and once again become denser than the underlying waters.

Because of the influence of stratification on the transport of contaminants within a lake or reservoir, the location of monitoring points will largely depend on temperature stratification. The monitoring points on water bodies that are not stratified will be more strongly influenced by horizontal flowpaths, shoreline configuration and other factors. The presence of temperature stratification can be determined by establishing temperature-depth profiles of the water body.

More information on lakes and impoundments may be found in the following references:

A Treatise on Limnology, Volumes I and II (Hutchinson, 1957, 1967) or

Textbook of Limnology (Cole, 1975)

#### 13.3.3.1.3 Wetlands

Wetlands are those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands include, but are not limited to, swamps, marshes, bogs, and similar areas.

Wetlands are generally recognized as one of the most productive and sensitive of biological habitats, often associated with critical habitat for State or Federally listed special-status species of plants or wildlife. Wetlands also may play a significant role in basin hydrology, moderating peak surface water flows and providing recharge to the ground water system. The definition of the extent and sensitivity of wetlands that may be affected by a release is essential to release characterization.

High organic content, fine-grained sediments, slow surface water movement and lush vegetative growth and biological activity contribute to a high potential for wetlands to concentrate contaminants from releases. This is especially true for bioaccumulative contaminants, such as heavy metals. The pH/Eh conditions encountered in many wetlands are relatively unique and can have a significant effect on a contaminant's toxicity, fate, etc. Seasonal die-off of the vegetation and flooding conditions within the basin may result in the wetlands serving as a significant secondary source of contaminants to downstream surface water receptors.

#### 13.3.3.1.4 Marine Environments

For the purpose of this guidance, marine environments are restricted to estuaries, intermediate between freshwater and saline, and ocean environments. Industrial development near the mouths of rivers and near bays outletting directly into the ocean is relatively widespread, and the estuarine environment may be a common receptor of releases from industrial facilities.

Estuaries are influenced by both fresh water and the open ocean. They have been functionally defined as tidal habitats that are partially enclosed by land but have some access to the open sea, if only sporadically, and in which ocean water is partially diluted by fresh water. Estuaries may also experience conditions where salinities are temporarily driven above the ocean levels due to evaporative losses. Because of the protection afforded by encircling land areas, estuaries are termed "low-energy" environments, indicating that wave energy and associated erosive and mixing processes are reduced.

The physical characteristics of an estuary that will influence the design of a monitoring program are similar to those considered for lakes and impoundments (i.e., length, width, shoreline, depth, and flow pathways). However, the increased probability for chemical stratification due to varying salinities may be most pronounced in areas where freshwater streams and rivers discharge into the estuary. The monitoring program design should also consider tidal influences on stratification and contaminant dispersion.

In addition, estuaries, or some portions of estuaries, can be areas of intergrained sediment deposition. These sediments may contain a significant organic fraction, which enhances the opportunity for metal/organic adsorption, and subsequent bioaccumulation. Hence, biomonitoring within an estuary may also be appropriate. The ionic strength of contaminants may also have an important effect on their toxicity, fate, etc., in the marine environment.

#### 13.3.3.2 Climatic and Geographic Conditions

A release to the surface water system will be influenced by local climatological/meteorological and geographic conditions. The release may be associated only with specific seasonal conditions like spring thaws or meteorological events such as storms. If the release is intermittent, the environmental conditions at the time of the release may help identify the cause of and evaluate the extent of the release. If the release is continuous, seasonal variations should also be evaluated.

The local climatic conditions should be reviewed to determine:

- The annual precipitation distribution (monthly averages);
- Monthly temperature variations;
- Diurnal temperature range (daytime/nighttime difference);
- Storm frequency and severity;
- Wind direction and speed; and

- Snowfall and snow pack ranges (if applicable).

This information will be useful in developing a sampling schedule and in selecting sampling methods. From these data, it should be possible to anticipate the range of climatic conditions at the site. These conditions may be far more complex than simple cold/hot or wet/dry seasons. Some areas have two or more "wet seasons", one characterized by prolonged showers, another by brief intense storms, and perhaps a third as a result of snowmelt. Cold/hot seasons may overlap these wet/dry seasons to create several climatologically identifiable seasons. Each season may affect the release differently and may require a separate characterization. The unique climatological seasons that influence the site should be identified. Typical winter, spring, summer and fall seasonal descriptions may not be appropriate or representative of the factors influencing the release. Sources of climatological data are given in Section 12 (Air).

In addition to the climatological/meteorological factors, local geographic conditions will influence the design of the sampling program. Topographic conditions and soil structure may make some areas prone to flash floods and stream velocities that are potentially damaging to sampling equipment. In other areas (e.g., the coastal dune areas of the southeastern states), virtually no runoff occurs. Soil porosity and vegetation are such that all precipitation either enters the ground water or is lost to evapotranspiration. (See Section 9 (Soil) for more information).

A description of the geographic setting will aid in developing a sampling program that is responsive to the particular conditions at the facility. When combined with a detailed understanding of the climatological/meteorological conditions in the area, a workable monitoring framework can be created.

#### **13.3.4 Sources of Existing Information**

Considerable information may already be available to assist in characterizing a release. Existing information should be reviewed to avoid duplication of previous efforts and to aid in focusing the RFI. Any information relating to releases from the unit, and to hydrogeological, meteorological, and environmental factors that could influence the persistence, transport or location of contaminants should be reviewed. This information may aid in:

- Delineating the boundaries of the sampling area;
- Choosing sampling and analytical techniques; and
- Identifying information needs for later phases of the investigation.

Information may be obtained from readily available sources of geological and meteorological data, waste characteristics, and facility operations records. (See also Sections 2, 3, 7 and Appendix A).

#### **13.4 Design of a Monitoring Program to Characterize Releases**

Following characterization of the contaminant source and environmental setting, a monitoring program is developed. This section outlines and describes factors that should be considered in design of an effective surface water monitoring program. The characterization of contaminant releases may take place in multiple phases. While the factors discussed in this section should be carefully considered in program design, each of these generic approaches may require modification for specific situations.

The primary considerations in designing a surface water monitoring program are:

- Establishing the objectives of the monitoring program;
- Determining the constituents of concern;
- Establishing the hydrologic characteristics of the receiving water and characteristics of the sediment and biota, if appropriate;
- Selecting constituents and/or indicators for monitoring;
- Selecting monitoring locations and monitoring frequency; and

- Determining the need for sediment monitoring and, hydrologic and biomonitoring.

#### **13.4.1 Objectives of the Monitoring Program**

The principal objectives of a monitoring program are to:

- Identify the characteristics of releases (e.g., continuous vs intermittent);
- Identify the fate of constituents;
- Identify the nature, rate, and extent of the release and actual or potential effects on water quality and biota; and
- Identify the effect of temporal variation on constituent fate and identify impacts on water quality and biota.

Periodic monitoring of the surface water system is often the only effective means of identifying the occurrence of releases and their specific effects. Releases can be continuous or intermittent, point source, or non-point source. The concept of monitoring is the same, regardless of the frequency or form of the release. A series of measurements, taken over time, better approximate the actual release to surface waters than a one-time grab sample.

The functional difference between monitoring the various types of discharges is the point of measurement. Point source discharges may be monitored at and/or near the discharge point to surface waters. The fate and potential effects of non-point source discharges should be inferred through measurement of the presence of constituents of concern or suitable indicators of water quality within the receiving water body.

The monitoring program should also establish the background condition against which to measure variations in a continuous release or the occurrence of an intermittent release. Such information will enable the facility owner or operator to compile data that will establish trends in releases from a given unit(s) as well as to identify releases from other sources.

Monitoring programs should characterize contaminant releases as a function of time. Climatologic factors such as frequency of intense rainfall, added effects of snowmelt, temperature extremes, and mixing in lakes and estuaries should be evaluated and quantified as causative agents for intermittent contaminant release.

Important concepts to consider in designing the monitoring program for surface water to help meet the above-stated objectives are described below.

#### 13.4.1.1            Phased Characterization

The initial phase of a surface water release characterization program may be directed toward verification of the occurrence of a release identified as suspected by the regulatory agency. It may also serve as the first step for characterizing surface water systems and releases to those systems in cases where a release has already been verified.

The initial characterization will typically be a short-duration activity, done in concert with evaluation of other media that may either transport contaminants to surface waters, or may themselves be affected by discharges from surface waters (i.e., inter-media transport). It may be particularly difficult to define intermittent discharges in the initial characterization effort, especially if the contaminants from these releases are transient in the surface water body.

If the waste characterization is adequate, the initial characterization phase may rely upon monitoring constituents and suitable indicator parameters to aid in defining the nature, rate, and extent of a release. Subsequent phases of release characterization will normally take the form of an expanded environmental monitoring program and hydrologic evaluation, sensitive to seasonal variations in contaminant release and loading to the receiving water bodies, as well as to natural variation in hydrologic characteristics (e.g., flow velocity and volume, stream cross section).



#### 13.4.1.2 Development of Conceptual Model

To effectively design a monitoring program, it is important to develop a conceptual model or understanding of the fate of constituents of the release in the receiving water body. This conceptual understanding will assist in answering the following questions.

- What portion of the receiving water body will be affected by the release and what conditions (e.g., low flow, immediate stormwater runoff) represent reasonable worst case conditions under which sampling should occur?
- What should the relative concentrations of contaminants be at specific receptor points within the water body (e.g., public water supply intakes downstream of a site)?
- How does the release of concern relate to background contamination in the receiving water body as a result of other discharges?
- How might the monitoring program be optimized, based on contaminant dispersion and relative concentrations within the receiving water body?

The fate of waste constituents entering surface waters is highly dependent on the hydrologic characteristics of the various classifications of water bodies, (i.e., streams and rivers, lakes and impoundments, wetlands, and estuaries, as discussed earlier). Because of their complexity, methods for characterization of contaminant fate in wetlands and estuaries is not presented in detail in this guidance. The reader is referred to Mills (1985) for further detail on characterizing contaminant fate in wetlands and estuaries.

#### 13.4.1.3 Contaminant Concentration vs Contaminant Loading

Concentration and loading are different means of expressing contaminant levels in a release or receiving water body. The concept is important in the selection of constituents for monitoring. Both concentration and loading should be

evaluated with respect to the release and the receiving waters. Basing an evaluation solely on concentration may obscure the actual events. In addition, it is essential to quantify individual sources of contaminants and the relationships between media, as well as the loading found in the receiving water body, to effectively define the nature and extent of the contaminant release.

Contaminant concentrations in receiving waters have specific value in interpreting the level of health or environmental effects anticipated from the release. Contaminant loading provides a common denominator for comparison of contaminant inputs between monitoring points. In addition, especially in the case of contaminants that are persistent in sediments (e.g., heavy metals), loadings are a convenient means of expressing ongoing contributions from a specific discharge. The distinction between concentration and loading is best drawn through the following example.

A sample collected from a stream just upgradient of a site boundary (Station A) has a concentration of 50 micrograms per liter ( $\mu\text{g/l}$ ) of chromium. A second sample collected just downstream of the site (Station B) has a chromium concentration of 45  $\mu\text{g/l}$ . From these data it appears that the site is not releasing additional chromium to the stream. If, however, the stream flow is increasing between these two sampling locations, a different interpretation is apparent. If the stream flow at the upstream location is 1,000 gallons per minute (gpm) and the downstream location is 1,300 gpm, the actual loading of chromium to the stream at the two locations is as follows:

Station A

$$\text{Chromium} = (50.0 \mu\text{g/l})(1,000 \text{ gal/min})(10^{-9} \text{ kg}/\mu\text{g})(60 \text{ min/hr})(3.785 \text{ l/gal}) = 0.0114 \text{ kg/hr}$$

Station B

$$\text{Chromium} = (45.0 \mu\text{g/l})(1,300 \text{ gal/min})(10^{-9} \text{ kg}/\mu\text{g})(60 \text{ min/hr})(3.785 \text{ l/gal}) = 0.0133 \text{ kg/hr}$$

It is now apparent that somewhere between the two sampling stations is a source(s) contributing 0.0019 kg/hr of chromium. If all of the flow difference (i.e.,

300 gpm) is from a single source, then this source would have a chromium concentration of 27.9 µg/l:

$$\text{Chromium} = [(0.0019 \text{ kg/hr})(10^9 \text{ µg/kg})(1\text{hr}/60\text{min})(1 \text{ min}/300 \text{ gal})(1 \text{ gal}/3.785 \text{ l})] = 27.9 \text{ µg/l}$$

If, however, 90 percent of this flow difference (i.e., 270 gpm) was due to ground-water discharge with a chromium concentration below detectable limits and the remaining 10 percent (i.e., 30 gpm) was the result of a direct discharge from the facility, this discharge could have a chromium concentration of 279 µg/l.

#### 13.4.1.4 Contaminant Dispersion Concepts

Contaminant dispersion concepts and models of constituent fate can be used to define constituents to be monitored and the location and frequency of monitoring. Dispersion may occur in streams, stratified lakes or reservoirs, and in estuaries. Dispersion may be continuous, seasonal, daily, or a combination of these.

The discussion below is based on information contained in the Draft Superfund Exposure Assessment Manual (EPA, 1987) relative to simplified models useful in surface water fate analyses. The reader is directed to that document for a more in-depth discussion of models. The equations presented below are based on the mixing zone concept originally developed for EPA's National Pollutant Discharge Elimination System (NPDES) under the Clean Water Act. To avoid confusion over regulatory application of these concepts in the NPDES program, and the approach presented below (basically to aid in the development of a monitoring program), the following discussion refers to use of the "Dispersion Zone".

The following equation provides an approximate estimate of the concentration of a substance downstream from a point source release, after dilution in the water body:

$$C_r = \frac{C_u Q_u + C_w Q_w}{Q_u + Q_w}$$

where:

- $C_r$  = downstream concentration of substance following complete dispersion (mass/volume)
- $C_u$  = upstream concentration of substance before effluent release point (mass/volume)
- $C_w$  = concentration of substance in effluent (mass/volume)
- $Q_w$  = effluent flow rate (volume/time)
- $Q_u$  = upstream flow rate before effluent release point (volume/time)

The following equation may be used to estimate instream concentrations after dilution in situations where waste constituents are introduced via inter-media transfer or from a non-point source, or where the release rate is known in terms of mass per unit time, rather than per unit effluent volume:

$$C = \frac{T_r + M_u}{Q_t}$$

where:

- $T_r$  = inter-media transfer rate (mass/time)
- $M_u$  = upstream mass discharge rate (mass/time)
- $Q_t$  = stream flow rate after inter-media transfer or non-point source release (volume/time)

The above two equations assume the following:

- Dispersion is instantaneous and complete;
- The waste constituent is conserved (i.e., all decay or removal processes are disregarded); and
- Stream flow and rate of contaminant release to the stream are constant (i.e., steady-state conditions).

For a certain area downstream of the point of release, the assumption of complete dispersion may not be valid. Under certain situations, the dispersion zone can extend downstream for a considerable distance, and concentrations can be considerably higher within the dispersion zone than those estimated by the equation. The length of this zone can be approximated by the following equation:

$$DZ = \frac{0.4 w^2 u}{0.6 d \sqrt{gds}}$$

where:

- DZ = dispersion zone length (length units)
- w = width of the water body (length units)
- u = stream velocity (length/time)
- d = stream depth (length units)
- s = slope (gradient) of the stream channel (length/length)
- g = acceleration due to gravity (32 ft/sec<sup>2</sup>)

Within the dispersion zone, contaminant concentrations will show spatial variation. Near the release point the contaminant will be restricted (for a discharge along one shoreline) to the nearshore area and (depending on the way the discharge is introduced and its density) can be vertically confined. As the water moves downstream, the contaminant will disperse within surrounding ambient water and the plume will widen and deepen. Concentrations will generally decrease along the plume centerline and the concentration gradients away from the centerline will decrease. Eventually, as described above, the contaminant will become fully dispersed within the stream; downstream from this point concentration will be constant throughout the stream cross-section, assuming that the stream flow rate remains constant.

It is important to understand this concentration variability within the dispersion zone if measurements are to be made near the release. Relatively straightforward analytical expressions (See Neely, 1982) are available to calculate the spatial variation of concentration as a function of such parameters as stream width, depth, velocity, and dispersion coefficients. Dispersion coefficients characterize the dispersion between the stream water and contaminated influx;

they can, in turn, be estimated from stream characteristics such as depth, gradient, and path (i.e., straight or bends).

The above considerations are for instream concentrations resulting from the releases of concern. If total instream concentrations are required, the concentrations determined from background water samples should also be considered. In addition, if introduction of the contaminant occurs over a fixed stream reach, as might be the case with a non-point discharge, it should be assumed that the dispersion zone begins at the furthest downstream point within this reach.

#### **13.4.1.5            Conservative vs Non-Conservative Species**

The expressions presented thus far have assumed that the contaminant(s) of concern is conservative (i.e., that the mass loading of the contaminant is affected only by the mechanical process of dilution). For contaminants that are non-conservative, the above equations would provide a conservative estimate of contaminant loading at the point of interest within the receiving water body.

In cases where the concentration after dilution of a non-conservative substance is still expected to be above a level of concern, it may be useful to estimate the distance downstream where the concentration will remain above this level and at selected points in between. The reader is referred to the Draft Superfund Exposure Assessment Manual (EPA, 1987), for details regarding this estimation procedure and to specific State Water Quality Standards for determination of acceptable instream concentrations.

#### **13.4.2            Monitoring Constituents and Indicator Parameters**

##### **13.4.2.1           Hazardous Constituents**

The facility owner or operator should propose a list of constituents and indicator parameters, if appropriate, to be included in the Surface Water investigation. This list should be based on a site-specific understanding of the composition of the release source(s) and the operative release mechanisms, as well as the physical and chemical characteristics of the various classes of contaminants. These factors, as well as potential release mechanisms and migration pathways,

have been discussed in Sections 13.3 and 13.4.1. Also refer to Sections 3 and 7 of this guidance, and to the lists of constituents provided in Appendix B.

#### 13.4.2.2 Indicator Parameters

Indicator parameters (e.g., chemical and biochemical oxygen demand, pH, total suspended solids, etc.) may also play a useful role in release characterization. Though indicators can provide useful data for release verification and characterization, specific hazardous constituent concentrations should always be monitored. Furthermore, many highly toxic constituents may not be detected by indicators because they do not represent a significant amount of the measurement.

Following are brief synopses of some common indicator parameters and field tests that can be used in investigations of surface water contamination. The use of biomonitoring as an indicator of contamination is discussed in Section 13.4.5.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)--BOD is an estimate of the amount of oxygen required for the biochemical degradation of organic material (carbonaceous demand) and the oxygen used to oxidize inorganic material such as sulfides and ferrous iron. It may also measure the oxygen used to oxidize reduced forms of nitrogen (nitrogenous demand) unless their oxidation is prevented by an inhibitor. Because the complete stabilization of a BOD sample may require an extended period, 5 days has been accepted as the standard incubation period. While BOD measures only biodegradable organics, non-biodegradable materials can exert a demand on the available oxygen in an aquatic environment. COD measures the total oxygen demand produced by biological and chemical oxidation of waste constituents. Availability of results for the COD in approximately 4 hours, versus 5 days for the BOD, may be an important advantage of its use in characterizing releases of a transient nature.

COD values are essentially equivalent to BOD when the oxidizable materials present consist exclusively of organic matter. COD values exceed BOD values when non-biodegradable materials that are susceptible to oxidation are present. The reverse is not often the case; however, refinery wastes provide a notable exception. There are some organic compounds, such as pulp and paper mill cellulose, that are non-biodegradable, yet oxidizable. Nitrogenous compounds, which may place a

significant drain on available oxygen in aquatic environments, are not measured in the COD test. In addition, chlorides interfere with the COD test, leading to overestimates of the actual COD. BOD/COD ratios, as an indicator of biodegradability, are discussed in Section 9 (Soil). BOD and COD may be useful indicator parameters if the release is due primarily to degradable organic wastes.

Total Organic Carbon (TOC)--Total organic carbon is valuable as a rapid estimator of organic contamination in a receiving water. TOC, however, is not specific to a given contaminant or even to specific classes of organics. In addition, TOC measurements have little use if the release is primarily due to inorganic wastes.

Dissolved Oxygen (DO)--Measurements of DO may be readily made in the field with an electronic DO meter, which has virtually replaced laboratory titrations. Especially in lake environments, it is valuable to know the DO profile with depth. The bottoms of lakes are often associated with anoxic conditions (absence of oxygen) because of the lack of mixing with the surface and reduced or non-existent photosynthesis. Influx of a contaminant load with a high oxygen demand can further exacerbate oxygen deficiencies under such conditions. In addition, low DO levels favor reduction, rather than oxidation reactions, thus altering products of chemical degradation of contaminants. DO levels less than 3 mg/liter (ppm) are considered stressful to most aquatic vertebrates (e.g., fish and amphibians).

pH--pH is probably one of the most common field measurements made of surface waters. It is defined as the inverse log of the hydrogen ion concentration of an aqueous medium. pH is generally measured in the field with analog or digital electronic pH meters.

As an indicator of water pollution, pH is important for two reasons:

- The range within which most aquatic life forms are tolerant is usually quite narrow. Thus, this factor has significant implications in terms of impact to aquatic communities; and
- The pH of a solution may be a determining factor in moderating other constituent reactions.



Temperature--Along with pH, temperature is a fundamental parameter that should always be recorded in the field when a water sample is collected. Temperature is most often measured by electronic meters that can simultaneously record pH and/or specific conductance. Temperature is a significant parameter because:

- Most aquatic species are sensitive to elevated temperatures;
- Elevated temperatures can be an indication of a contaminant plume;
- Most chemical reactions are temperature-dependent; and
- Temperature defines strata in thermally-stratified lakes.

Alkalinity--Alkalinity is the capacity of water to resist a depression in pH. It is, therefore, a measure of the ability of the water to accept hydrogen ions without resulting in creation of an acid medium. Most natural waters have substantial buffering capacity (a resistance to any alteration in pH, toward either the alkaline or acid side) through dissolution of carbonate-bearing minerals, creating a carbonate/bicarbonate buffer system.

Alkalinity is usually expressed in calcium carbonate ( $\text{CaCO}_3$ ) equivalents and is the sum of alkalinities provided by the carbonate, bicarbonate, and hydroxide ions present in solution. Alkalinities in the natural environment usually range from 45 to 200 milligrams per liter (mg/l). Some limestone streams have extremely high buffering capacities, while other natural streams are very lightly buffered and are extremely sensitive to acid (or alkaline) loadings.

Hardness--The sum of carbonate and bicarbonate alkalinities is also termed carbonate hardness. Hardness is generally considered a measure of the total concentration of calcium and magnesium ions present in solution, expressed as  $\text{CaCO}_3$  equivalents.

Calcium and magnesium ions play a role in plant and animal uptake of contaminants; knowledge of the hardness of a surface water is necessary for evaluation of the site-specific bioaccumulative potential of certain contaminants (e.g., heavy metals).

**Total Solids**--Analytically, the total solids (TS) content of a water is that remaining after evaporation at 103-115° C or 180°C, depending on the method. The residue remaining represents a sum of the suspended, colloidal, and dissolved solids. Hazardous constituents with high vapor pressures (i.e., volatiles, semi-volatiles) will not remain after evaporation, and will not contribute to the TS determination.

**Suspended Solids**--Suspended solids are those materials that will not pass a glass-fiber filter. Suspended solids contain both organic and inorganic compounds. For the purpose of comparison to water samples, the average domestic wastewater contains about 200 ppm (mg/l) of suspended solids.

**Volatile Suspended Solids**--Volatile suspended solids are the volatile organic portion of the suspended solids. Volatile suspended solids are the components of suspended solids that volatilize at a temperature of 600° C. The residue or ash is termed fixed suspended solids and is a measure of the inorganic fraction (i.e., mineral content). The only inorganic salt that will degrade below 600° C is magnesium carbonate.

**Total Dissolved Solids**--Total dissolved solids content is obtained by subtracting suspended solids from total solids. Its significance lies in the fact that it cannot be removed from a surface water or effluent stream through physical means or simple chemical processes, such as coagulation.

**Salinity**--The major salts contributing to salinity are sodium chloride (NaCl) and sulfates of magnesium and calcium (MgSO<sub>4</sub>, CaSO<sub>4</sub>). The following represents an example of classification of saline waters on the basis of salt content.

<b><u>Type of Water</u></b>	<b><u>Total Dissolved Solids (As Salts)</u></b>
brackish	1,000 to 35,000 mg/l
seawater	35,000 mg/l
brine	> 35,000 mg/l

**Specific Conductance**--Conductivity measures the capacity to conduct current. Its counterpart is, of course, resistance, measured in ohms. The unit of conductivity has been defined as the mho. Specific conductance is conductivity/unit length. The most common units for specific conductance are mho/cm. Specific conductance can be

measured instantaneously with electronic conductivity meters to comparatively high levels of accuracy and precision in the field and is an excellent real-time indicator parameter.

Conductivity generally rises with increased concentration of dissolved (ionic) species. Therefore, waters with high salinities, or high total dissolved solids, can be expected to exhibit high conductivities. Variations in specific conductance within a stream reach or a portion of an impoundment may indicate the presence of contaminant release points.

Major Ion Chemistry--The nature and prevalence of ionic species may serve as indicators of pollution from waste sources containing inorganics. Ions result from the dissociation of metal salts. The cation (e.g.,  $\text{Na}^+$ ,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ) is typically a metallic species and the anion (e.g.,  $\text{Cl}^-$ ,  $\text{SO}_4^{--}$ ) a non-metallic species.

A common approach to use of ion chemistry as an indicator of waste contamination in surface waters is to analyze for anions. Standard Methods (American Public Health Association, 1985), protocol no. 429 includes the following common anions as analytes:

- Chloride ( $\text{Cl}^-$ )
- Fluoride ( $\text{F}^-$ )
- Bromide ( $\text{Br}^-$ )
- Nitrate ( $\text{NO}_3^-$ )
- Nitrite ( $\text{NO}_2^-$ )
- Phosphate ( $\text{PO}_4^{--}$ )
- Sulfate ( $\text{SO}_4^{--}$ )

While elevated concentrations of these anions may indicate the presence of inorganic constituents or other contaminants, no information will be provided regarding the identity of specific constituents or contaminants. In addition, elevated levels of anions may be associated with effluent from domestic refuse and/or runoff from fertilized agricultural fields.

The nature and concentrations of naturally-occurring ions in surface waters are a function of the geologic setting of the area, and may be temporarily affected by stormwater runoff, which may cause resuspension of streambed sediments.

In reference to their inertness with respect to constituent and biological degradation, ionic species are termed "conservative." The fact that their mass is not altered (i.e., is conserved) in surface waters permits them to be used in simple dilution modeling.

### **13.4.3 Selection of Monitoring Locations**

The selection of monitoring locations should be addressed prior to sample acquisition because it may affect the selection of monitoring equipment and because monitoring locations will affect the representativeness of samples taken during the monitoring program. Samples must be taken at locations representative of the water body or positions in the water body with specific physical or chemical characteristics. As discussed in Section 13.4.1.2 (Development of Conceptual Model), one of the most important preliminary steps in defining monitoring locations in a surface water monitoring program is developing a conceptual model of the manner in which the release is distributed within the receiving water body. This is dependent on the physical and chemical characteristics of the receiving water, the point source or non-point source nature of the discharge, and the characteristics of the constituents themselves.

As a practical example, if a release contains contaminants whose specific gravities exceed that of water, it may behave almost as a separate phase within the receiving water body, traveling along the bottom of the water body. As another example, certain contaminants may be found in comparatively low concentrations in sediments or within the water column, yet may accumulate in aquatic biota via bioaccumulation. In this case monitoring of the biota would be advised. If the facility owner or operator is unaware of these phenomena, it would be possible for the monitoring program to show no evidence of contamination.

In general, it will be desirable to locate monitoring stations in three areas relative to the discharge in question:

- Background monitoring stations:

Background monitoring should be performed in an area known not to be influenced by the release of concern (e.g., upstream of a release).

- Monitoring stations at the release point(s) or area:

If the release is a point source or area source, periodic monitoring should be performed at monitoring stations near the discharge origin to determine the range of contaminant concentrations. The contaminant stream (e.g., leachate seep, runoff) should also be subjected to monitoring.

- Monitoring of the receiving water body within the area of influence:

One means of evaluating the water quality effects of a discharge is to monitor the discharge point and model its dispersion (e.g., using dispersion zone concepts discussed previously) within the receiving water body. The results of this modeling may be used to determine appropriate sampling locations. Actual sampling of the area thought to be influenced by the release is required. The "area of influence" may be defined as that portion of the receiving water within which the discharge would show a measurable effect. As described previously, the area to be sampled is generally defined in a phased fashion, based on a growing base of monitoring data. It is usually prudent to start with a conservatively large area and continually refine its boundaries. This is particularly true where sensitive receptors (e.g., public water supply intakes, sensitive wetlands, recreation areas) lie downstream of the release. In addition, in order to determine the full extent of the release (and its effects), samples should be taken at locations beyond the perceived area of influence.

The majority of the effort of the monitoring program will take place within the area of influence, as defined above. Many factors are involved in selecting monitoring stations within this area, the most critical being:

- The homogeneity of the water body in terms of temperature, flow, salinity, and other physical and chemical characteristics;
- The representativeness of the monitoring point, in terms of both contaminant characteristics and use factors;
- The presence of areas of pronounced water quality degradation; and
- Defensible monitoring design, including the choice of the monitoring scheme (random, stratified random, systematic, etc.), the experimental design, and adequate sample size determination.

Estuarine areas are particularly difficult in terms of selecting monitoring locations that will allow an adequate evaluation of constituent distribution, because detailed knowledge of the hydrologic characteristics of the estuary is required to accurately locate representative monitoring points. Freshwater - salt water stratification is a particularly important consideration. If stratification is known to occur or is suspected, sampling should be conducted at a range of depths within the estuary as well as at surface locations.

The selection of sampling locations is described in much greater detail in EPA (1973, 1982).

#### **13.4.4 Monitoring Schedule**

The monitoring schedule or frequency should be a function of the type of release (i.e., intermittent vs continuous), variability in water quality of the receiving water body (possibly as a result of other sources), stream flow conditions, and other factors causing the release (e.g., meteorological or process design factors). Therefore, frequency of monitoring should be determined by the facility owner or operator on a site-specific basis. Sampling points with common monitoring

objectives should be sampled as close to simultaneously as possible, regardless of the monitoring frequency established.

Factors important in determining the required frequency of monitoring include:

- The homogeneity of the receiving water in terms of factors that may affect the fate of constituents. The most important of these are flow and seasonal or diurnal stratification.
- The characteristics of the releases. Releases may be continuous or event-associated.

As an example, continuous, point source releases of low variability subject to few, if any, additional releases may require relatively infrequent monitoring. On the other hand, releases known to be related to recurrent causes, such as rainfall and runoff, may require monitoring associated with the event. Such monitoring is termed "event" sampling. To evaluate the threshold event required to trigger sampling, as well as the required duration of the monitoring following the event, it is necessary that the role of the event in creating a release from the unit be well understood. In what is probably a very common example, if stormwater runoff is the event of concern, a hydrograph for various storm return intervals and durations should be estimated for the point or area of interest and the magnitude and duration of its effects evaluated.

Continuous monitoring can be accomplished through in situ probes that provide frequent input to field data storage units. However, continuous monitoring is feasible only for the limited number of constituents and indicator parameters for which reliable automatic sampling/recording equipment is available.

In estuaries, samples are generally required through a tidal cycle. Two sets of samples are taken from an area on a given day, one at ebb or flood slack water and another at three hours earlier or later at half tide interval. Sampling is scheduled such that the mid-sampling time of each run coincides with the calculated occurrence of the tidal condition.

Where investigating discharges of contaminated ground water to streams or rivers, it is important to sample during low flow conditions (e.g., using State critical low flow designations) to better assess the possible effects of the release(s) of concern.

#### **13.4.5 Hydrologic Monitoring**

The monitoring program should also include provisions for hydrologic monitoring. Specifically, the program should provide for collection of data on the hydrologic condition of the surface water body at the time of sampling.

For example, some indication of the stage and discharge of a stream being monitored needs to be recorded at the time and location each water sample is collected. Similarly, for sampling that occurs during storms, a record of rainfall intensity over the duration of the storm needs to be obtained. Without this complementary hydrologic data, misinterpretation of the water quality data in terms of contaminant sources and the extent of contamination is possible.

The techniques for hydrologic monitoring that could be included in a monitoring program range in complexity from use of simple qualitative descriptions of streamflow to permanent installation of continuously-recording stream gages. The techniques appropriate in a given case will depend on the characteristics of the unit and of the surface waters being investigated. Guidance on hydrologic monitoring techniques can be found in the references cited in Section 13.6.1.

#### **13.4.6 The Role of Biomonitoring**

The effects of contaminants may be reflected in the population density, species composition and diversity, physiological condition, and metabolic rates of aquatic organisms and communities. Biomonitoring techniques can provide an effective complement to detailed chemical analyses for identifying chemical contamination of water bodies. They may be especially useful in those cases where releases involve constituents with a high propensity to bioaccumulate. This includes most metal species and organics with a high bioconcentration factor (e.g.,  $>10$ ) or a high octanol/water partition coefficient (e.g.,  $\geq 2.3$ ). These properties were discussed in Section 13.3.



Biomonitoring techniques may include:

- Community ecology studies;
- Evaluation of food chain/sensitive species impacts; and
- Bioassays.

These techniques are discussed below.

#### 13.4.6.1 Community Ecology Studies

Indicator species are useful for evaluating the well-being of an aquatic community that may be stressed by the release of contaminants. For example, the condition of the benthic macroinvertebrate community is commonly used as an indicator of the presence of contaminants. The objective of studying the naturally-occurring biological community is to determine community structure that would be expected, in an undisturbed habitat. If significant changes occur, perturbations in the community ecology may be linked to the disturbance associated with release of contaminants to the water body.

EPA is engaged in research to develop rapid bioassessment techniques using benthic macroinvertebrates. Although protocols are being considered, in general these techniques suffer from lack of data on undisturbed aquatic communities and associated water quality information. For some areas (e.g., fisheries), however, indices to community health based on benthic invertebrate communities are available (Hilsenhoff 1982, Cummins and Wilgbach, 1985).

Because species diversity is a commonly-used indicator of the overall health of a community, depressed community diversity may be considered an indicator of contamination. For example, if a release to surface waters has a high chemical oxygen demand (COD) and, therefore, depresses oxygen levels in the receiving water body, the number of different species of organisms that can colonize the water body may be reduced. In this case the oxygen-sensitive species (e.g., the mayfly), is lost from the community and is replaced by more tolerant species. The number of tolerant species is small, but the number of individuals within these species that can colonize the oxygen-deficient waters may be quite large. Therefore,

the overall species diversity could be low, even though the numbers of organisms may be high.

Evaluations of community ecology should however, be sensitive to the role that habitat variability may play in altering community structure. Diversity of habitat may be altered by natural physical conditions (e.g., a rapid increase in stream gradient), substrate characteristics (e.g., silty versus rocky substrate), and so forth. It may also be difficult to directly link contaminant levels with the presence or absence of aquatic organisms, unless there is a secondary impact that is more self-evident, such as high oxygen demand, turbidity, or salinity.

#### 13.4.6.2 Evaluation of Food Chain Sensitive/Species Impacts

At this level of biomonitoring, the emphasis is actually on the threat to specific fish or wildlife species, or man, as a result of bioaccumulation of constituents from the release being carried through the food web. Bioaccumulative contaminants are not rapidly eliminated by biological processes and accumulate in certain organs or body tissues. Their effect may not be felt by individual organisms that initially consume the contaminated substrate or take up the contaminants from the water. However, organisms at higher trophic levels consume the organisms of the lower trophic levels. Consequently, contaminants may become bioaccumulated in organisms and biomagnified through the food web.

Examination of the potential for bioaccumulation and biomagnification of contaminants requires at least a cursory characterization of the community to define its trophic structure, that is, which organisms occupy which relative positions within the community. Based on this definition, organisms representative of the various trophic levels may be collected, sacrificed, and analyzed to determine the levels of the contaminants of interest present.

If a specific trophic level is of concern, it may be possible to short-cut the process by selectively collecting and analyzing organisms from that level for the contaminants of concern. This may be the case, for instance, if certain organisms are taken by man either commercially or through recreational fishing, for consumption. It may also be necessary to focus on the prey of special-status fish or wildlife (e.g., eagles and other birds of prey) to establish their potential for

exposure. This type of biomonitoring may be especially useful if constituents released have a relatively high potential to bioaccumulate. A discussion of indicators that are generally predictive of constituents which have a significant potential for bioaccumulation was presented in Section 13.3.

In addition, in the selection of organisms it is important to consider the ability of a given organism to accumulate a class of contaminants and the residential vs migratory nature of the organisms. For example, bullfrogs are superior for accumulating metals but poor for organics; spawning (thus migratory) salmon would be much less useful for characterizing a release from a local facility than would resident fish.

#### 13.4.6.3 Bioassay

Bioassay may be defined as the study of specially selected representative species to determine their response to the release of concern, or to specific constituents of the release. The organisms are "monitored" for a period of time established by the bioassay method. The objective of bioassay testing is to establish a concentration-response relationship between the contaminants of concern and representative biota that can be used to evaluate the effects of the release. Bioassay testing may involve the use of indigenous organisms (U.S. EPA, 1973) or organisms available commercially for this purpose. Bioassays have an advantage over strict constituent analyses of surface waters and effluents in that they measure the total effect of all constituents within the release on aquatic organisms (within the limits of the test). Such results, therefore, are not as tightly constrained by assumptions of contaminant interactions. Discussions of bioassay procedures are provided by Peltier and Weber (1985) and Horning and Weber (1985).

The criterion commonly used to establish the endpoint for a bioassay is mortality of the test organisms, although other factors such as depressed growth rate, reproductive success, behavior alteration, and flesh tainting (in fish and shellfish) can be used. Results are commonly reported as the LC50 (i.e., the lethal concentration that resulted in 50 percent mortality of the test organisms within the time frame of the test) or the EC50 (i.e., the effective concentration that resulted in 50 percent of the test organisms having an effect other than death within the time frame of the test).

One potential use of bioassays during the RFI is to predict the effect of a release on sensitive species residing in the affected surface water(s). Bioassay may be especially useful if the release is intermittent. In this case, samples of the waste may be taken from the unit of concern and used to conduct bioassay tests. The bioassay may be conducted using the waste at 100 percent strength, and in diluted form, to obtain a concentration response relationship. The results of this testing may then be used to predict the effects of a release on the surface water biota.

Bioassays can serve as important complements to the overall monitoring program. In considering the role and design of bioassays in a monitoring program, the facility owner or operator should be aware of the advantages and limitations of toxicity testing. The study design must account for factors such as species sensitivity and frequency of monitoring which may be different from the considerations that feed into chemical monitoring programs. Toxicity testing techniques are an integral part of the Clean Water Act program to control the discharge of toxic substances. Many issues associated with toxicity testing have been addressed in this context in the Technical Support Document for Water Quality-Based Toxics Control (Brandes et al, 1985).

### **13.5 Data Management and Presentation**

The owner or operator will be required to report on the progress of the RFI at appropriate intervals during the investigation. The data should be reported in a clear and concise manner, and interpretations should be supported by the data. The following data presentation methods are suggested for the various phases of the surface water investigation. Further information on the various procedures is given in Section 5. Section 5 also provides guidance on various reports that may be required.

#### **13.5.1 Waste and Unit Characterization**

Waste and unit characteristics should be presented as:

- Tables of waste constituents, concentrations, effluent flow and mass loadings;

- Tables of relevant physical and chemical properties of potential contaminants (e.g., solubility);
- Narrative description of unit operations;
- Surface map and plan drawings of facility, unit(s), and surface waters; and
- Identification of "reasonable worst case" contaminant release to surface waters.

### **13.5.2 Environmental Setting Characterization**

The environment of the waste unit(s) and surface waters should be described in terms of physical and biological environments in the vicinity. This description should include:

- A map of the area portraying the location of the waste unit in relation to potential receiving waters;
- A map or narrative classification of surface waters (e.g., type of surface water, uses of the surface water, and State classification, if any);
- A description of the climatological setting as it may affect the surface hydrology or release of contaminants; and
- A narrative description of the hydrologic conditions during sampling periods.

### **13.5.3 Characterization of the Release**

The complex nature of the data involving multiple monitoring events, monitoring locations, matrices (water, sediment, biota), and analytes lends itself to graphic presentation. The most basic presentation is a site map or series of maps

that locate the monitoring stations for each monitoring event. These maps may also be adapted to include isopleths for specific analytes; however, since the isopleths imply a continuity within their borders, they may not be appropriate unless they are based on an adequate number of monitoring points and representative data. The contours should be based on unit intervals whose accuracy ranges do not overlap. In most situations, two separate reporting formats are appropriate. First, the data should be included as tables. These tables should generally be used to present the analytical results for a given sample. Each table could include samples from several locations for a given matrix, or could include samples from each location for all sample matrices. Data from these tables can then be summarized for comparison purposes using graphs.

Graphs are most useful for displaying spatial and temporal variations. Spatial variability for a given analyte can be displayed using bar graphs where the vertical axis represents concentration and the horizontal axis represents downstream distance from the discharge. The results from each monitoring station can then be presented as a concentration bar. Stacked bar graphs can be used to display these data from each matrix at a given location or for more than one analyte from each sample.

Similarly, these types of graphs can be used to demonstrate temporal variability if the horizontal axis represents time rather than distance. In this configuration, each graph will present the results of one analyte from a single monitoring location. Stacked bars can then display multiple analytes or locations. Line graphs, like isopleths, should be used cautiously because the line implies a continuity, either spatial or temporal, that may not be accurately supported by the data.

Scatter plots are useful for displaying correlations between variables. They can be used to support the validity of indicator parameters by plotting the indicator results against the results for a specific constituent.

Graphs are used to display trends and correlations. They should not be used to replace data tables, but rather to enhance the meaning of the data.

## **13.6 Field and Other Methods**

The purpose of this section is to provide an overview of methods that can be used to characterize the nature, rate, and extent of contaminant releases to surface water. Detailed descriptions of specific methods can be found in the indicated references.

The methods presented in this section relate to four specific areas, as follows:

- Surface Water Hydrology;
- Sampling and Constituent Analysis of Surface Water, Sediments, and Biota;
- Characterization of the Condition of the Aquatic Community; and
- Bioassay Methods.

### **13.6.1 Surface Water Hydrology**

The physical attributes of the potentially affected water body should be characterized to effectively develop a monitoring program and to interpret results. Depending on the characteristics of the release and the environmental setting, any or all of the following hydrologic measurements may need to be undertaken.

- Overland flow:
  - Hydraulic measurement;
  - Rainfall/runoff measurement;
  - Infiltration measurement; and
  - Drainage basin characterization (including topographic characteristics, soils and geology, and land use).
- Open channel flow:
  - Measurement of stage (gaging activities);
  - Measurement of width, depth, and cross-sectional area;
  - Measurement of velocity;

- Measurement of channel discharge;
  - Measurement of channel discharge at controls (e.g., dams and weirs); and
  - Definition of flow pathways - solute dispersion studies.
- Closed conduit flow:
    - Measurement of discharge.
  - Lakes and impoundments:
    - Morphometric mapping;
    - Bathymetric mapping;
    - Temperature distributions; and
    - Flow pathways.

The following references provide descriptions of the measurements described above.

National Oceanic and Atmospheric Administration. Rainfall Atlas of the U.S.

Viessman, et al., 1977. Introduction to Hydrology.

USGS. 1977. National Handbook of Recommended Methods for Water-Data Acquisition Chapter 1 (Surface Water) and Chapter 7 (Physical Basin Characteristics for Hydrologic Analyses).

U.S Department of Interior. 1981. Water Measurement Manual. Bureau of Reclamation. GPO No. 024-003-00158-9. Washington, D.C.

Chow. 1964. Open Channel Hydraulics. McGraw-Hill. New York, N.Y.

In addition, the following monographs in the Techniques of Water Resources Investigations series of the USGS (USGS-WSP-1822, 1982) give the reader more detailed information on techniques for measuring discharge and other characteristics of various water bodies and hydrologic conditions:



Benson and Dalrymple. 1967. General Field and Office Procedures for Indirect Discharge Measurement.

Bodhaine, 1968. Measurement of Peak Discharge at Culverts by Indirect Methods. USGS-TWI-03-AS.

Buchanan and Somers. 1968. Stage Measurements at Gaging Stations.

Carter and Davidian. 1968. General Procedure for Gaging Streams. USGS-TWI-03-AL.

## **13.6.2            Sampling of Surface Water, Runoff, Sediment, and Biota**

### **13.6.2.1        Surface Water**

The means of collecting water samples is a function of the classification of the water body, as discussed in Section 13.3.3.1. The following discussion treats lakes and impoundments separately from streams and rivers although, as indicated below, the actual sampling methods are similar in some cases. Wetlands are considered an intergrade between these waters. Stormwater and snowmelt runoff is also treated as a separate category (Section 13.6.2.2). Although estuaries also represent somewhat of an intergrade, estuary sampling methods are similar to those for large rivers and lakes.

#### **13.6.2.1.1      Streams and Rivers**

These waters represent a continuum from ephemeral to intermittent to perennial. Streams and rivers may exhibit some of the same characteristics as lakes and impoundments. The degree to which they are similar is normally a function of channel configuration (e.g., depth, cross sectional area and discharge rate). Larger rivers are probably more similar to most lakes and impoundments, with respect to sampling methods, than to free-flowing headwater streams. In general, however, streams and rivers exhibit a greater degree of mixing due to their free-flowing characteristics than can be achieved in lakes and impoundments. Mixing and dilution of inflow can be slow to fast, depending on the point of discharge to the stream or river and the flow conditions.

Stream and river sampling methods do not differ appreciably from those outlined in the following section (Lakes and Impoundments). However, the selection of monitoring stations must consider additional factors created by differential flow velocities within the stream cross section. Strong currents and turbulence as a result of channel configuration may affect the amount of mixing and the distribution of contaminants in the stream. The reader may wish to refer to the references provided in Section 13.3.1 for a discussion of the manner in which differential velocities are handled in stream gaging studies to obtain representative discharge measurements.

#### 13.6.2.1.2 Lakes and Impoundments

These waters are, by definition, areas where flow velocity is reduced, limiting the circulation of waters from sources such as discharging streams or ground water. They often include a shoreline wetland where water circulation is slow, dilution of inflowing contaminants is minimal, and sediments and plant life become significant factors in sampling strategies. The deeper zones of open water may be vertically stratified and subject to periodic turnover, especially in temperate climates. Sampling programs should be designed to obtain depth-specific information as well as to characterize seasonal variations.

Access to necessary monitoring stations may be impeded by both water depth and lush emergent or floating aquatic vegetation, requiring the use of a floating sampling platform or other means to appropriately place the sampling apparatus. It is common to employ rigid extensions of monitoring equipment to collect surface samples at distances of up to 30 or 40 feet from the shoreline. However, a boat is usually the preferred alternative for distances over about six feet. A peristaltic pump may also be used to withdraw water samples, and has the added advantage of being able to extract samples to a depth of 20 to 30 feet below the surface.

Many sampling devices are available in several materials. Samples for trace metals should not be collected in metal bottles, and samples for organics should not be collected in plastic bottles. Teflon or Teflon-coated sampling equipment, including bottles, is generally acceptable for both types of constituents. EPA (1982) and EPA (1986) provide an analysis of the advantages and disadvantages of many

sampling bottles for specific sampling situations. Detailed descriptions of the use of dippers/transfer devices, pond samplers, peristaltic pumps, and Kemmerer bottles are provided by EPA (1984).

Depth-specific samples in lake environments are usually collected with equipment such as Kemmerer bottles (commonly constructed of brass), Van Dorn samplers (typically of polyvinyl chloride or PVC construction), or Nansen tubes. The depth-specific sample closure mechanism on these devices is tripped by dropping a weight (messenger) down the line. Kemmerer bottles and Nansen tubes may also be outfitted with a thermometer that records the temperature of the water at the time of collection.

#### 13.6.2.1.3 Additional Information

Additional information regarding specific surface water sampling methods may be found in the following general references:

U.S. EPA. 1986. Methods for Evaluating Solid Wastes. EPA/SW-846. GPO No. 955-001-00000-1. Office of Solid Waste. Washington, D.C. 20460.

U.S. EPA. 1984. Characterization of Hazardous Waste Sites -- A Methods Manual: Volume II. Available Sampling Methods. EPA-600/4-84-076. NTIS PB-168771. Washington, D.C. 20460.

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### 13.6.2.2 Runoff Sampling

Runoff resulting from precipitation or snowmelt creates an intermittent release situation that requires special treatment for effective sampling. The contaminant release mechanism in runoff situations may be overflow of ponds containing contaminants or erosion of contaminated soils. Based on an evaluation of the waste characteristics and the environmental setting, the facility owner or operator can determine whether waste constituents will be susceptible to this release mechanism and migration pathway.

Once it has been determined that erosion of contaminated soils is of concern, the quantity of soil transported to any point of interest, such as the receiving water body, can be determined through application of an appropriate modification of the Universal Soil Loss Equation (USLE). The USLE was initially developed by the U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service (ASCS) to assist in the prediction of soil loss from agricultural areas. The initial formula is reproduced below:

$$A = RKLSCP$$

where:

A	=	Estimated annual average soil loss (tons/acre)
R	=	Rainfall intensity factor
K	=	Soil erodibility factor
L	=	Slope-length factor
S	=	Slope-gradient factor
C	=	Cropping management factor*
P	=	Erosion control practice factor*

\*C and P factors can be assumed to equal unity in the equation if no specific crop or erosion management practices are currently being employed. Otherwise, these factors can be significantly less than unity, depending on crop or erosion control practices.

Section 2.6 (Soil Contamination) of the Draft Superfund Exposure Assessment Manual (EPA, 1987) provides a discussion of the application of a modified USLE to characterization of releases through soil erosion. This discussion is summarized in Appendix H (Soil Loss Calculation).

If the potential for a significant contaminant release exists, based on analysis of the hydrologic situation and waste site characteristics, event samples should be taken during high runoff periods. In situations where high runoff is predictable, such as spring runoff or the summer thundershower season, automatic samplers may be set to sample during these periods. Perhaps the most effective way to ensure sampling during significant events is to have personnel available to collect samples at intervals throughout and following the storm. Flow data should be collected coincident with sample collection to permit calculation of contaminant loading in the runoff at various flows during the period. Automated sampling equipment is available that will collect individual samples and composite them either over time or with flow amount, with the latter being preferred. Flow-proportional samplers are usually installed with a flow-measuring device, such as a weir with a continuous head recorder. Such devices are readily available from commercial manufacturers and can be rented or leased. Many facilities with an NPDES discharge permit routinely use this equipment in compliance monitoring.

Automated samplers are discussed in Section 8 of Handbook for Sampling and Sample Preservation of Water and Wastewater (EPA, 1982) (NTIS PB 83-124503); this publication also includes other references to automated samplers and a table of devices available from various manufacturers.

#### 13.6.2.3 Sediment

Sediment is traditionally defined as the deposited material underlying a body of water. Sediment is formed as waterborne solids (particulates) settle out of the water column and build up as bottom deposits.

Sedimentation is greatest in areas where the stream velocity decreases, such as behind dams and flow control structures, and at the inner edge of bends in stream channels. Sediments also build up where smaller, fast-flowing streams and runoff discharge into larger streams and lakes. These areas can be important investigative

areas. Some sections of a streambed may be virtually without sediments. In some streams or some areas of streams, water velocity may be too fast for sediments to deposit and actually may scour the bottom, transporting material and depositing it further downstream. The stream bed in such an area will be primarily rocks and debris.

In some situations, such as low-flow conditions, the overlying water temporarily recedes, exposing sediments to the air. Runoff channels, small lakes, and small streams and rivers may on occasion dry completely. In these cases, samples can be collected using the same procedures described in the Soils section (Section 9) of this document.

For this discussion, the definition of sediment will be expanded to include any material that may be overlain by water at any time during the year. This definition then includes what may otherwise be considered submerged soils and sludges. Submerged soils are found in wetlands and marshes. They may be located on the margins of lakes, ponds, and streams, or may be isolated features resulting from collected runoff, or may appear in areas where the ground-water table exists at or very near the land surface. In any instance they are important investigative areas.

Sludges are included for discussion here because many RCRA facilities use impoundments for treatment or storage and these impoundments generally have a sludge layer on the bottom. Sampling these sludges involves much the same equipment and techniques as would be used for sediments.

There are essentially two ways to collect sediment samples, either by coring or with grab/dredges. Corers are metal tubes with sharpened lower edges. The corer is forced vertically into the sediment. Sediments are held in the core tube by friction as the corer is carefully withdrawn; they can then be transferred to a sample container. There are many types and modifications of corers available. Some units are designed to be forced into the sediments by hand or hydraulic pressure; others are outfitted with weights and fins and are designed to free fall through the water column and are driven into the sediment by their fall-force.

Corers sample a greater thickness of sediments than do grab/dredges and can provide a profile of the sediment layers. However, they sample a relatively small

surface area. Most corers are less than four inches in diameter and are more commonly two inches in diameter.

Grab/dredges are basically clamshell-type scoops that sample a larger surface area but offer less depth of penetration. Typical grab/dredge designs are the Ponar, Eckman, and Peterson versions; each has a somewhat different operating mechanism and slightly different advantages. Some use spring force to close the jaws while others are counter-levered like ice tongs.

In sediment sampling, vertical profiling is not normally required because deposition of hazardous material is often a recent activity in terms of sedimentary processes. Grab/dredges that sample a greater surface area may be more appropriate than corers. Similarly, shallow sludge layers contained in surface impoundments should be sampled with grab/dredges because corer penetration could damage the impoundment liner, if present. Thicker sludge layers which may be present in surface impoundments, may be sampled using coring equipment if it is important to obtain vertical profile information.

Submerged soils are generally easier to sample with a corer, than with a grab/dredge because vegetation and roots can prevent the grab/dredges from sealing completely. Under these conditions, most of the sample may wash out of the device as it is recovered. Corers can often be forced through the vegetation and roots to provide a sample. In shallow water, which may overlies submerged soils, sampling personnel can wade through the water (using proper equipment and precautions) and choose sample locations in the small, clear areas between vegetative stems and roots.

A wide variety of sampling devices are available for collection of sediment samples. Each has advantages and disadvantages in a given situation, and a variety of manufacturers produce different versions of the same device. As with water sampling, it is important to remember that metal samplers should not be used when collecting samples for trace metal analysis, and sampling devices with plastic components should not be used when collecting samples for analysis of organics.

The following references describe the availability and field use of sediment samplers:

U.S. EPA. 1982. Handbook for Sampling and Sample Preservation of Water and Wastewater. Environmental Monitoring and Support Laboratory, EPA-600/4-82-029. NTIS PB 83-124503.

U.S. EPA. 1985. Methods Manual for Bottom Sediment Sample Collection. NTIS PB 86-107414.

USGS. 1977, update June 1983. National Handbook of Recommended Methods for Water-Data Acquisition.

U.S. EPA. 1984. Characterization of Hazardous Waste Sites -- A Methods Manual: Volume II. Available Sampling Methods. EPA-600/4-84-076. NTIS PB 85-168771.

#### 13.6.2.4 Biota

Collection of biota for constituent analysis (whole body or tissue) may be necessary to evaluate exposure of aquatic organisms or man to bioaccumulative contaminants. For the most part, collection should be restricted to representative fish species and sessile macroinvertebrates, such as mollusks. Mollusks are filter-feeders; bioaccumulative contaminants in the water column will be extracted and concentrated in their tissues. Fish species may be selected on the basis of their commercial or recreational value, and their resultant probability of being consumed by man or by special status-species of fish or wildlife.

The literature on sampling aquatic organisms is extensive. Most sampling methods include capture techniques that be collected using sampling bottles (as for water samples) or nets of appropriate mesh sizes. Periphyton may be most easily collected by scraping off the substrate to which the organisms are attached. Other techniques using artificial substrates are available if a quantitative approach is required. Aquatic macroinvertebrates may be collected using a wide variety of methods, depending on the area being sampled; collection by hand or using forceps may be efficient. Grab sampling, sieving devices, artificial substrates and drift nets may also be used effectively. EPA (1973) provides a discussion of these techniques, as well as a method comparison and description of data analysis techniques.



Fish collection techniques may be characterized generally as follows (USGS, 1977):

- Entangling gear:  
Gill nets and trammel nets.
- Entrapping gear:  
Hoop nets, basket traps, trap nets, and fyke and wing nets.
- Encircling gear:  
Haul seine, purse seine, bay seine, and Danish seine.
- Electroshocking gear:  
Boat shockers, backpack shockers, and electric seines.

Selection of sampling equipment is dependent on the characteristics of the water body, such as size and conditions, the size of the fish to be collected, and the overall objectives of the study. Fisheries Techniques (Nielsen and Johnson, 1983) and Guidelines for Sampling Fish in Inland Waters (Backiel and Welcomme, 1980) provide basic descriptions of sampling methods and data interpretation from fisheries studies.

### 13.6.3 Characterization of the Condition of the Aquatic Community

Evaluation of the condition of aquatic communities may proceed from two directions. The first consists of examining the structure of the lower trophic levels as an indication of the overall health of the aquatic ecosystem. With respect to RFI studies, a healthy water body would be one whose trophic structure indicates that it is not impacted by contaminants. The second approach focuses on a particular group or species, possibly because of its commercial or recreational importance or because a substantial historic data base already exists.

The first approach emphasizes the base of the aquatic food chain, and may involve studies of plankton (microscopic flora and fauna), periphyton (including bacteria, yeast, molds, algae, and protozoa), macrophyton (aquatic plants), and benthic macroinvertebrates (e.g., insects, annelid worms, mollusks, flatworms, roundworms, and crustaceans). These lower levels of the aquatic community are

studied to determine whether they exhibit any evidence of stress. If the community appears to have been disturbed, the objective is to characterize the source(s) of the stress and, specifically, to focus on the degree to which the release of waste constituents has caused the disturbance or possibly exacerbated an existing problem. An example of the latter would be the further depletion of already low dissolved oxygen levels in the hypolimnion of a lake or impoundment through the introduction of waste with a high COD and specific gravity.

The sampling methods referenced in Section 13.6.2.4 may be adapted (by using them in a quantitative sampling scheme) to collect the data necessary to characterize aquatic communities. Hynes (1970) and Hutchinson (1967) provide an overview of the ecological structure of aquatic communities.

Benthic macroinvertebrates are commonly used in studies of aquatic communities. These organisms usually occupy a position near the base of the food chain. Just as importantly, however, their range within the aquatic environment is restricted, so that their community structure may be referenced to a particular stream reach or portion of lake substrate. By comparison, fish are generally mobile within the aquatic environment, and evidence of stress or contaminant load may not be amenable to interpretation with reference to specific releases.

The presence or absence of particular benthic macroinvertebrate species, sometimes referred to as "indicator species," may provide evidence of a response to environmental stress. Several references are available in this regard. For more information, the reader may consult Selected Bibliography on the Toxicology of the Benthic Invertebrates and Periphyton (EPA, 1984).

A "species diversity index" provides a quantitative measure of the degree of stress within the aquatic community, and is an example of a common basis for interpretation of the results of studies of aquatic biological communities. The following equation (the Sannon-Wiener Index) demonstrates the concept of the diversity index:

$$H = \sum_{i=1}^S (P_i) (\log_2 P_i)$$

where:

- H = species diversity index
- s = number of species
- P<sub>i</sub> = proportion of total sample belonging to the *i*th species

Measures of species diversity are most useful for comparison of streams with similar hydrologic characteristics or for the analysis of trends over time within a single stream. Additional detail regarding the application of other measures of community structure may be found in the following references:

U.S. EPA. 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Water and Effluents.

USGS. 1977, Update May, 1983. National Handbook of Recommended Methods of Water-Data Acquisition.

Curns, J. Jr., and K.L. Dickson, eds. 1973. ASTM STP 528: Biological Methods for the Assessment of Water Quality. American Society for Testing and Materials. STP528. Philadelphia, PA.

The second approach to evaluating the condition of an aquatic community is through selective sampling of specific organisms, most commonly fish, and evaluation of standard "condition factors" (e.g., length, weight, girth). In many cases, receiving water bodies are recreational fisheries, monitored by state or federal agencies. In such cases, it is common to find some historical record of the condition of the fish population, and it may be possible to correlate operational records at the waste management facility with alterations in the status of the fish population.

Sampling of fish populations to evaluate condition factors employs the same methodologies referenced in Section 13.6.2.4. Because of the intensity of the effort usually associated with obtaining a representative sample of fish, it is common to coordinate tissue sampling for constituent analysis with fishery surveys.

#### 13.6.4 Bioassay Methods

The purpose of a bioassay, as discussed in more detail in Section 13.4.6.3, is to predict the response of aquatic organisms to specific changes within the environment. In the RFI context, a bioassay may be used to predict the potential adverse environmental effects of releases to surface water. Thus, bioassay is not generally considered to be an environmental characterization or monitoring technique. As indicated below, bioassay may be required for Federal water quality programs or state programs, especially where stream classification (e.g., warm-water fishery, cold-water fishery) is involved.

Bioassays may be conducted on any aquatic organism including algae, periphyton, macroinvertebrates, or fish. Bioassay includes two main techniques, acute toxicity tests and chronic toxicity tests. Each of these may be done in a laboratory setting or using a mobile field laboratory. Following is a brief discussion of acute and chronic bioassay tests.

Acute Toxicity Tests--Acute toxicity tests are used in the NPDES permit program to identify effluents containing toxic wastes discharged in toxic amounts. The data are used to predict potential acute and chronic toxicity in the receiving water, based on the LC50 and appropriate dilution, and application of persistence factors. Two types of tests are used; static and flow-through. The selection of the test type will depend on the objectives of the test, the available resources, the requirements of the test organisms, and effluent characteristics. Special environmental requirements of some organisms may preclude static testing.

It should be noted that a negative result from an acute toxicity test with a given effluent sample does not preclude the presence of chronic toxicity, nor does it negate the possibility that the effluent may be acutely toxic under different conditions, such as variations in temperature or contaminant loadings.

There are many sources of information relative to the performance of acute bioassays. Methods for Measuring the Acute Toxicity of Effluents to Freshwater and Marine Organisms (Peltier and Weber, 1985) provides a comprehensive treatment of the subject.

Chronic Toxicity Tests--Chronic toxicity tests may include measurement of effluent effects on growth and reproductive success. These tests usually require long periods of time, depending on the life cycles of the test organisms. Chronic bioassays are generally relatively sophisticated procedures and are more intensive in terms of manpower, time and expense than are acute toxicity tests. The inherent complexity of these tests dictate careful planning with the regulatory agency prior to initiation of the work. Methods for Measuring the Chronic Toxicity of Effluents to Aquatic Organisms (Horning and Weber, 1985) is a companion volume to the methods document noted above, and contains method references for chronic toxicity tests. A discussion of bioassay procedures is also provided in Protocol for Bioassessment of Hazardous Waste Sites, NTIS PB 83-241737. (Tetra Tech, 1983).

Chronic toxicity tests are also used in the NPDES permit program to identify and control effluents containing toxic wastes in toxic amounts.

### 13.7 Site Remediation

Although the RFI Guidance is not intended to provide detailed guidance on site remediation, it should be recognized that certain data collection activities that may be necessary for a Corrective Measures Study may be collected during the RFI. EPA has developed a practical guide for assessing and remediating contaminated sites that directs users toward technical support, potential data requirements and technologies that may be applicable to EPA programs such as RCRA and CERCLA. The reference for this guide is provided below.

U.S. EPA. 1988. Practical Guide for Assessing and Remediating Contaminated Sites. Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

The guide is designed to address releases to ground water as well as soil, surface water and air. A short description of the guide is provided in Section 1.2 (Overall RCRA Corrective Action Process), under the discussion of Corrective Measures Study.

## 13.8 Checklist

### RFI CHECKLIST - SURFACE WATER

Site Name/Location \_\_\_\_\_

Type of Unit \_\_\_\_\_

1. Does waste characterization include the following information? (Y/N)
  - Constituents of concern \_\_\_\_\_
  - Concentrations of constituents \_\_\_\_\_
  - Mass of the constituent \_\_\_\_\_
  - Physical state of waste (e.g., solid, liquid, gas) \_\_\_\_\_
  - Water solubility \_\_\_\_\_
  - Henry's Law Constant \_\_\_\_\_
  - Octanol/Water Partition Coefficient ( $K_{ow}$ ) \_\_\_\_\_
  - Bioconcentration Factor (BCF) \_\_\_\_\_
  - Adsorption Coefficient ( $K_{oc}$ ) \_\_\_\_\_
  - Physical, biological, and chemical degradation \_\_\_\_\_
  
2. Does unit characterization include the following information? (Y/N)
  - Age of unit \_\_\_\_\_
  - Type of unit \_\_\_\_\_
  - Operating practices \_\_\_\_\_
  - Quantities of waste managed \_\_\_\_\_
  - Presence of cover \_\_\_\_\_
  - Dimensions of unit \_\_\_\_\_
  - Presence of natural or engineered barriers \_\_\_\_\_
  - Release frequency \_\_\_\_\_
  - Release volume and rate \_\_\_\_\_
  - Non-point or point source release \_\_\_\_\_
  - Intermittent or continuous release \_\_\_\_\_

RFI CHECKLIST - SURFACE WATER (Continued)

3. Does environmental setting information include the following? (Y/N)
- Areal extent of drainage basin \_\_\_\_\_
  - Location and interconnection of all streams, lakes and other surface water features \_\_\_\_\_
  - Flow identification as ephemeral, intermittent or perennial \_\_\_\_\_
  - Channel alignment, gradient and discharge rate \_\_\_\_\_
  - Flood and channel control structures \_\_\_\_\_
  - Source of lake and impoundment water \_\_\_\_\_
  - Lake and impoundment depths and surface area \_\_\_\_\_
  - Vertical temperature stratification of lakes and impoundments \_\_\_\_\_
  - Wetland presence and role in basin hydrology \_\_\_\_\_
  - NPDES and other discharges \_\_\_\_\_
  - USGS gaging stations or other existing flow monitoring systems \_\_\_\_\_
  - Surface water quality characteristics \_\_\_\_\_
  - Average monthly and annual precipitation values \_\_\_\_\_
  - Average monthly temperature \_\_\_\_\_
  - Average monthly evaporation potential estimates \_\_\_\_\_
  - Storm frequency and severity \_\_\_\_\_
  - Snowfall and snow pack ranges \_\_\_\_\_
4. Have the following data on the initial phase of the release characterization been collected? (Y/N)
- Monitoring locations \_\_\_\_\_
  - Monitoring constituents and indicator parameters \_\_\_\_\_
  - Monitoring frequency \_\_\_\_\_
  - Monitoring equipment and procedures \_\_\_\_\_
  - Concentrations of constituents and locations at which they were detected \_\_\_\_\_
  - Background monitoring results \_\_\_\_\_

## RFI CHECKLIST - SURFACE WATER (Continued)

---

		(Y/N)
●	Hydrologic and biomonitoring results	_____
●	Inter-media transfer data	_____
●	Analyses of rate and extent of contamination	_____
5.	Have the following data on the subsequent phase(s) of the release characterization been collected?	(Y/N)
●	New or relocated monitoring locations	_____
●	Constituents and indicators added or deleted for monitoring	_____
●	Modifications to monitoring frequency, equipment or procedures	_____
●	Concentrations of constituents and locations at which they were detected	_____
●	Background monitoring results	_____
●	Hydrologic and biomonitoring results	_____
●	Inter-media transfer data	_____
●	Analyses of rate and extent of contamination	_____

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## **APPENDIX G**

### **AIR RELEASE SCREENING ASSESSMENT METHODOLOGY**

**DRAFT FINAL  
(Revised)**

**AIR RELEASE  
SCREENING ASSESSMENT  
METHODOLOGY**

**MAY 1989**

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## 1.0 INTRODUCTION

A screening method has been developed for evaluating which waste management units have air releases warranting further investigation under a RCRA Facility Investigation (RFI). This method can be used as an intermediate step between the general qualitative determination of the RCRA Facility Assessment (RFA) regarding identification of air emissions that warrant an RFI, and the actual performance of a complicated and costly RFI. Specifically, this screening methodology provides a basis for identifying air releases with the potential to have resulted in off-site exposures that meet or exceed health-based criteria in the RFI Guidance.

This screening methodology has been developed as a technical aid for routine use by EPA Regional and State staff who may not be familiar with air release assessments. However, it should also be considered a resource available to prioritize waste management units which may warrant the conduct of an RFI for the air media. Alternative resources (e.g., available air monitoring data, more sophisticated modeling analyses, judgmental factors) may also provide important input to the RFI decision-making process.

The screening methodology itself is explained in Section 2 and example applications of it are presented in Section 3. A discussion of background information that addresses the technical basis for the air release screening methodology is presented in Appendix A.

## **2.0 SCREENING METHODOLOGY**

This section presents the air release screening assessment methodology. This methodology can be used as a transition between the general qualitative determination made in the RFA regarding air emissions that warrant an RFI, and the actual performance of an RFI.

The primary (recommended) screening approach involves the application of available emission rate models and dispersion models. An alternative approach involves the use of technical aids based on scaling modeling results for a limited set of source scenarios.

The screening methodology for releases of organics is based on using the CHEMDAT6 air emission models, available from EPA's Office of Air Quality Planning and Standards (OAQPS), (U.S. EPA, December 1987). Specifically, the following unit categories are directly addressed in this section:

- Disposal impoundments
- Storage impoundments
- Oil Films on Storage Impoundments
- Mechanically Aerated Impoundments
- Diffused Air Systems
- Land treatment (emissions after tilling)
- Oil Film Surfaces on Land Treatment Units
- Closed landfills
- Open landfills
- Wastepiles

The alternative approach presented in this section involves scaling the emission rate results from numerous source scenarios that have been modeled using CHEMDAT6. These scaling computations can become tedious if numerous source scenarios are evaluated. In addition, the direct use of CHEMDAT6 models will provide more representative unit-specific emission estimates. Therefore, it is strongly recommended that EPA Regional and State agency staff develop a capability to use CHEMDAT6 directly to model unit-specific and facility-specific scenarios.

CHEMDAT6 has been developed for use on a microcomputer using LOTUS spreadsheet software; therefore, these models can easily be used by staff familiar with LOTUS applications. However, the basic strategy described in this section to estimate ambient concentrations can still be successfully used even without using LOTUS.

The screening methodology for organic emissions from storage tanks is based on emission factors in EPA's AP-42, "Compilation of Air Pollutant Emission Factors" (U.S. EPA, September 1985). The following categories of tanks are addressed:

- Fixed roof tanks
- Floating roof tanks
- Variable vapor space tanks.

Open tanks should be assessed using the methodology for storage impoundments.

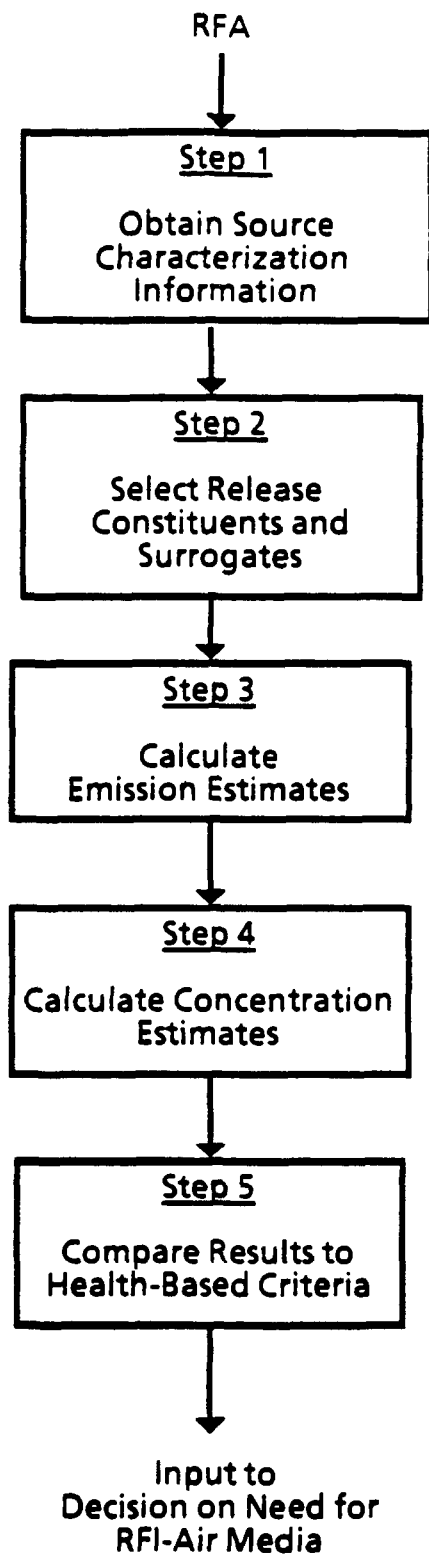
The screening methodology for particulate matter releases from wind erosion of storage piles and batch dumping and loader activity on the pile is based on emission factors in EPA's AP-42 (U.S. EPA, September 1985). The screening methodology for particulate matter releases from wind erosion of flat, exposed, contaminated surface areas is based on emission factors in EPA's "Fugitive Emissions from Integrated Iron and Steel Plants" (U.S. EPA, March 1978). The EPA-OAQPS is currently developing guidance regarding particulate emissions for treatment, storage, and disposal facilities.

## **2.1      Overview**

The air release screening assessment methodology involves applying emission rate and dispersion results to estimate long-term ambient concentrations at receptor locations for comparison to health-based criteria. The methodology consists of five steps as follows (see Figure 2-1):

- Step 1 - Obtain Source Characterization Information: This information (e.g., unit size, operational schedule) is needed to define the emission potential of the specific unit.

FIGURE 2-1  
SCREENING METHODOLOGY OVERVIEW



- **Step 2- Select Release Constituents and Surrogates:** The primary approach involves using the actual physical/chemical properties for all unit-specific constituents for emission modeling purposes. The alternative (scaling) screening approach uses a limited set of constituents or surrogates to represent a wide range of potential release constituents. This surrogate approach significantly simplifies the screening assessment process.
- **Step 3 - Calculate Emission Estimates:** The primary approach involves the use of emission rate models based on unit-specific source conditions. Modeling results of emission rates for a wide range of source conditions are also presented in Appendices C through Q. As an alternative approach, these modeling results can be interpolated to estimate an emission rate specific to the unit.
- **Step 4 - Calculate Concentration Estimates:** Emission rates from Step 3 are used to calculate concentration estimates at receptor locations of interest. The primary approach involves the application of dispersion models based on site-specific meteorological conditions. As an alternative approach, dispersion conditions are accounted for by use of modeling results available in Appendix R for typical annual meteorological conditions.
- **Step 5 - Compare Concentration Results to Health-Based Criteria:** Concentration results from Step 4 can be compared to constituent-specific health-based criteria provided in the RFI Guidance.

For some applications, Step 4 (Calculate Concentration Estimates) will not warrant the use of emission models because it can be assumed that all the volatile wastes handled will eventually be emitted to the air. This assumption is generally appropriate for highly volatile organic compounds placed in a disposal unit like a surface impoundment. In these cases, the air emission rate can be assumed to be equivalent to the disposal rate, so that an emission rate model may not be required. This assumption is valid because of the long-term residence time of wastes in the disposal units. In open units like surface impoundments, a substantial portion of the volatile constituents will frequently be released to the atmosphere within

several days. However, for more complex situations (e.g., storage or treatment units where total volatilization of the constituents is not expected), air emission models can be used to obtain a more refined long-term release rate.

Results from the air release screening assessment, using the above steps, will provide input to decisions on the need for an RFI for the air media. They can also be used to prioritize air emission sources at a facility (i.e., by identification of the major onsite air emission sources) as well as to prioritize the total release potential at candidate facilities.

## **2.2      Step 1 - Source Characterization Information**

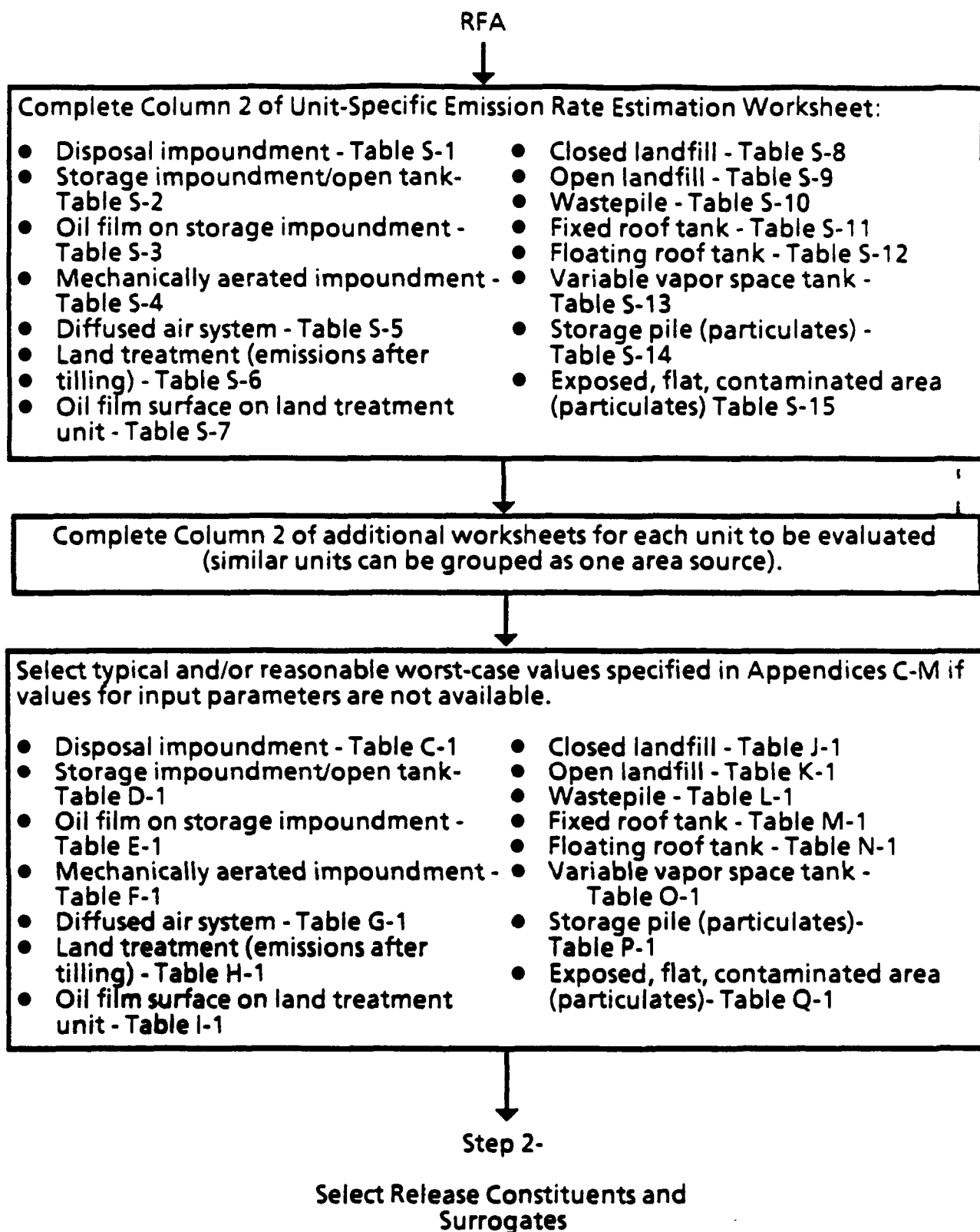
Implementation of the air release screening assessment methodology involves collecting source characterization information, as illustrated in Figure 2-2. Specifically, this involves completion of Column 2 of unit-specific Emission Rate Estimation Worksheets (included in Appendix S) as specified in Figure 2-2. Parameters in Column 2 of the worksheet represent standard input used by the CHEMDAT6 air emission models or input to the AP-42 emission equations. Source characterization information should be available from the RFA but it may be necessary to request additional information from the facility owner or operator on an ad hoc basis.

Additional worksheets should be completed for each unit to be evaluated. Similar units can be grouped together and considered as one area source to simplify the assessment process. For example, several contiguous landfills of similar design could be evaluated efficiently as one (combined) source.

Completeness and quality of the source characterization information are very important and, as previously stated, directly affect the usefulness of the screening assessment results. Certain source characterization parameters are considered critical inputs to the screening assessment. These critical input parameters are needed to define the total mass of constituents in the waste input to the unit being evaluated or the potential for release of particles less than 10 microns. These parameters have been identified in the unit-specific worksheet (Tables S-1 through S-13 for VO sources and Tables S-14 and 15 for particulate sources).



**FIGURE 2-2**  
**STEP 1 - OBTAIN SOURCE CHARACTERIZATION INFORMATION**



Unit-specific values for some of the source characterization parameters may be difficult to determine. For example, air porosity values of the fixed waste are needed for evaluating emissions from open landfills, closed landfills, and wastepiles, and total porosity values of the fixed waste are needed to evaluate emissions from open landfills and wastepiles. However, unit-specific data are typically not available for these parameters. If unit-specific values for input parameters are not available, typical and/or reasonable worst-case values should be selected from the range of values specified in Appendices C through Q.

Selection of source scenario input data should be based on realistic physical and chemical limitations. For example, the waste concentration value for a constituent should not exceed the constituent-specific solubility in water.

### **2.3      Step 2 - Release Constituent Surrogates**

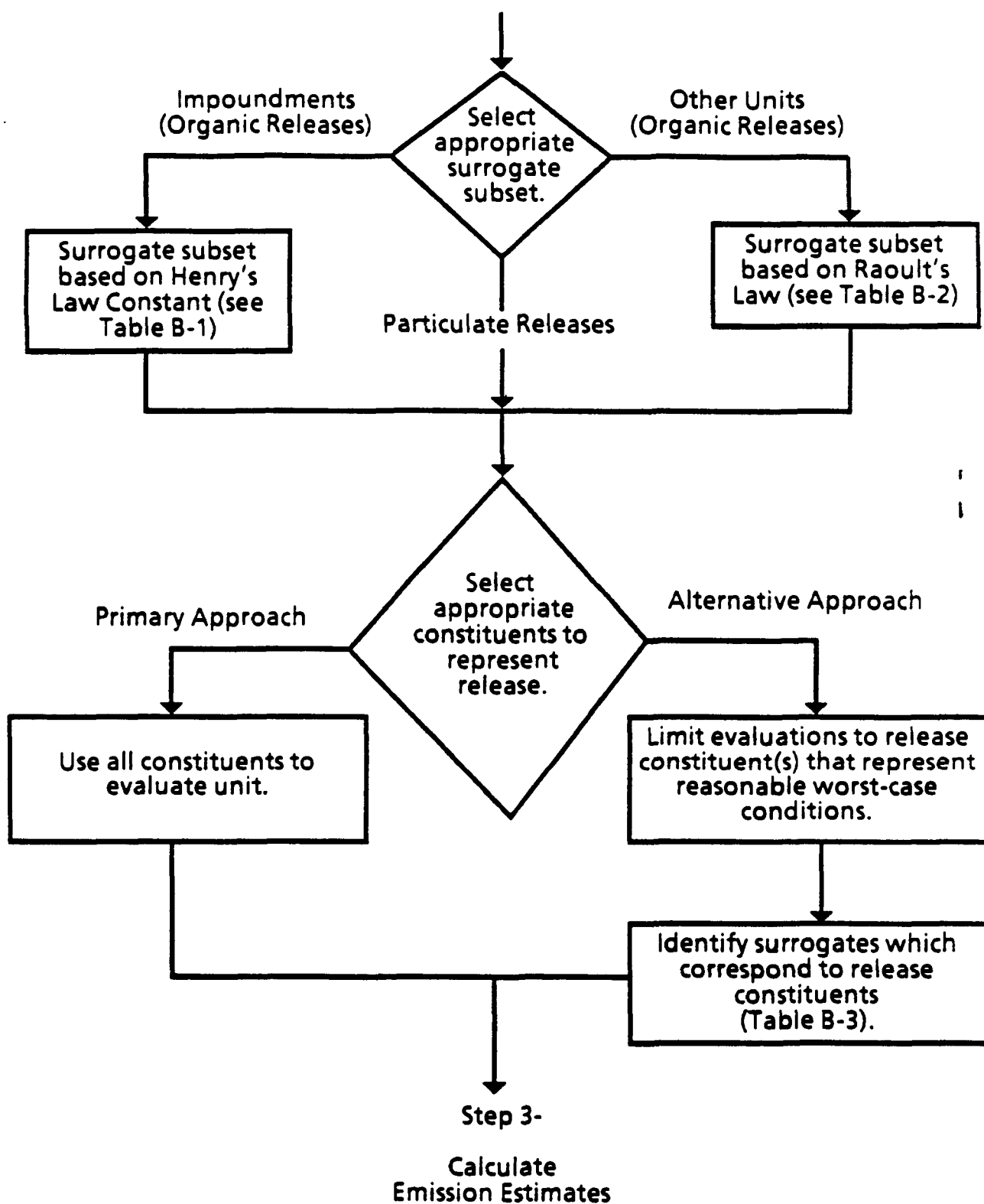
The primary approach involves using the actual physical/chemical properties for all unit-specific constituents for emission modeling purposes. The alternative screening approach (scaling) uses a limited set of constituents or surrogates.

A limited set of surrogates is used to represent the constituents of concern in this alternative screening method to represent a wide range of potential release constituents. This significantly simplifies the screening assessment process since the list of potential air release constituents included in the RFI Guidance is extensive. Selection of appropriate source release constituent surrogates is illustrated in Figure 2-3. Table B-3 presents the appropriate surrogate to be used for each constituent of concern. This step is not used in screening for particle emissions from storage piles and exposed areas.

Table B-3 of Appendix B, presents the appropriate surrogate to be used for each constituent of concern. Two subsets of surrogates are presented in Appendix B. The first subset is applicable to emissions that can be estimated based on Henry's Law Constant (i.e., applicable for low concentrations, less than 10 percent, of wastes in aqueous solution). Surrogates based on Henry's Law Constant are appropriate for units like storage and disposal impoundments. Henry's Law Constant surrogates are presented in Table B-1.

**FIGURE 2-3**  
**STEP 2 - SELECT RELEASE CONSTITUENTS AND SURROGATES**

Source Characterization Information



The second subset is applicable to emissions that can be estimated based on Raoult's Law. Raoult's Law predicts the behavior of most concentrated mixtures of water and organic solvents (i.e., solution with over 10 percent solute). Surrogates based on Raoult's Law are appropriate for units like landfills, wastepiles, land treatment units and storage tanks. Raoult's Law surrogates are listed in Table B-2.

It is also necessary to select surrogates from the appropriate subset (i.e., from the Henry's Law Constant or Raoult's Law subset selected) to represent release constituents of interest. The primary approach is to use all surrogates from the appropriate subset to evaluate the unit. This approach will provide a comprehensive data base for the screening assessment. An alternative approach is to select release constituent(s)/surrogate(s) that represent reasonable worst-case conditions. Release constituents having the most restrictive health-based criteria and those having high volatility are frequently associated with these reasonable worst-case (long-term) release conditions.

## **2.4      Step 3 - Emission Estimates**

Two approaches for calculating emission estimates are identified in Figure 2-4. The primary approach involves the calculation of unit-specific emission rates based on available models (e.g., CHEMDAT6, et cetera). This approach is recommended for most applications.

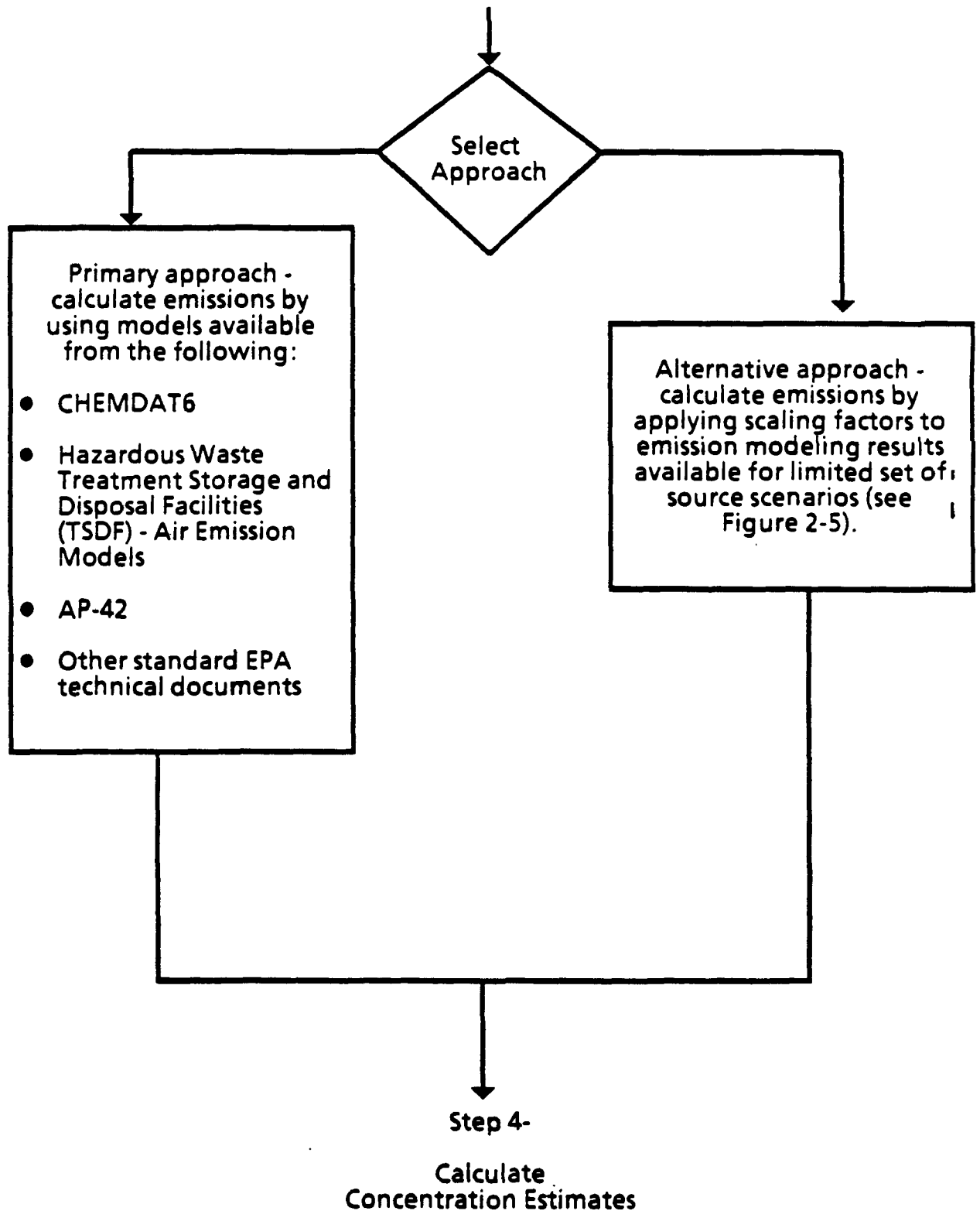
The alternative approach involves the calculation of emissions by applying scaling factors to emission modeling results presented in Appendices C through Q for a limited set of source scenarios. This approach is appropriate when a rapid preliminary estimate is needed and modeling resources are not available. However, the primary approach will provide more representative unit-specific emission estimates.

Specific instructions for implementing the alternative emission estimation approach are presented in Figure 2-5.

Emission rate modeling results for a wide range of source scenario conditions are presented in Appendices C through Q to facilitate implementation of the alternative emission estimation approach. These available modeling results can be

**FIGURE 2-4**  
**STEP 3 - CALCULATE EMISSION ESTIMATES**

Source Characterization Information/Constituent Surrogates



**FIGURE 2-5**  
**STEP 3 - CALCULATE EMISSION ESTIMATES (ALTERNATIVE APPROACH)**

Source Characterization Information/Constituent Surrogates

Obtain Emission Rate Estimation Worksheets (as selected in Step 1):

- Disposal impoundment - Table S-1
- Storage impoundment/open tank - Table S-2
- Oil film on storage impoundment - Table S-3
- Mechanically aerated impoundment - Table S-4
- Diffused air system - Table S-5
- Land treatment - Table S-6
- Oil film surface on land treatment unit - Table S-7
- Closed landfill - Table S-8
- Open landfill - Table S-9
- Wastepile - Table S-10
- Fixed roof tank - Table S-11
- Floating roof tank - Table S-12
- Variable vapor space tank - Table S-13
- Storage pile (particulates) - Table S-14
- Exposed, flat, contaminated area (particulates) - Table S-15

Select the source scenario for each modeling parameter (identified in Col. 1 of worksheets) that best represents unit-specific conditions from available cases (appropriate alternative case numbers are identified in Col. 3 of the worksheet and case specifications are presented in Appendices C-Q):

- Disposal impoundment - Table C-1
- Storage impoundment/open tank - Table D-1
- Oil film on storage impoundment - Table E-1
- Mechanically aerated impoundment - Table F-1
- Diffused air system - Table G-1
- Land treatment - Table H-1
- Oil film surface on land treatment unit - Table I-2
- Closed landfill - Table J-1
- Open landfill - Table K-1
- Wastepile - Table L-1
- Fixed roof tank - Table M-1
- Floating roof tank - Table N-1
- Variable vapor space tank - Table O-1
- Storage pile (particulates) - Table P-1
- Exposed, flat, contaminated area (particulates) Table Q-1

Compute parameter-specific scaling factors by completing Cols. 4-11 (12 for Raoult's Law surrogates) of the worksheet or Col. 4 for particulate worksheets based on modeling results presented in Appendices C-Q (computational instructions are presented with each worksheet):

- Disposal impoundment - Table C-2
- Storage impoundment/open tank - Table D-2
- Oil film on storage impoundment - Table E-2
- Mechanically aerated impoundment - Table F-2
- Diffused air system - Table G-2
- Land treatment - Table H-2
- Oil film surface on land treatment unit - Table I-2
- Closed landfill - Table J-2
- Open landfill - Table K-2
- Wastepile - Table L-2
- Fixed roof tank - Table M-2
- Floating roof tank - Table N-2
- Variable vapor space tank - Table O-2
- Storage pile (particulates) - Table P-2
- Exposed, flat, contaminated area (particulates) Table Q-2

Complete unit-specific emission rate, which accounts for unit-specific scaling factors (last line item on each worksheet based on instructions presented with each worksheet).

Step 4-

Calculate Concentration Estimates

interpolated to estimate a unit-specific emission rate. The process for calculating emission rate estimates for application to a specific unit (i.e., unit-specific application) is summarized in Figure 2-5.

Calculating emission rate estimates is accomplished by completing an Emission Rate Estimation Worksheet, included in Appendix S. A separate worksheet is provided in Appendix S for each unit category. Column 2 (unit-specific values for each modeling parameter) of the worksheet should already have been completed during Step 1.

The alternative emission estimation approach presented in Figure 2-5 also involves scaling the emission rate modeling results available in Appendices C through Q to represent unit-specific conditions. This is accomplished by first computing individual parameter-specific factors and then combining the results to calculate a unit-specific emission rate for each surrogate of interest. Therefore, it is necessary to select the appropriate source scenario that best represents unit-specific conditions for each modeling parameter (identified in Column 1 of the worksheet). Column 3 of the worksheet identifies the appropriate candidate scenario cases for each parameter. The source scenario case specifications (i.e., values of the modeling parameters for each case) are presented in Table C -1 (disposal impoundment), D-1 (storage impoundment), E-1 (oil film on storage impoundment), F-1 (mechanically aerated impoundment), G-1 (diffused air system), H-1 (land treatment), I-1 (oil film surface on land treatment unit), J-1 (closed landfill), K-1 (open landfill), L-1 (wastepile), M-1 (fixed roof tank), N-1 (floating roof tank), O-1 (variable vapor space tank), P-1 (storage piles), and Q-1 (exposed, flat, contaminated areas).

It is also recommended that a second scenario case be selected for each parameter in order to bracket source conditions. The selection of a second scenario is appropriate if unit-specific source conditions are different than those presented in the source scenario case specifications (Appendices C-Q).

Parameter-specific scaling factors are computed by following instructions in each worksheet and by completing Columns 4-11 (12). (Column 12 is needed for Raoult's Law surrogates.) Information needed to complete Columns 4-11 (12) is available in Appendices C through Q. Information needed to complete worksheets for particulate emissions are available in Appendices P and Q. Instructions for

computing unit-specific emission rates based on applying scaling factors are included in each worksheet.

The last set of three source scenario cases for unit-category modeling results presented in Appendices C through Q represents the following:

- Reasonable best-case emission rate for unit category (for a typical source surface area or tank size)
- Typical emission rate for unit category (for a typical source surface area or tank size)
- Reasonable worst-case emission rate for unit category (for a typical source surface area or tank size)

Frequently these cases can be used to rapidly estimate typical and extreme emission rates. However, they should not be considered as absolute values. These scenarios generally represent the range of source conditions identified in the Hazardous Waste Treatment, Storage and Disposal Facilities (TSDF) Air Emission Models (U.S. EPA, December 1987). But frequently this information was incomplete, and subjective estimates were postulated instead. Therefore, the emission rates for best, typical and worst case source scenarios should only be used as a preliminary basis to compare and prioritize sources.

At times one of the source scenario cases presented in the Appendices may be representative of the modeling parameters for the unit scenario being evaluated. For these situations, it is not necessary to implement all of the intermediate computational steps otherwise needed to complete the worksheet. Instead, the modeling results presented in Appendices C through Q can be used to directly represent unit-specific emission rates. However, it may be necessary to scale these results to account for the unit-specific surface area and waste constituent concentrations. (Scaling can be accomplished by the approach specified in each worksheet).



## 2.5 Step 4 - Concentration Estimates

Emission rate values from Step 3 are used as input to calculate concentration estimates at receptor locations of interest. Dispersion conditions are accounted for by use of available modeling results for typical annual meteorological conditions. A summary of this process is included in Figure 2-6. Dispersion models can be applied to directly estimate concentration. This primary approach is recommended for most applications. The EPA-Industrial Source Complex (ISC) model is generally appropriate for a wide range of sources in flat or rolling terrain. Alternative models are identified in the Guideline On Air Quality Models (Revised) (U.S. EPA, July 1988).

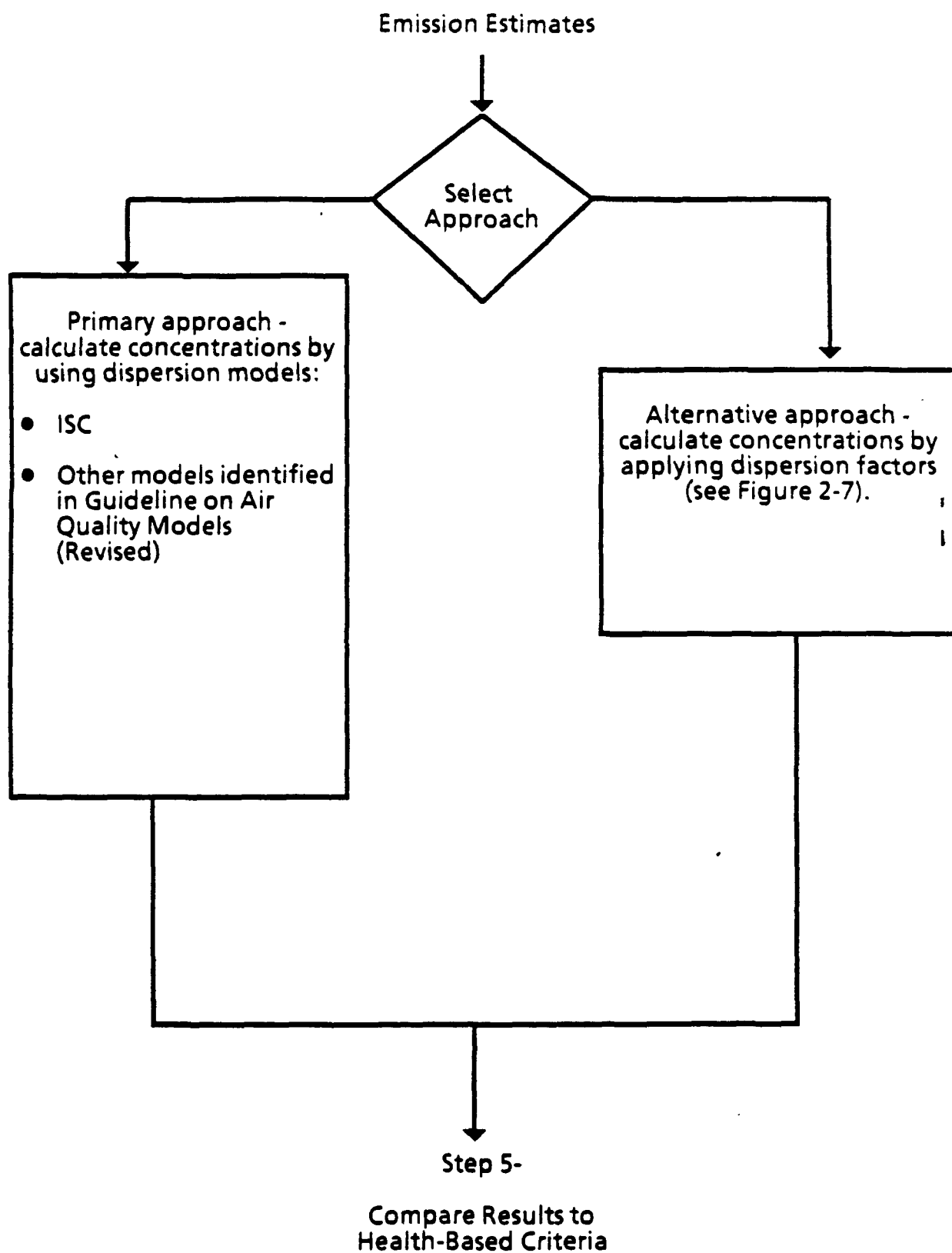
An alternative approach to obtain concentration estimates (for flat terrain sites) involves the application of dispersion factors presented in Appendix R. A Concentration Estimation Worksheet (Table R-1) is used as the basis for concentration calculations. This approach is appropriate when a rapid preliminary estimate is needed and modeling resources are not available. However, the primary approach will provide more representative site-specific concentration estimates.

Specific instructions for implementing the alternative concentration estimation approach are presented in Figure 2-7.

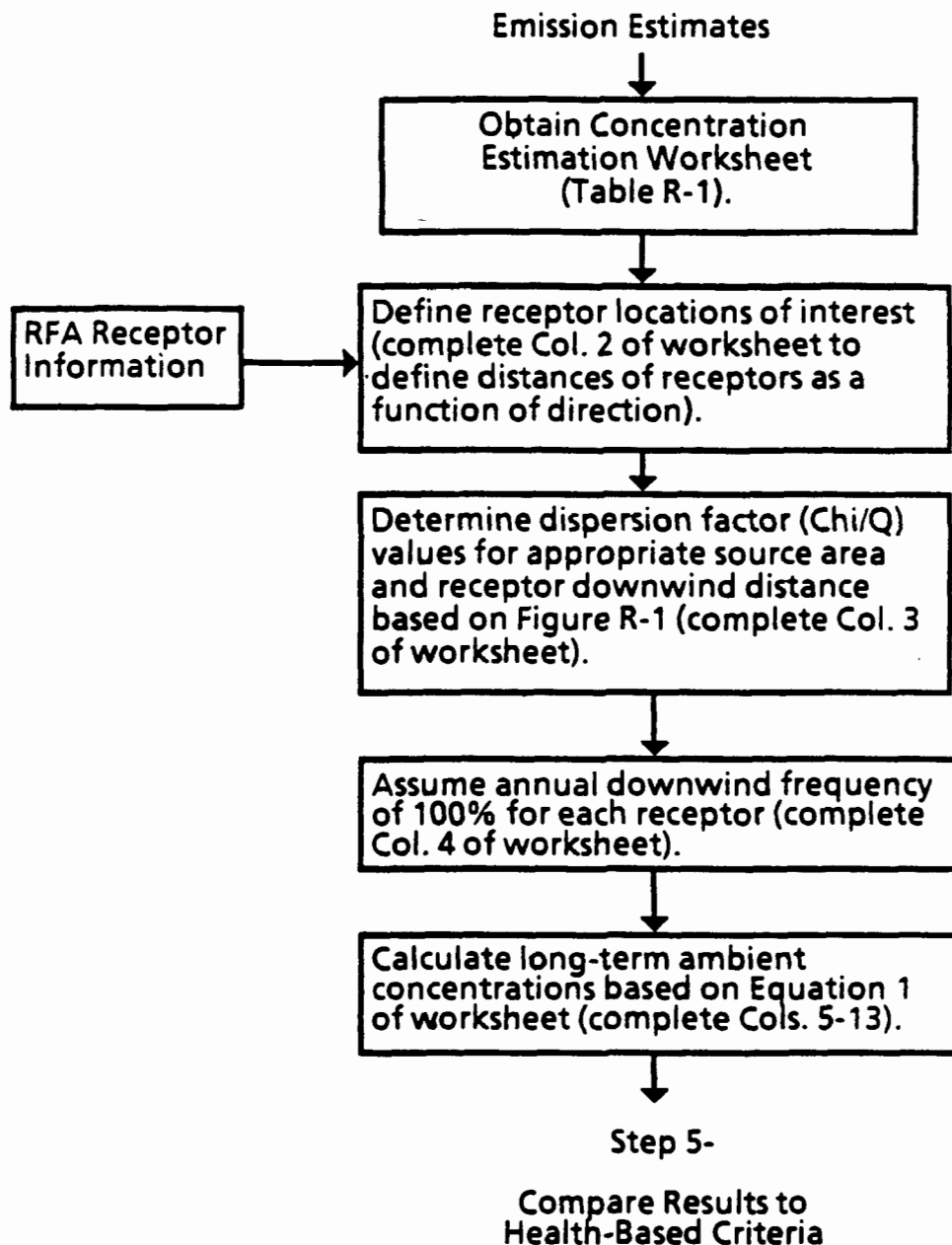
Concentrations should be estimated at locations corresponding to receptors of concern (pursuant to RFI Guidance). Receptor information may also be available from the RFA. Column 2 of the worksheet should be completed to define distances to receptors as a function of direction.

Ambient concentrations are influenced by atmospheric dispersion conditions in addition to emission rates. Atmospheric dispersion conditions for ground-level non-buoyant releases (as is the case for surface impoundment, landfill, land treatment unit, and wastepile applications) can be accounted for by the use of dispersion factors. Appropriate dispersion factors based on Figure R-1 should be used to complete Column 3 of the worksheet. The dispersion factors presented in Figure R-1 include individual plots for a range of unit-surface-area sizes. Instruction regarding the use of these plots to determine unit- and receptor-specific dispersion factors is included with Figure R-1.

**FIGURE 2-6**  
**STEP 4 - CALCULATE CONCENTRATION ESTIMATES**



**FIGURE 2-7**  
**STEP 4 - CALCULATE CONCENTRATION ESTIMATES**  
**(ALTERNATIVE APPROACH)**



The dispersion factors presented in Figure R-1 are based on the assumption that winds are flowing in one direction (i.e., toward the receptor of interest) 100 percent of the time on an annual basis. This conservative assumption of a wind direction frequency of 100% for each receptor of interest should be used if Figure R-1 is used as the basis to estimate dispersion conditions for Column 4 of the worksheets.

The information entered into Column 3 and 4 of the worksheet, plus the emission rate results calculated during Step 3, provides the required input to calculate ambient concentrations. Specifically, Equation 1 presented in the worksheet should be used to obtain ambient concentrations for each surrogate and receptor location. Equation 1 of Table R-1 includes a safety factor of 10 which is applied to all concentration estimates based on the scaling approach. This factor accounts for the inherent uncertainty involved in the scaling approach. This safety factor is applicable to all concentration estimates based on emission rates obtained via the scaling approach. These results should be entered into Columns 5 through 13 of the worksheet.

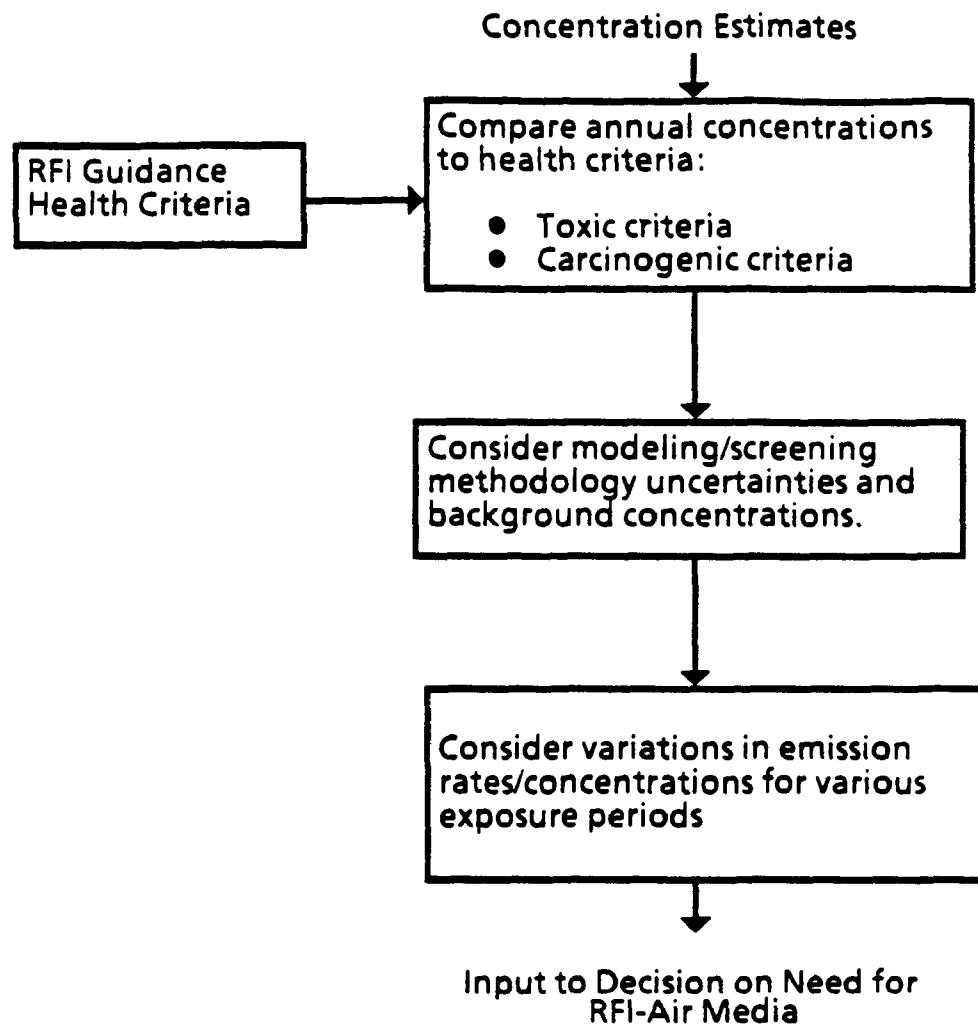
## **2.6      Step 5 - Health Criteria Comparisons**

Concentration results from Step 4 can be compared to constituent-specific health-based criteria provided in the RFI Guidance (see Figure 2-8). To facilitate this comparison, it is recommended that the appropriate reference toxic and carcinogenic criteria be entered in the space allocated in the Concentration Estimation Worksheet.

Interpretation of the ambient concentration estimates should also account for the uncertainties associated with the following components of the assessment:

- Inaccuracies in input source characterization data will directly affect concentration results.
- Emission rate models have not been extensively verified. However, OAQPS states, "In general, considering the uncertainty of field emission measurements, agreement between measured and predicted emissions generally agree within an order of magnitude." (U.S. EPA, April 1987). These verifications have been for short-term emission conditions. Model

**FIGURE 2-8**  
**STEP 5 - COMPARE RESULTS TO HEALTH-BASED CRITERIA**



performance is expected to be better for long-term emission rate estimation (as used for this screening assessment).

- Inaccuracies associated with use of the alternative emission estimation approach presented in Figure 2-5.
  - Source conditions for the unit of interest may not be the same as those for the source scenarios presented in Appendices C-Q. Therefore, scenarios should be selected to bracket the unit-specific conditions in order to obtain a range of emission rate estimates.
  - The use of scaling factors for each source parameter may yield somewhat different emission rate values compared to those based on direct use of a model with unit-specific inputs. These differences are attributed to the interrelationships of source parameters which may not be linear. A comparison of direct modeling results versus scaling estimates is presented in Exhibit 2-1.
- Atmospheric dispersion models for long-term applications (as used for this screening assessment) typically are accurate within a factor of  $\pm 2$  to 3 for flat terrain (inaccuracy can be a factor of  $\pm 10$  in complex terrain).

Therefore, "safety factors" commensurate with these uncertainties should be applied to concentration estimates for health criteria comparisons.

The calculations of emission rate and concentration estimates obtained have been for a 1-year period. Some units, such as closed landfills, will have different average emission rates for longer exposure periods for certain constituents. The air pathway health-based criteria included in the RFI Guidance are based on a 70-year exposure period. Appendices C through Q each contain a set of scenario cases for 1-, 5-, 10-, and 70-year exposures for information purposes. However, only inactive units are expected to have an average 70-year emission rate that is significantly different from the 1-year rate. All of the emission results presented in Appendices C through Q are assumed to be active with the exception of closed landfills (Appendix J). Air concentrations for each one-year period within the reference 70 year exposure period should be less than those associated with constituent-specific health criteria.

**EXHIBIT 2-1**

**RATIO OF SCALING ESTIMATES TO CHEMDAT6  
EMISSION RATE MODELING RESULTS (FIGURE 2-5)**

Unit Type	Reasonable Best Case/Worst Case Emission Rate Scenarios									
	Henry's Law Surrogates:	MHLB	HHLB	LHMB	MHMB	HHMB	LHHB	MHHB	HHHB	--
	Raoult's Law Surrogates:	HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
	Particle Case:	Particle	--	--	--	--	--	--	--	--
Disposal Impoundment		<u>0.81</u> 1.00	<u>0.81</u> 1.00	<u>0.86</u> 1.04	<u>0.81</u> 1.00	<u>0.81</u> 1.00	<u>0.68</u> 1.03	<u>0.81</u> 1.00	<u>0.81</u> 1.00	--
Storage Impoundment		<u>1.10</u> 1.51	<u>1.00</u> 1.43	<u>1.10</u> 1.50	<u>1.00</u> 1.52	<u>1.10</u> 1.43	<u>0.97</u> 0.79	<u>1.00</u> 1.51	<u>1.00</u> 1.43	--
Oil Film on Storage Impoundment		<u>1.10</u> 1.06	<u>1.10</u> 1.05	<u>1.10</u> 1.04	<u>1.10</u> 4.10	<u>1.08</u> 3.25	<u>1.10</u> 4.12	<u>1.24</u> 1.25	<u>1.10</u> 1.00	<u>1.10</u> 1.00
Mechanically Aerated Impoundment		<u>1.00</u> 0.84	<u>1.00</u> 1.00	<u>1.00</u> 0.76	<u>1.00</u> 0.91	<u>1.00</u> 0.99	<u>1.00</u> 0.81	<u>1.00</u> 0.93	<u>1.00</u> 1.00	--
Diffused Air System		<u>1.00</u> 1.00	<u>1.00</u> 1.00	<u>1.00</u> 1.00	<u>1.00</u> 0.99	<u>1.00</u> 1.00	<u>1.00</u> 0.99	<u>1.01</u> 1.00	<u>1.00</u> 0.99	--
Land Treatment (after tilling)		<u>1.20</u> 0.91	<u>1.06</u> 0.98	<u>1.00</u> 1.00	<u>3.67</u> 0.74	<u>2.83</u> 0.75	<u>1.27</u> 0.91	<u>5.28</u> 1.40	<u>1.06</u> 0.99	<u>1.00</u> 1.00
Oil Film Surface on Land Treatment Unit		<u>0.92</u> 1.31	<u>0.92</u> 1.28	<u>0.92</u> 1.25	<u>3.93</u> 1.09	<u>5.68</u> 1.06	<u>3.98</u> 1.09	<u>1.08</u> 0.77	<u>0.92</u> 1.00	<u>0.92</u> 1.03
Closed Landfill		<u>1.20</u> 1.01	<u>1.18</u> 1.01	<u>1.16</u> 1.00	<u>1.14</u> 1.01	<u>1.11</u> 1.01	<u>1.14</u> 1.02	<u>1.18</u> 1.02	<u>1.18</u> 0.99	<u>1.20</u> 1.00
Open Landfill		<u>1.29</u> 1.02	<u>1.16</u> 1.19	<u>1.23</u> 1.05	<u>0.94</u> 0.73	<u>1.23</u> 0.90	<u>0.91</u> 0.70	<u>0.40</u> 0.72	<u>0.98</u> 0.94	<u>0.98</u> 0.94
Wastepile		<u>0.99</u> 1.00	<u>0.98</u> 1.02	<u>0.98</u> 1.00	<u>0.99</u> 1.00	<u>0.98</u> 1.00	<u>0.99</u> 1.01	<u>1.25</u> 0.79	<u>1.02</u> 1.00	<u>1.02</u> 1.00
Fixed Roof Tank		*	*	*	<u>0.82</u> 0.53	<u>0.81</u> 0.53	<u>0.82</u> 0.50	<u>0.90</u> 0.89	*	*
Floating Roof Tank		*	*	*	<u>1.00</u> 1.01	<u>0.96</u> 1.01	<u>0.98</u> 1.00	<u>0.95</u> 1.01	*	*
Variable Vapor Space Tank		<u>1.00</u> 0.92	<u>1.00</u> 1.00	<u>1.00</u> 0.96	<u>1.00</u> 1.00	<u>1.00</u> 0.91	<u>1.00</u> 0.95	<u>1.00</u> 1.00	<u>1.00</u> 0.92	<u>1.00</u> 1.02
Storage Pile (Particulates)		<u>0.88</u> 1.00	--	--	--	--	--	--	--	--
Contaminated Area (Particulates)		<u>0.98</u> 0.98	--	--	--	--	--	--	--	--

### **3.0 EXAMPLE APPLICATIONS**

Two case studies have been selected to demonstrate the application of the alternative (scaling) air assessment screening methodology based on the technical aids presented in Appendices B through S. The first example involves a storage impoundment and the second a closed landfill.

#### **3.1 Case Study A**

Case Study A involves a storage impoundment located close to a small community. The closest resident lives 0.2 mile south of the unit. The impoundment has a surface area of 1 acre, a depth of 0.9 meter, and a typical storage time cycle of 1.2 days. Wind data from the nearest National Weather Service station indicate that northerly winds occur 10 percent of the time annually. Waste records for the unit indicate the frequent appearance of carbon tetrachloride. Limited waste analyses indicate that a 1,000-ppm concentration of this constituent in the impoundment is a reasonable assumption. The object of this example screening assessment is to estimate the ambient concentrations at the nearest residence. Following is a summary of this example application.

##### **Step 1 - Obtain Source Characterization Information**

The appropriate Emission Rate Estimation Worksheet for this case study is Table S-2 for storage impoundment units. The unit information provided above is sufficient to complete Column 2 for Lines 1-4 of the worksheet (see Exhibit 3-1) pursuant to Instruction A of the Worksheet (Table S-2).

##### **Step 2 - Select Release Constituent Surrogates**

Based on Figure 2-3, it is apparent that the Henry's Law Constant surrogate subset (Table B-1) is appropriate for a storage impoundment unit. Evaluation of Table B-3 indicates that the following surrogate is applicable to Case Study A:



# EXHIBIT 3-1

TABLE S-2

## EMISSION RATE ESTIMATION WORKSHEET - STORAGE IMPOUNDMENT EXAMPLE

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11
	Modeling Parameters	<u>Instruction A:</u> Input Unit-Specific Values	<u>Instruction B:</u> Select a Representative Case from Appendix D - Table D-1 (underline selected case)	<u>Instruction C:</u> Determine Surrogate-Specific Scaling Factors**							
				HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB
1	Area*	<u>1</u> acres	--	--	--	--	--	--	--	--	--
2	Depth*	<u>0.9</u> m	<u>1,2,3</u> or 4	_____	0.57	_____	_____	_____	_____	_____	_____
3	Retention time*	<u>1.2</u> days	<u>5, 6, 7</u> or 8	_____	4.1	_____	_____	_____	_____	_____	_____
4	Constituent concentration*	<u>1000</u> ppm	--	--	--	--	--	--	--	--	--
<u>INSTRUCTION D:</u> Complete Lines 5-6 and 8				<u>SURROGATE-SPECIFIC VALUES</u>							
5	Account for Area [unit-specific area/(Case 18 area = 0.4 acres)]			_____	2.5	_____	_____	_____	_____	_____	_____
6	Account for Unit-Specific Concentration [unit-specific conc./(Case 18 conc. = 1,000 ppm)]			_____	1.0	_____	_____	_____	_____	_____	_____
7	Typical Surrogate-Specific Emission Rate (Case 18), 10 <sup>6</sup> g/yr			34.0	39.24	3.25	38.10	38.40	1.97	38.74	39.24
8	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #5 x #6 x #7)			_____	229.0	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2 and 3 from Appendix D - Emission Rate Estimate from Table D-2 divided by Typical Emission Rate defined in Case 18 (see line 7).

<u>Constituent</u>	<u>Surrogate No.</u>	<u>Surrogate Code</u>
• Carbon tetrachloride	3	HHLB

### Step 3 - Calculate Emission Estimates

This step involves implementing Instructions B-D of the Worksheet (Table S-2). Instruction B involves selection of representative cases from Table D-1 which best match actual unit values in Column 2. A review of Table D-1 indicates that Case 1 (based on a depth of 0.9 meter) best estimates the depth of the example case (also a depth of 0.9 meters has been specified for Case Study A). Table D-1 also indicates that Case 5 (based on a retention cycle of 1 day) best represents the example case (a retention cycle of 1.2 days has been specified for Case Study A).

Implementation of Instruction C involves determination of surrogate-specific scaling factors. For this example this involved completion of Column 5 for lines 2 and 3 of the Worksheet (Table S-2). Emission rates for Cases 1 and 5, and a typical emission rate (Case 18) were obtained from Table D-2 as follows:

Case	Emission Rate (10 <sup>6</sup> g/yr)
	Carbon Tetrachloride
Case 1	22.5
Case 5	161.5
Case 18	39.2

Column 5 of the worksheet (for carbon tetrachloride) was completed via the following computations (Case 18 represents a typical emission rate for the source category of storage impoundment):

\*Line 2:

$$\frac{\text{Case 1 Emission Rate (from Table D-2)}}{\text{Case 18 Emission Rate (from Line 7 of the Worksheet)}} = \frac{22.5}{39.2} = 0.57$$

\*Line 3:

$$\frac{\text{Case 5 Emission Rate (from Table D-2)}}{\text{Case 18 Emission Rate (from Line 7 of the Worksheet)}} = \frac{161.5}{39.2} = 4.1$$

Implementation of Instruction D of the Worksheet (Table S-2) involves completion of Lines 5-6 and 8 as follows:

\*Line 5:

$$\frac{\text{Unit-Specific Area (from Column 2 of the Worksheet)}}{\text{Case 18 Area (this value is identified in the Worksheet instructions for Line 5)}} = \frac{1.0}{0.4} = 2.5$$

\*Line 6:

$$\frac{\text{Unit-Specific Concentration}}{\text{Case 18 Concentration}} = \frac{1,000}{1,000} = 1.0$$

\*Line 8:

$$\begin{aligned}\text{Emission Rate} &= \text{Line 2} \times \text{Line 3} \times \text{Line 5} \times \text{Line 6} \times \text{Line 7} \\ &= 0.57 \times 4.1 \times 2.5 \times 1.0 \times 39.2 \\ &= 229.0 \times 10^6 \text{g/yr} \\ &= 229.0 \text{ Mg/y}\end{aligned}$$

#### Step 4 - Calculate Concentration Estimates

This step involves use of the Concentration Estimation Worksheet (Table R-1). Application of the Worksheet involves implementation of Instructions A-D included in Table R-1. The example Concentration Estimation Worksheet for Case Study A is presented in Exhibit 3-2. Implementation of Instruction A involves input of the distance of the receptor from the downwind unit boundary for sectors of interest. Notice that the receptor distance of 0.2 mile (Column 2) corresponds with the south (downwind) sector. This is because the frequency of northerly winds obtained from the National Weather Service (as stated at the beginning of 3.1) represents the

**EXHIBIT 3-2**  
**TABLE R-1**  
**CONCENTRATION ESTIMATION WORKSHEET - UNIT CATEGORY: CLOSED LANDFILL EXAMPLE**

Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 13
<b>Downwind Sector</b>	<b>Instruction A: Input Distance to Receptors** (miles)</b>	<b>Instruction B: Determine Dispersion Factor (Figure R-1)</b>	<b>Instruction C: Assume Annual Downwind Frequency of 100% (percent)</b>	<b>Instruction D: Compute Long-Term Concentration Estimates (<math>\mu\text{g}/\text{m}^3</math>) Based on Equation 1* (select and circle appropriate surrogate subset, Henry's Law Constant or Raoult's Law or particle case)</b>								
				MHLB or HVHB or particle case	HHLB or HVMB	LHMB or HVLB	MHMB or MVHB	HHMB or MVMB	LHHB or MVLB	MHHB or LVMB	HHHB or VHVHB	---- or VHVLB
N												
NNE												
NE												
ENE												
E												
ESE												
SE												
SSE												
S	0.2	$6.4 \times 10^{-5}$	100		4600							
SSW												
SW												
WSW												
W												
WNW												
NW												
NNW												
Health Criteria ( $\mu\text{g}/\text{m}^3$ ) Based on RFI Guidance		Toxic Criteria Carcinogenic Criteria		NA 0.03***								

- \* Equation 1 Long-Term Concentration Est ( $\mu\text{g}/\text{m}^3$ ) = Col 3 x Col 4 x (unit/surrogate-specific Emission Rates, Mg/yr, based on Appendix S Worksheets) x (Conversion Factor =  $3.17 \times 10^2$ ) x (Safety Factor = 10)
- \*\* Distance from downward unit boundary
- \*\*\* Criterion for carbon tetrachloride
- NA Not available
- Mg/yr =  $10^6\text{g/yr}$

direction "from which the wind is flowing." This is standard meteorological terminology. Therefore, northerly winds affect receptors south of the unit.

Implementation of Instruction B involves determination of the appropriate dispersion factor for the downwind distance selected. The dispersion factor obtained from Figure R-1 for this example is  $6.4 \times 10^{-5} \text{ sec/m}^3$  (entered in Column 3 of the Concentration Estimation Worksheet). This value is applicable to a receptor 0.2 mile downwind from a 1-acre area source.

Implementation of Instruction C involves entering the downwind frequency for the sector of interest in Column 4 of the Worksheet. The downwind frequency (conservatively assumed to be 100 percent if Table R-1 dispersion factors are used) for a receptor located south of the unit is entered in Column 4 of the Worksheet.

Implementation of Instruction D involves computation of air concentrations based on Equation 1 of the Worksheet (Table R-1). The concentration estimate for carbon tetrachloride was calculated using Equation 1 of the Worksheet as follows:

- **Worksheet estimate:**

$$\begin{aligned}\text{Concentration } (\mu\text{g/m}^3) &= \text{Col. 3} \times \text{Col. 4} \times \text{Emission Rate} \times (\text{unit conversion} = \\ &\quad 3.17 \times 10^2) \times (\text{Safety factor} = 10) \\ &= (6.4 \times 10^{-5}) \times (100) \times (229.0) \times (3.17 \times 10^2) \times (10) \\ &= 4600 \mu\text{g/m}^3\end{aligned}$$

### **Step 5 - Compare Results to Health Criteria**

Available health-based criteria from the RFI Guidance were entered into the Concentration Estimation Worksheet (see Exhibit 3-2). These results indicate that carbon tetrachloride concentrations at the nearest receptor significantly exceed the carcinogenic health-based criteria. Based on the expected carbon tetrachloride concentrations, this unit is a prime candidate for unit-specific emission rate and dispersion modeling to confirm the need for an RFI for the air media.

### 3.2 Case Study B

Case Study B involves a closed landfill of 7 acres with a waste-bed thickness of 25 feet and a cap thickness of 6 feet. Benzene is believed to be a primary constituent of the waste (approximately 10 percent). The closest resident lives 1 mile east of the unit. The prevailing winds (which occur 20 percent of the time annually, based on available facility data) are from the west (i.e., these winds will affect the downwind sector east of the unit). Following is a summary of the screening assessment for Case Study B.

#### Step 1 - Obtain Source Characterization Information

The appropriate Emission Rate Estimation Worksheet for Case Study B is Table S-8 for closed landfill units: The unit information provided is sufficient to complete Column 2 of the worksheet, with one exception (see Exhibit 3-3): the air porosity of the fixed waste is not known. Therefore, typical conditions [i.e., 25 percent as represented by Cases 14 and 22 (see Table J-1) will be assumed for this assessment].

#### Step 2 - Select Release Constituent Surrogates

Based on Figure 2-3, it is apparent that the Raoult's Law surrogate subset (Table B-2) is appropriate for a closed landfill unit. Evaluation of Table B-3 indicates that the following surrogate is applied to Case Study B:

<u>Constituent</u>	<u>Surrogate No.</u>	<u>Surrogate Code</u>
Benzene	1	HVHB

#### Step 3 - Calculate Emission Estimates

The calculational inputs for the Emission Rate Estimations Worksheets for Case Study B are presented in Exhibit 3-3 and 3-4. Scenario Case 1 (Exhibit 3-3) and Scenario Case 2 (Exhibit 3-4) were selected to bracket the actual waste-bed thickness for the example unit. Scenario Case 1 is associated with a waste-bed thickness of 15-feet and Case 2 with a 30-foot bed thickness. The actual waste-bed thickness is 25 feet. The resulting benzene emission rate estimates range from  $46.4 \times 10^6$ g/yr to  $83.4 \times 10^6$ g/yr.

**EXHIBIT 3-3**  
**TABLE S-8**  
**EMISSION RATE ESTIMATION WORKSHEET - CLOSED LANDFILL EXAMPLE**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
	Modeling Parameters	<u>Instruction A:</u> Input Unit-Specific Values	<u>Instruction B:</u> Select a Representative Case from Appendix J - Table J-1 (underline selected case)	<u>Instruction C:</u> Determine Surrogate-Specific Scaling Factors**								
				HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
1	Area*	<u>7</u> acres	--	--	--	--	--	--	--	--	--	--
2	Waste-bed thickness*	<u>25</u> ft	<u>1</u> , 2, 3 or 4	<u>1.0</u>	_____	_____	_____	_____	_____	_____	_____	_____
3	Cap thickness	<u>6</u> ft	5, 6, <u>7</u> or 8	<u>0.95</u>	_____	_____	_____	_____	_____	_____	_____	_____
4	Constituent content of waste*	<u>10</u> percent	<u>9</u> , 10, 11 or 12	<u>1.0</u>	_____	_____	_____	_____	_____	_____	_____	_____
5	Air porosity (fixed waste)	<u>25</u> percent	13, <u>14</u> , 15 or 16	<u>1.0</u>	_____	_____	_____	_____	_____	_____	_____	_____
<u>INSTRUCTION D:</u> Complete Lines 6 and 8				<u>SURROGATE-SPECIFIC VALUES</u>								
6	Account for Area [unit-specific area/(Case 22 area = 3.5 acres)]			<u>2.0</u>	_____	_____	_____	_____	_____	_____	_____	_____
7	Typical Surrogate-Specific Emission Rate (Case 22), 10 <sup>6</sup> g/yr			24.4	22.4	47.0	0.445	0.398	0.808	1.55E-05	119	264
8	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #4 x #5 x #6 x #7)			<u>46.4</u>	_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2-5 from Appendix J - Emission Rate Estimate from Table J-2 divided by Typical Emission Rate defined in Case 22 (see line 7).

**EXHIBIT 3-4**  
**TABLE S-8**  
**EMISSION RATE ESTIMATION WORKSHEET - CLOSED LANDFILL EXAMPLE**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
	Modeling Parameters	<u>Instruction A:</u> Input Unit-Specific Values	<u>Instruction B:</u> Select a Representative Case from Appendix F - Table F-1 (underline selected case)	<u>Instruction C:</u> Determine Surrogate-Specific Scaling Factors**								
				HVHP	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
1	Area*	<u>7</u> acres	--	--	--	--	--	--	--	--	--	--
2	Waste-bed thickness*	<u>25</u> ft	1, <u>2</u> , 3 or 4	<u>1.8</u>	_____	_____	_____	_____	_____	_____	_____	_____
3	Cap thickness	<u>6</u> ft	5, 6, <u>7</u> or 8	<u>0.95</u>	_____	_____	_____	_____	_____	_____	_____	_____
4	Constituent content of waste*	<u>10</u> percent	<u>9</u> , 10, 11 or 12	<u>1.0</u>	_____	_____	_____	_____	_____	_____	_____	_____
5	Air porosity (fixed waste)	<u>25</u> percent	13, <u>14</u> , 15 or 16	<u>1.0</u>	_____	_____	_____	_____	_____	_____	_____	_____
<u>INSTRUCTION D:</u> Complete Lines 6 and 8												
<u>SURROGATE-SPECIFIC VALUES</u>												
6	Account for Area [unit-specific area/(Case 22 area = 3.5 acres)]			<u>2.0</u>	_____	_____	_____	_____	_____	_____	_____	_____
7	Typical Surrogate-Specific Emission Rate (Case 22), 10 <sup>6</sup> g/yr			<u>24.4</u>	22.4	47.0	0.445	0.398	0.808	1.55E-05	119	264
8	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #4 x #5 x #6 x #7)			<u>83.4</u>	_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2-5 from Appendix J - Emission Rate Estimate from Table J-2 divided by Typical Emission Rate defined in Case 22 (see line 7).



#### **Step 4 - Calculate Concentration Estimates**

The example Concentration Estimation Worksheets for Case Study B are presented in Exhibits 3-5 (Scenario Case 1) and 3-6 (Scenario Case 2). The resulting benzene concentration at the nearest receptor is estimated to range from 69  $\mu\text{g}/\text{m}^3$  to 124  $\mu\text{g}/\text{m}^3$ .

#### **Step 5 - Compare Results to Health Criteria**

A review of results presented in Exhibits 3-5 and 3-6 indicates that the estimated benzene concentrations of 69  $\mu\text{g}/\text{m}^3$  to 124  $\mu\text{g}/\text{m}^3$  are approximately 1000 times the carcinogenic criterion of 0.1  $\mu\text{g}/\text{m}^3$ . A toxic criterion is not available for benzene. Based on the results presented in Exhibits 3-5 and 3-6, this unit is a prime candidate for an air release RFI.

**EXHIBIT 3-5  
TABLE R-1  
CONCENTRATION ESTIMATION WORKSHEET - UNIT CATEGORY: CLOSED LANDFILL EXAMPLE (Scenario Case 1)**

Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 13
Downwind Sector	<u>Instruction A:</u> Input Distance to Receptors** (miles)	<u>Instruction B:</u> Determine Dispersion Factor (Figure R-1)	<u>Instruction C:</u> Assume Annual Downwind Frequency of 100% (percent)	<u>Instruction D:</u> Compute Long-Term Concentration Estimates ( $\mu\text{g}/\text{m}^3$ ) Based on Equation 1* (select and circle appropriate surrogate subset, Henry's Law Constant or Raoult's Law or particle case)								
				MHLB or HVHB or particle case	HHLB or HVMB	LHMB or HVLB	MHMB or MVHB	HHMB or MVMB	LHHB or MVLB	MHHB or LVMB	HHHB or VHVHB	---- or VHVLB
N												
NNE												
NE												
ENE												
E	1.0	$4.7 \times 10^{-6}$	100	69								
ESE												
SE												
SSE												
S												
SSW												
SW												
WSW												
W												
WNW												
NW												
NNW												
Health Criteria ( $\mu\text{g}/\text{m}^3$ ) Based on RFI Guidance		Toxic Criteria Carcinogenic Criteria		NA 0.1***								

\* Equation 1 Long-Term Concentration Est. ( $\mu\text{g}/\text{m}^3$ ) = Col 3 x Col 4 x (unit/surrogate-specific Emission Rates, Mg/yr, based on Appendix S Worksheets) x (Conversion Factor =  $3.17 \times 10^2$ ) x (Safety Factor = 10)

\*\* Distance from downward unit boundary

\*\*\* Criterion for benzene

NA Not available

Mg/yr =  $10^6\text{g}/\text{yr}$

**EXHIBIT 3-6**  
**TABLE R-1**  
**CONCENTRATION ESTIMATION WORKSHEET - UNIT CATEGORY: CLOSED LANDFILL EXAMPLE (Scenario Case 2)**

Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 13
Downwind Sector	<u>Instruction A:</u> Input Distance to Receptors** (miles)	<u>Instruction B:</u> Determine Dispersion Factor (Figure R-1)	<u>Instruction C:</u> Assume Annual Downwind Frequency of 100% (percent)	<u>Instruction D:</u> Compute Long-Term Concentration Estimates ( $\mu\text{g}/\text{m}^3$ ) Based on Equation 1* (select and circle appropriate surrogate subset, Henry's Law Constant or Raoult's Law or particle case)								
				MHLB or HVHB or particle case	HHLB or HVMB	LHMB or HVLB	MHMB or MVHB	HHMB or MVMB	LHHB or MVLB	MHHB or LVMB	HHHB or VHVHB	---- or VHVLB
N												
NNE												
NE												
ENE												
E	10	4.7 x 10 <sup>6</sup>	100	124								
ESE												
SE												
SSE												
S												
SSW												
SW												
WSW												
W												
WNW												
NW												
NNW												
Health Criteria ( $\mu\text{g}/\text{m}^3$ ) Based on RFI Guidance		Toxic Criteria Carcinogenic Criteria		NA 0.1***								

\* Equation 1 Long-Term Concentration Est ( $\mu\text{g}/\text{m}^3$ ) = Col 3 x Col 4 x (unit/surrogate specific Emission Rates, Mg/yr, based on Appendix S Worksheets) x (Conversion Factor =  $3.17 \times 10^{-7}$ ) x (Safety Factor = 10)

\*\* Distance from downward unit boundary

\*\*\* Criterion for benzene

NA Not available

Mg/yr =  $10^6\text{g}/\text{yr}$

#### 4.0 REFERENCES

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## **Appendix A**

### **Background Information**

## **A.0 BACKGROUND INFORMATION**

The air release screening assessment methodology has been developed based on use of available air emissions models applicable to facilities for treatment, storage, and disposal of hazardous waste, and on results of atmospheric dispersion modeling. The emission models were used to calculate emission rates for a wide range of source scenarios. (An emission rate is defined as the source release rate for the air pathway in terms of mass per unit of time.) These modeling results have been summarized in this document so that they can be easily used by Environmental Protection Agency (EPA) Regional and State Agency staff to estimate emission rates for facility-specific and unit-specific applications. These source-specific emission rates can be used in conjunction with dispersion modeling results, representative of typical annual conditions, to estimate long-term ambient concentrations at locations of interest. (Ambient concentrations are defined as the concentrations of the released constituent downwind from the source.) The emission rate and atmospheric dispersion modeling approaches used to develop the screening methodology are discussed in the subsections that follow.

### **A.1 Emission Rate Models**

The air release screening assessment methodology has been based primarily on application of air emission models (available on a diskette for use on a microcomputer) developed by EPA's Office of Air Quality Planning and Standards (OAQPS) to estimate organic releases for hazardous waste treatment, storage, and disposal facilities (TSDFs) (U.S. EPA, December 1987). Computer-compatible air emission models (referred to as CHEMDAT6 models) are available for the following sources:

- Surface impoundments, which for modeling purposes include quiescent impoundments, aerated impoundments, and open-top tanks
  - Disposal impoundments
  - Storage impoundments
  - Oil films on storage impoundments
  - Aerated impoundments

- Land treatment
  - Soil emissions subsequent to waste tilling
  - Oil film surfaces
- Closed landfills
- Open landfills
- Wastepiles

Since the results presented in this document are based on the December 1987 version of CHEMDAT6, subsequent modifications to any of these models may require revisions to this screening methodology

The available models for CHEMDAT6 provide a basis to estimate emissions for numerous unit categories (e.g., surface impoundments, landfills) as previously listed. Therefore, the CHEMDAT6 models will be applicable to a wide range of air release screening assessments. CHEMDAT6 (December 1987 versions) does not, however, include models for the following sources:

- Land treatment - waste application
- Fixation pits
- Container loading
- Container storage
- Container cleaning
- Stationary tank loading
- Stationary tank storage
- Fugitive emissions
- Vacuum truck loading

However, guidance for estimating organic emissions from these sources is available from OAQPS (U.S. EPA, December 1987).

In addition to the CHEMDAT6 model, emission equations from EPA's AP-42, "Compilation of Air Pollutant Emission Factors" and "Fugitive Emissions from Integrated Iron and Steel Plants" have been used for estimating organic emissions from storage tanks and particulate matter emissions that are less than 10 microns in diameter from storage piles and exposed areas which result from wind erosion and activities on storage piles.

## A.2 Source Scenarios

A wide range of source scenarios were evaluated as a basis for developing the air release assessment methodology. This involved identification of a limited set of surrogates to represent the numerous individual potential air release constituents of concern. This also involved evaluating of the sensitivity of the input parameters used by the CHEMDAT6 air emission models and the AP-42 emission equation input parameters.

### A.2.1 Release Constituent Surrogates

A limited set of surrogates was required to simplify the air release assessment methodology since the list of potential air release constituents included in the RFI Guidance (U.S. EPA, 1988) is extensive. The set of surrogates selected for this application was the same list developed by OAQPS for assessment of organic emissions from TSDFs (see Appendix B).

Two subsets of surrogates are presented in Appendix B. The first subset is applicable to air emission modeling applications based on the use of the Henry's Law Constant (Table B-1) and the second subset is based on use of Raoult's Law (Table B-2). Raoult's Law accurately predicts the behavior of most concentrated mixtures of water and organic solvents (i.e., solutions over 10 percent solute). According to Raoult's Law, the rate of volatilization of each chemical in a mixture is proportional to the product of its concentration in the mixture and its vapor pressure. Therefore, Raoult's Law can be used to characterize potential for volatilization. This is especially useful when the unit of concern entails container storage, tank storage, or treatment of concentrated waste streams.

The Henry's Law Constant is the ratio of the vapor pressure of a constituent to its aqueous solubility (at equilibrium). This constant can be used to assess the relative ease with which the compound may vaporize from the aqueous solution and will be most useful when the unit being assessed is a surface impoundment or tank containing dilute wastewaters. The potential for significant vaporization increases as the value for the Henry's Law Constant increases; when it is greater than  $10E-3$ , rapid volatilization will generally occur.



The surrogates presented in Appendix B span the range from very high volatility to low volatility (frequently classified as semi-volatiles). Biodegradation potential has also been accounted for in the surrogate specifications. Therefore, a cross-reference of constituents has also been provided in Appendix B (Table B-3). This listing provides the basis for the identification of the appropriate surrogate for individual air release constituents of interest. Instructions for use of Appendix B data are provided in Section 2.

#### A.2.2 Sensitivity Analyses

Sensitivity analyses of the input parameters used by the CHEMDAT6 air emission models emission rate relative to output were evaluated to determine the feasibility of developing a source characterization index. The object of the source characterization index was to define a simple relationship between the primary source description parameters and the emission rate of the release. This evaluation was accomplished by modeling a series of source scenario cases for each unit category (i.e., categories such as surface impoundments and landfills). Each of these source scenario cases represents long-term (i.e., annual) emission conditions. A base case representative of typical source conditions was defined for each unit category. These typical conditions were specified based on TSDF survey results and on guidance presented in the OAQPS air emissions modeling report (U.S. EPA, December 1987). This base case provided a standard for comparison to results of parametric analyses. The parametric analyses consisted of varying (one at a time) the input values for the most sensitive modeling parameters. These input parameter values were varied over a range of expected source conditions. In addition to the parametric analyses and the typical (base-case) scenario, a reasonable best-case (minimum emission rate) and a reasonable worst-case (maximum emission rate) source scenario were also modeled. The most sensitive modeling parameters and their associated range of values were determined by considering model sensitivity results and TSDF source survey information presented in the OAQPS air emission modeling report (U.S.EPA, December 1987), as well as other judgmental factors. A similar sensitivity analysis was performed for the three tank types.

A summary of the air emissions modeling parameters, input values, and modeling results (emission rates) is presented in Appendices C through Q. Evaluation of these results indicates that emission rates are highly dependent on numerous sensitive source parameters. Therefore, these complex relationships are not conducive to development of a source characterization index (i.e., defining a simple relationship between the primary source description parameters and the emission rate of the release). However, the modeling results presented in Appendices C through Q provide data which can be interpolated to estimate unit-specific emission rates with minimal guidance. The methodology for application of these data is discussed in Section 2.

### **A.3      Atmospheric Dispersion Conditions**

Atmospheric dispersion conditions affect the downwind dilution of emissions from a source. Available EPA dispersion models can be used to account for site specific meteorological and source conditions. For this screening assessment, modeling results are presented which represent typical dispersion conditions (neutral stability and 10-mph winds) in the United States.

Dispersion modeling results to be used for the screening assessment (assuming flat terrain) are presented in Appendix R (Figure R-1) and are applicable to ground-level sources with non-buoyant releases (this assumption is valid for surface impoundments, land treatment units, landfills, waste piles, tanks, and exposed areas). These results are presented in terms of dispersion factors. Dispersion factors can be considered as the ratio of the ambient concentration to the source emission rate. Therefore, dispersion factors facilitate the calculation of ambient concentrations if emission rate estimates are available.

The dispersion factors presented in Figure R-1 were developed from similar dispersion graphs presented in a standard technical reference (Turner, 1969). These dispersion factors are applicable to long-term (e.g., annual) conditions. It has been assumed that dispersion factors (and, thus also ambient concentrations) decrease as a function of downwind distance but are uniform in the crosswind direction within a 22.5 degree sector (22.5 degree sectors correspond with major compass directions such as N, NNW, NW, etc.). The dispersion factors presented in Figure R-1 also account for the initial plume size, which corresponds to the surface area of the

source (Turner, 1969). Results presented in Figure R-1 are expected to be similar to results from the EPA-approved Industrial Source Complex dispersion model.

## **Appendix B**

### **Release Constituent Surrogate Data**

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**TABLE B-1**  
**SURROGATE PROPERTIES - HENRY'S LAW CONSTANT SUBSET**

Code	No.	Characteristics	Henry's Law* Constant 298°K
MHLB	6	medium Henry's Law, low biodegradation	2.22E-05
HHLB	3	high Henry's Law, low biodegradation	3.00E-02
LHMB	8, 9	low Henry's Law, medium biodegradation	1.58E-07
MHMB	5	medium Henry's Law, medium biodegradation	4.08E-05
HHMB	2	high Henry's Law, medium biodegradation	1.18E-03
LHHB	7	low Henry's Law, high biodegradation	1.58E-07
MHHB	4	medium Henry's Law, high biodegradation	6.80E-05
HHHB	1	high Henry's Law, high biodegradation	5.38E-03

\*Key: low Henry's Law Constant  $< 1.0\text{E-}05$  atm-m<sup>3</sup>/g mol  
medium Henry's Law Constant  $1.0\text{E-}05$  -  $1.0\text{E-}3$   
high Henry's Law Constant  $> 1.0\text{E-}03$

**TABLE B-2  
SURROGATE PROPERTIES - RAOULT'S LAW SUBSET**

Code	No.	Characteristics	Vapor Pressure (25°C)
HVHB	1	high volatility, high biodegradation	206
HVMB	2	high volatility, medium biodegradation	182
HVLB	3	high volatility, low biodegradation	256
MVHB	4	medium volatility, high biodegradation	2.62
MVMB	5	medium volatility, medium biodegradation	2.02
MVLB	6	medium volatility, low biodegradation	2.91
LVMB	7, 8, 9	low volatility, medium biodegradation	0.0001
VHVHB	10, 11	very high volatility, high biodegradation	1890
VHVLB	12	very high volatility, low biodegradation	2030

\*Key: low volatility, < 1.0E-05 atm  
medium volatility, 1.0E-05 - 1.0E-3  
high volatility, 1.0E-03 - 1.0  
very high volatility, > 1.0

**TABLE B-3**  
**LISTING OF CONSTITUENT-SPECIFIC SURROGATES**

Constituent	CAS No.	Henry's Law Constant Surrogate Code	Raoult's Law Surrogate Code
Acrylamide	79-06-1	7	4
Acrylonitrile	107-13-1	4	1
Aldicarb	116-06-3	8	9
Aldrin	309-00-2	3	7
Aniline	62-53-3	8	5
Arsenic	7440-38-2	0	0
Benz(a)anthracene	56-55-3	9	7
Benzene	71-43-2	1	1
Benzo(a)pyrene	50-32-8	9	8
Beryllium	7440-41-7	0	0
Bis(2-chloroethyl)ether	111-44-4	5	5
Bromodichloromethane	75-27-4	3	7
Cadmium	7440-43-9	0	0
Carbon tetrachloride	56-23-5	3	3
Chlordane	57-74-9	6	7
1-Chloro-2, 3-epoxypropane (Epichlorohydrin)	106-89-8	6	3
Chloroform	67-66-3	3	3
Chromium (hexavalent)	7440-47-3	0	0
DDT	50-29-3	3	7
Dibenz(a,h) anthracene	53-70-3	9	7
1,2-Dibromo-3-Chloropropane (DBCP)	96-12-8	6	6
1,2-Dibromoethane	106-93-4	3	3
1,2-Dichloroethane	107-06-2	3	3
1,1-Dichloroethylene	75-35-4	3	3
Dichloromethane (Methylene chloride)	75-09-2	1	1

**TABLE B-3**  
**LISTING OF CONSTITUENT-SPECIFIC SURROGATES (Continued)**

Constituent	CAS No.	Henry's Law Constant Surrogate Code	Raoult's Law Surrogate Code
2,4-Dichlorophenol	120-83-2	8	5
2,4-Dinitrophenol	51-28-5	9	3
2,4-Dinitrotoluene	121-14-2	9	6
1,4-Dioxane	123-91-1	6	3
1,2-Diphenylhydrazine	122-66-7	9	7
Endosulfan	115-29-7	9	7
Ethylene oxide	75-21-8	4	10
Heptachlor	76-44-8	3	7
Hexachlorobenzene	118-74-1	6	7
Hexachlorobutadiene	87-68-3	3	6
Hexachloroethane	67-72-1	9	6
Hydrazine	302-01-2	9	3
Isobutyl alcohol	78-83-1	7	4
Lindane (gamma-Hexachlorocyclohexane)	58-89-9	9	7
3-Methyl-cholanthrene	56-49-5	6	7
4,4-Methylene-bis-(2-chloroaniline)	101-14-4	3	6
Methyl parathion	298-00-0	6	6
Nickel	1440-02-0	0	0
Nickel (refinery dust)	7440-02-0	0	0
Nickel subsulfide	12035-72-2	0	0
2-Nitropropane	79-46-9	6	3
N-Nitroso-N-methyl urea	684-93-5	5	9
N-Nitroso-pyrrolidine	930-55-2	2	2
Pentachlorobenzene	608-93-5	3	6
Pentachlorophenol	87-86-5	9	7



**TABLE B-3**  
**LISTING OF CONSTITUENT-SPECIFIC SURROGATES (Continued)**

Constituent	CAS No.	Henry's Law Constant Surrogate Code	Raoult's Law Surrogate Code
Perchloroethylene (Tetrachloroethylene)	127-18-4	3	3
Styrene	100-42-5	3	6
1,2,4,5-Tetrachlorobenzene	95-94-3	3	6
1,1,2,2-Tetrachloroethane	79-34-5	6	6
2,3,4,6-Tetrachlorophenol	58-90-2	9	6
Tetraethyl lead	78-00-2	3	6
Thiourea	62-56-6	6	3
Toxaphene	8001-35-2	3	6
1,1,2-Trichloroethane	79-00-5	6	3
Trichloroethylene	79-01-6	3	3
2,4,5-Trichlorophenol	95-95-4	6	6
2,4,6-Trichlorophenol	88-06-2	6	6

## **Appendix C**

### **Emission Rate Estimates Disposal Impoundments (Quiescent Surfaces)**

**TABLE C-1  
EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - DISPOSAL IMPOUNDMENT\***

Modeling Parameters	CASE NUMBERS																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17**	18***	19****
Area (acres)	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Depth (m)	0.9	1.8	3.6	5.0	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	0.9	1.8	3.6
Turnovers (per yr)	2	2	2	2	0.5	1	2	3	2	2	2	2	2	2	2	2	1	2	3
Constituent concentration (ppm)	1000	1000	1000	1000	1000	1000	1000	1000	10	1000	2000	4000	1000	1000	1000	1000	10	1000	4000
Air temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Wind speed (mph)	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

- \* Input assumptions:  
 - Active biomass = 0.0 g/l  
 - Biomass solids in = 0.0 m<sup>3</sup>/sec  
 - Submerged air flow = 0.0 m<sup>3</sup>/sec
- \*\* Reasonable Best Case (minimum) Emissions (assuming typical source area)
- \*\*\* Typical Emission Conditions (assuming typical source area)
- \*\*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical source area)

Note: If actual input values vary significantly from the above scenarios it is recommended that CHEMDATA be used to calculate emission estimates directly

**TABLE C-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - DISPOSAL IMPOUNDMENT**

Henry's Law Constant Surrogate	(Case 1)	(Case 2)	(Case 3)	(Case 4)	(Case 5)	(Case 6)	(Case 7)	(Case 8)
MHLB	16.2	32.4	64.8	89.9	8.1	16.2	32.4	48.6
HHLB	16.2	32.4	64.8	90.0	8.1	16.2	32.4	48.6
LHMB	11.0	14.1	16.1	16.7	7.3	11.0	14.1	15.4
MHMB	16.2	32.4	64.8	90.0	8.1	16.2	32.4	48.6
HHMB	16.2	32.4	64.8	90.0	8.1	16.2	32.4	48.6
LHHB	8.0	9.4	10.1	10.4	6.0	8.0	9.4	9.9
MHHB	16.2	32.4	64.8	90.0	8.1	16.2	32.4	48.6
HHHB	16.2	32.4	64.8	90.0	8.1	16.2	32.4	48.6
Henry's Law Constant Surrogate	(Case 9)	(Case 10)	(Case 11)	(Case 12)	1 Year (Case 13)	5 Years (Case 14)	10 Years (Case 15)	70 Years (Case 16)
MHLB	0.3	32.4	64.8	129.6	32.4	32.4	32.4	32.4
HHLB	0.3	32.4	64.8	129.6	32.4	32.4	32.4	32.4
LHMB	0.1	14.1	28.2	56.4	14.1	14.1	14.1	14.1
MHMB	0.3	32.4	64.8	129.6	32.4	32.4	32.4	32.4
HHMA	0.3	32.4	64.8	129.6	32.4	32.4	32.4	32.4
LHHB	0.1	9.4	18.7	37.5	9.4	9.4	9.4	9.4
MHHB	0.3	32.4	64.8	129.6	32.4	32.4	32.4	32.4
HHHB	0.3	32.4	64.8	129.6	32.4	32.4	32.4	32.4
Henry's Law Constant Surrogate	(Case 17)	(Case 18)	(Case 19)					
MHLB	0.1	32.4	388.4					
HHLB	0.1	32.4	388.8					
LHMB	0.1	14.1	67.5					
MHMB	0.1	32.4	388.8					
HHMB	0.1	32.4	388.8					
LHHB	0.1	9.4	41.6					
MHHB	0.1	32.4	388.8					
HHHB	0.1	32.4	388.8					

## **Appendix D**

### **Emission Rate Estimates Storage Impoundments/Open Tanks (Quiescent Surfaces)**

**TABLE D-1  
EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - STORAGE IMPOUNDMENT\***

Modeling Parameters	CASE NUMBERS																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17**	18***	19****
Area (acres)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Depth (m)	0.9	1.8	3.6	5.0	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	0.9	1.8	5.0
Retention time (days)	20	20	20	20	1	20	50	550	20	20	20	20	20	20	20	20	550	20	1
Constituent concentration (ppm)	1000	1000	1000	1000	1000	1000	1000	1000	10	1000	2000	4000	1000	1000	1000	1000	10	1000	4000
Air temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Wind speed (mph)	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

- \* Input assumptions:  
 - Active biomass = 0.0 g/l  
 - Biomass solids in = 0.0 m<sup>3</sup>/sec
- \*\* Reasonable Best Case (minimum) Emissions (assuming typical source area)
- \*\*\* Typical Emission Conditions (assuming typical source area)
- \*\*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical source area)

Note: If actual input values vary significantly from the above scenarios it is recommended that CHEMDAT6 be used to calculate emission estimates directly

**TABLE D-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - STORAGE IMPOUNDMENTS**

Henry's Law Constant Surrogate	(Case 1)	(Case 2)	(Case 3)	(Case 4)	(Case 5)	(Case 6)	(Case 7)	(Case 8)
MHLB	20.7	34.0	57.9	69.4	99.4	34.0	16.7	1.8
HHLB	22.5	39.2	74.1	94.1	161.5	39.2	17.9	1.8
LHMB	3.1	3.2	3.3	3.4	3.9	3.2	3.0	1.2
MHMB	22.0	38.1	69.0	86.0	143.8	38.1	17.7	1.8
HHMB	22.3	38.4	72.2	90.9	148.7	38.4	17.7	1.8
LHHB	1.9	2.0	2.1	2.1	2.0	2.0	1.9	1.0
MHHB	22.2	38.7	71.2	89.3	153.6	38.7	17.8	1.8
HHHB	22.5	39.2	74.1	94.1	161.5	39.2	17.9	1.8
Henry's Law Constant Surrogate	(Case 9)	(Case 10)	(Case 11)	(Case 12)	1 Year (Case 13)	5 Years (Case 14)	10 Years (Case 15)	70 Years (Case 16)
MHLB	0.3	34.0	68.0	136.1	34.0	34.0	34.0	34.0
HHLB	0.4	39.2	78.5	156.9	39.2	39.2	39.2	39.2
LHMB	0.03	3.2	6.5	13.0	3.2	3.2	3.2	3.2
MHMB	0.4	38.1	76.2	152.4	38.1	38.1	38.1	38.1
HHMB	0.4	38.4	76.8	153.6	38.4	38.4	38.4	38.4
LHHB	0.02	2.0	3.9	7.9	2.0	2.0	2.0	2.0
MHHB	0.4	38.7	77.5	155.0	38.7	38.7	38.7	38.7
HHHB	0.4	39.2	78.5	156.9	39.2	39.2	39.2	39.2
Henry's Law Constant Surrogate	(Case 17)	(Case 18)	(Case 19)					
MHLB	0.01	34.02	536.88					
HHLB	0.01	39.24	1084.72					
LHMB	0.01	3.25	10.96					
MHMB	0.01	38.10	854.63					
HHMB	0.01	38.40	986.11					
LHHB	0.01	1.97	10.96					
MHHB	0.01	38.74	942.28					
HHHB	0.01	39.24	1084.72					

## **Appendix E**

### **Emission Rate Estimates Oil Films on Storage Impoundments**



**TABLE E-1  
EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - OIL FILM ON STORAGE IMPOUNDMENT\***

Modeling Parameters	CASE NUMBERS																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17**	18***	19****
Area (acres)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Depth of oil film (m)	7.2E-04	7.2E-03	7.2E-02	7.2E-01	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-04	7.2E-02	7.2E-01
Retention time (days)	20	20	20	20	1	20	50	365	20	20	20	20	20	20	20	20	365	20	1
Constituent concentration in oil (ppm)	200	200	200	200	200	200	200	200	100	200	1000	5000	200	200	200	200	100	200	5000
Air temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Wind speed (mph)	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

- \* Input assumptions.  
 - Oil (fraction of waste) = 1.0  
 - Molecular weight of oil = 282  
 - Density of oil = 1.0

\*\* Reasonable Best Case (minimum) Emissions (assuming typical source area)

\*\*\* Typical Emission Conditions (assuming typical source area)

\*\*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical source area)

**Note.** If actual input values vary significantly from the above scenarios it is recommended that CHEMDAT6 be used to calculate emission estimates directly.

**TABLE E-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - OIL FILMS ON STORAGE IMPOUNDMENTS**

Raoult's Law Surrogate	(Case 1)	(Case 2)	(Case 3)	(Case 4)	(Case 5)	(Case 6)	(Case 7)	(Case 8)
HVHB	3.94E-03	0.039	0.394	3.942	7.884	0.394	0.158	0.022
HVMB	3.94E-03	0.039	0.394	3.942	7.884	0.394	0.158	0.022
HVLB	3.94E-03	0.039	0.394	3.942	7.884	0.394	0.158	0.022
MVHB	3.94E-03	0.039	0.394	1.851	2.115	0.394	0.158	0.022
MVMB	3.94E-03	0.039	0.389	1.388	1.517	0.389	0.158	0.022
MVLB	3.94E-03	0.039	0.394	1.868	2.137	0.394	0.158	0.022
LVMB	1.08E-04	1.10E-04	1.10E-04	1.06E-04	1.02E-04	1.10E-04	1.10E-04	1.08E-04
VHVHB	3.94E-03	0.039	0.394	3.942	7.884	0.394	0.158	0.022
VHVLB	3.94E-03	0.039	0.394	3.942	7.884	0.394	0.158	0.022
Raoult's Law Surrogate	(Case 9)	(Case 10)	(Case 11)	(Case 12)	1 Year (Case 13)	5 Years (Case 14)	10 Years (Case 15)	70 Years (Case 16)
HVHB	0.197	0.394	1.971	9.855	0.394	0.394	0.394	0.394
HVMB	0.197	0.394	1.971	9.855	0.394	0.394	0.394	0.394
HVLB	0.197	0.394	1.971	9.855	0.394	0.394	0.394	0.394
HVHB	0.197	0.394	1.968	9.838	0.394	0.394	0.394	0.394
MVMB	0.195	0.389	1.945	9.727	0.389	0.389	0.389	0.389
MVLB	0.197	0.394	1.968	9.839	0.394	0.394	0.394	0.394
LVMB	5.50E-05	1.10E-04	5.50E-04	2.75E-03	1.10E-04	1.10E-04	1.10E-04	1.10E-04
VHVHB	0.197	0.394	1.971	9.855	0.394	0.394	0.394	0.394
VHVLB	0.197	0.394	1.971	9.855	0.394	0.394	0.394	0.394
Raoult's Law Surrogate	(Case 17)	(Case 18)	(Case 19)					
HVHB	1.08E-04	0.394	1863.51					
HVMB	1.08E-04	0.394	1886.53					
HVLB	1.08E-04	0.394	1904.63					
MVHB	1.08E-04	0.394	60.60					
MVMB	1.08E-04	0.394	41.68					
MVLB	1.08E-04	0.394	61.35					
LVMB	4.25E-05	1.10E-04	1.97E-03					
VHVHB	1.08E-04	0.394	1971.00					
VHVLB	1.08E-04	0.394	1971.00					

## **Appendix F**

### **Emission Rate Estimates Mechanically Aerated Impoundments**

**TABLE F-1**  
**EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - MECHANICALLY AERATED IMPOUNDMENT\***

Modeling Parameters	CASE NUMBERS																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21**	22***	23****
Area (acres)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Depth (m)	0.9	1.8	3.6	5.0	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	0.9	1.8	5.0
Retention time (days)	10	10	10	10	3	10	15	20	10	10	10	10	10	10	10	10	10	10	10	10	20	10	3
Constituent concentration (ppm)	1000	1000	1000	1000	1000	1000	1000	1000	10	1000	2000	4000	1000	1000	1000	1000	1000	1000	1000	1000	10	1000	4000
Fraction agitated	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.17	0.24	0.52	0.87	0.24	0.24	0.24	0.24	0.17	0.24	0.87
Air temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Wind speed (mph)	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

- \* Input assumptions:
- Active biomass = 0.0 g/l
  - Biomass solids in = 0.0 m<sup>3</sup>/sec
  - Submerged air flow = 0.0 m<sup>3</sup>/sec
  - Number of impellers = 1
  - Oxygen transfer correction factor = 0.83
  - Impeller diameter = 61 cm
  - Impeller speed = 126 rad/sec
- \*\* Reasonable Best Case (minimum) Emissions (assuming typical source area)
- \*\*\* Typical Emission Conditions (assuming typical source area)
- \*\*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical source area)

Note: If actual input values vary significantly from the above scenarios it is recommended that CH2MDA16 be used to calculate emission estimates directly

**TABLE F-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - MECHANICALLY AERATED IMPOUNDMENTS**

Henry's Law Constant Surrogate	(Case 1)	(Case 2)	(Case 3)	(Case 4)	(Case 5)	(Case 6)	(Case 7)	(Case 8)
MHLB	47.2	90.6	168.1	220.8	253.9	90.6	62.1	47.2
HHLB	49.2	98.4	196.5	272.6	326.9	98.4	65.6	49.2
LHMB	11.0	12.3	13.2	13.4	13.5	12.3	11.6	11.0
MHMB	48.3	94.7	182.6	246.5	289.4	94.7	64.0	48.3
HHMB	49.2	98.3	195.8	271.2	324.9	98.3	65.6	49.2
LHHB	7.9	8.5	8.9	9.0	9.1	8.5	8.2	7.9
MHHB	48.6	95.9	187.0	254.6	300.9	95.9	64.5	48.6
HHHB	49.2	98.4	186.4	272.3	326.6	98.4	65.6	49.2
Henry's Law Constant Surrogate	(Case 9)	(Case 10)	(Case 11)	(Case 12)	(Case 13)	(Case 14)	(Case 15)	(Case 16)
MHLB	0.91	90.6	181.2	362.4	86.6	90.6	95.4	97.0
HHLB	0.98	98.4	196.9	393.8	98.4	98.4	98.5	98.6
LHMB	0.12	12.3	24.7	49.4	8.9	12.3	25.5	40.2
MHMB	0.95	94.7	189.5	379.0	92.6	94.7	97.1	97.9
HHMB	0.98	98.3	196.5	393.0	98.0	98.3	98.5	98.5
LHHB	0.085	8.5	17.1	34.2	6.0	8.5	18.8	31.3
MHHB	0.96	95.9	191.9	383.8	94.4	95.9	97.6	98.1
HHHB	0.98	98.4	196.8	393.6	98.3	98.4	98.5	98.6
Henry's Law Constant Surrogate	1 Year (Case 17)	5 Years (Case 18)	10 Years (Case 19)	70 Years (Case 20)	(Case 21)	(Case 22)	(Case 23)	
MHLB	90.6	90.6	90.6	90.6	0.24	90.6	3,169.2	
HHLB	98.4	98.4	98.4	98.4	0.25	98.4	3,635.2	
LHMB	12.3	12.3	12.3	12.3	0.070	12.3	252.4	
MHMB	94.7	94.7	94.7	94.7	0.24	94.7	3,414.6	
HHMB	98.3	98.3	98.3	98.3	0.25	98.3	3,624.2	
LHHB	8.5	8.5	8.5	8.5	0.050	8.5	174.9	
MHHB	95.9	95.9	95.9	95.9	0.24	95.9	3,487.5	
HHHB	98.4	98.4	98.4	98.4	0.25	98.4	3,633.5	

## **Appendix G**

### **Emission Rate Estimates Diffused Air Systems**

**TABLE G-1  
EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - DIFFUSED AIR SYSTEM\***

Modeling Parameters	CASE NUMBERS																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21**	22***	23****
Area (acres)	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03	6.7E-03
Depth (m)	2	4	5	6	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	4	6
Retention time (hours)	4	4	4	4	3	4	5	6	4	4	4	4	4	4	4	4	4	4	4	4	6	4	3
Constituent concentration (ppm)	1000	1000	1000	1000	1000	1000	1000	1000	10	1000	2000	4000	1000	1000	1000	1000	1000	1000	1000	1000	10	1000	4000
Submerged air flow (m <sup>3</sup> /sec)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.04	0.045	0.05	0.04	0.04	0.04	0.04	0.03	0.04	0.05
Air temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Wind speed (mph)	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

- \* Input assumptions:
- Active biomass = 0.0 g/l
  - Biomass solids in = 0.0 m<sup>3</sup>/sec
  - Fraction agitated = 0.0
  - Number of impellers = 1
  - Oxygen transfer rating = 3 lb O<sub>2</sub>/h-hp
  - Power (total) = 75 hp
  - Oxygen transfer correction factor = 0.83
  - Impeller diameter = 61 cm
  - Impeller speed = 126 rad/sec
- \*\* Reasonable Best Case (minimum) Emissions (assuming typical source area)
- \*\*\* Typical Emission Conditions (assuming typical source area)
- \*\*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical source area)

**Note:** If actual input values vary significantly from the above scenarios it is recommended that CHM MDA16 be used to calculate emission estimates directly

**TABLE G-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - DIFFUSED AIR SYSTEM**

Henry's Law Constant Surrogate	(Case 1)	(Case 2)	(Case 3)	(Case 4)	(Case 5)	(Case 6)	(Case 7)	(Case 8)
MHLB	3.8	3.9	3.9	3.9	3.9	3.9	3.9	3.9
HHLB	110.0	205.4	248.5	289.0	262.3	205.4	168.8	143.2
LHMB	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
MHMB	6.2	6.4	6.4	6.4	6.4	6.4	6.3	6.3
HHMB	42.3	51.5	53.8	55.5	54.4	51.5	48.8	46.4
LHHB	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
MHHB	7.8	8.1	8.2	8.2	8.2	8.1	8.0	8.0
HHHB	83.4	128.9	144.6	157.5	149.2	128.9	113.4	101.3
Henry's Law Constant Surrogate	(Case 9)	(Case 10)	(Case 11)	(Case 12)	(Case 13)	(Case 14)	(Case 15)	(Case 16)
MHLB	0.039	3.9	7.8	15.6	3.6	3.9	4.0	4.2
HHLB	2.0	205.4	410.8	821.5	196.8	205.4	208.4	210.9
LHMB	8.6E-04	0.086	0.17	0.34	0.084	0.086	0.087	0.088
MHMB	0.064	6.4	12.8	25.5	5.9	6.4	6.6	6.9
HHMB	0.51	51.5	102.9	205.9	41.6	51.5	56.0	60.3
LHHB	5.5E-04	0.055	0.11	0.22	0.053	0.055	0.056	0.057
MHHB	0.081	8.1	16.2	32.4	7.3	8.1	8.5	8.9
HHHB	1.3	128.9	257.8	515.5	112.3	128.9	135.6	141.6
Henry's Law Constant Surrogate	1 Year (Case 17)	5 Years (Case 18)	10 Years (Case 19)	70 Years (Case 20)	Case 21	Case 22	Case 23	
MHLB	3.9	3.9	3.9	3.9	0.035	3.9	16.8	
HHLB	205.4	205.4	205.4	205.4	0.74	205.4	1522.0	
LHMB	0.086	0.086	0.086	0.086	8.4E-04	0.086	0.35	
MHMB	6.4	6.4	6.4	6.4	0.056	6.4	27.9	
HHMB	51.5	51.5	51.5	51.5	0.31	51.5	276.6	
LHHB	0.055	0.055	0.055	0.055	5.3E-04	0.055	0.23	
MHHB	8.1	8.1	8.1	8.1	0.068	8.1	36.3	
HHHB	128.9	128.9	128.9	128.9	0.58	128.9	808.0	



## **Appendix H**

### **Emission Rate Estimates Land Treatment (Emissions After Tilling)**

**TABLE H-1  
EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - LAND TREATMENT (EMISSIONS AFTER TILLING)\***

Modeling Parameters	CASE NUMBERS																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21**	22***	23****
Area (acres)	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
Annual waste (oil & water) throughput (10 <sup>6</sup> g/yr)	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Oil content of waste(%)	2	10	20	50	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	2	10	50
Constituent of interest content of oil (ppm)	2000	2000	2000	2000	500	2000	5000	10,000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	500	2000	10000
Soil porosity (%)	50	50	50	50	50	50	50	50	43	50	55	65	50	50	50	50	50	50	50	50	43	50	65
Tilling depth (cm)	20	20	20	20	20	20	20	20	20	20	20	20	15	20	40	65	20	20	20	20	65	20	15
Air temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

\* Input assumptions:

- Molecular weight of oil = 282
- Organics (VO) dissolved in water = 0.0
- Biodegradation considered = yes

\*\* Reasonable Best Case (minimum) Emissions (assuming typical source area)

\*\*\* Typical Emission Conditions (assuming typical source area)

\*\*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical source area)

Note: If actual input values vary significantly from the above scenarios it is recommended that CHEMPA16 be used to calculate emission estimates directly

**TABLE H-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - LAND TREATMENT (EMISSION AFTER TILLING)**

Raoult's Law Surrogate	(Case 1)	(Case 2)	(Case 3)	(Case 4)	(Case 5)	(Case 6)	(Case 7)	(Case 8)
HVHB	0.071	0.341	0.650	1.431	0.085	0.341	0.853	1.706
HVMB	0.072	0.357	0.708	1.730	0.089	0.357	0.892	1.784
HVLB	0.072	0.359	0.719	1.793	0.090	0.359	0.898	1.796
MVHB	0.044	0.108	0.153	0.243	0.027	0.108	0.271	0.542
MVMB	0.063	0.219	0.338	0.533	0.055	0.219	0.548	1.096
MVLB	0.071	0.338	0.639	1.382	0.085	0.338	0.845	1.690
LVMB	7.92E-04	1.80E-03	2.16E-03	3.60E-03	4.50E-04	1.80E-03	4.50E-03	9.00E-03
VHVHB	0.072	0.356	0.708	1.728	0.089	0.356	0.891	1.782
VHVLB	0.072	0.359	0.719	1.796	0.090	0.359	0.898	1.796
Raoult's Law Surrogate	(Case 9)	(Case 10)	(Case 11)	(Case 12)	(Case 13)	(Case 14)	(Case 15)	(Case 16)
HVHB	0.334	0.341	0.345	0.349	0.346	0.341	0.325	0.308
HVMB	0.355	0.357	0.357	0.358	0.357	0.357	0.354	0.351
HVLB	0.359	0.359	0.359	0.359	0.359	0.359	0.359	0.359
MVHB	0.091	0.108	0.121	0.147	0.125	0.108	0.077	0.060
MVMB	0.194	0.219	0.235	0.262	0.240	0.219	0.169	0.133
MVLB	0.330	0.338	0.342	0.347	0.343	0.338	0.319	0.300
LVMB	1.44E-03	1.80E-03	1.80E-03	2.52E-03	2.16E-03	1.80E-03	1.08E-03	1.08E-03
VHVHB	0.355	0.356	0.357	0.358	0.357	0.356	0.354	0.350
VHVLB	0.359	0.359	0.359	0.359	0.359	0.359	0.359	0.359
Raoult's Law Surrogate	(Case 17)	(Case 18)	(Case 19)	(Case 20)	(Case 21)	(Case 22)	(Case 23)	
HVHB	0.341	0.341	0.341	0.341	0.017	0.341	8.118	
HVMB	0.357	0.357	0.357	0.357	0.018	0.357	8.847	
HVLB	0.359	0.359	0.359	0.359	0.018	0.359	8.982	
MVHB	0.108	0.108	0.108	0.108	0.006	0.108	1.908	
MVMB	0.219	0.219	0.219	0.219	0.011	0.219	4.194	
MVLB	0.338	0.338	0.338	0.338	0.017	0.338	7.974	
LVMB	1.80E-03	1.80E-03	1.80E-03	1.80E-03	9.00E-05	1.80E-03	2.70E-02	
VHVHB	0.356	0.356	0.356	0.356	0.018	0.356	8.838	
VHVLB	0.359	0.359	0.359	0.359	0.018	0.359	8.982	

## **Appendix I**

### **Emission Rate Estimates Oil Film Surface on Land Treatment Units**

**TABLE I-1  
EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - OIL FILM SURFACE ON LAND TREATMENT UNITS\***

Modeling Parameters	CASE NUMBERS																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17**	18***	19****
Area (acres)	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
Depth of oil film (m)	7.2E-04	7.2E-03	7.2E-02	7.2E-01	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-02	7.2E-04	7.2E-02	7.2E-01
Number of Applications per year	365	365	365	365	20	50	365	730	365	365	365	365	365	365	365	365	20	365	730
Constituent concentration in oil (ppm)	200	200	200	200	200	200	200	200	100	200	1000	5000	200	200	200	200	100	200	5000
Air temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Wind speed (mph)	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

\* Input assumptions:

- Flow = 0.0 m<sup>3</sup>/sec
- Oil (fraction of waste) = 1.0
- Molecular weight of oil = 282
- Density of oil = 1.0 g/cc

\*\* Reasonable Best Case (minimum) Emissions (assuming typical source area)

\*\*\* Typical Emission Conditions (assuming typical source area)

\*\*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical source area)

Note: If actual input values vary significantly from the above scenarios it is recommended that CHEMDAT6 be used to calculate emission estimates directly

**TABLE I-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - OIL FILM SURFACE ON LAND TREATMENT UNIT**

Raoult's Law Surrogate	(Case 1)	(Case 2)	(Case 3)	(Case 4)	(Case 5)	(Case 6)	(Case 7)	(Case 8)
HVHB	1.3	13.1	131.4	1,205.2	7.2	18.0	131.4	262.8
HVMB	1.3	13.1	131.4	1,225.5	7.2	18.0	131.4	262.8
HVLB	1.3	13.1	131.4	1,242.0	7.2	18.0	131.4	262.8
MVHB	1.3	12.2	30.8	34.7	7.1	15.4	30.8	32.7
MVMB	1.3	11.0	22.0	23.8	6.9	13.2	22.0	22.8
MVLB	1.3	12.3	31.2	35.1	7.1	15.5	31.2	33.1
LVMB	1.55E-03	1.54E-03	1.45E-03	1.31E-03	1.54E-03	1.53E-03	1.45E-03	1.31E-03
VHVHB	1.3	13.1	131.4	1,314.0	7.2	18.0	131.4	262.8
VHVLB	1.3	13.1	131.4	1,314.0	7.2	18.0	131.4	262.8
Raoult's Law Surrogate	(Case 9)	(Case 10)	(Case 11)	(Case 12)	1 Year (Case 13)	5 Years (Case 14)	10 Years (Case 15)	70 Years (Case 16)
HVHB	65.7	131.4	657.0	3,285.0	131.4	131.4	131.4	131.4
HVMB	65.7	131.4	657.0	3,285.0	131.4	131.4	131.4	131.4
HVLB	65.7	131.4	657.0	3,285.0	131.4	131.4	131.4	131.4
HVHB	15.4	30.8	154.2	771.1	30.8	30.8	30.8	30.8
MVMB	11.0	22.0	109.9	549.7	22.0	22.0	22.0	22.0
MVLB	15.6	31.2	155.9	779.5	31.2	31.2	31.2	31.2
LVMB	7.23E-04	1.45E-03	7.23E-03	0.036	1.45E-03	1.45E-03	1.45E-03	1.45E-03
VHVHB	65.7	131.4	657.0	3,285.0	131.4	131.4	131.4	131.4
VHVLB	65.7	131.4	657.0	3,285.0	131.4	131.4	131.4	131.4
Raoult's Law Surrogate	(Case 17)	(Case 18)	(Case 19)					
HVHB	0.036	131.4	46,072.4					
HVMB	0.036	131.4	47,942.7					
HVLB	0.036	131.4	49,634.6					
MVHB	0.036	30.8	846.7					
MVMB	0.036	22.0	580.7					
MVLB	0.036	31.2	857.3					
LVMB	7.62E-04	1.45E-03	0.038					
VHVHB	0.036	131.4	65,699.1					
VHVLB	0.036	131.4	65,699.7					

**Appendix J**  
**Emission Rate Estimates**  
**Closed Landfills**

**TABLE J-1  
EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - CLOSED LANDFILL (VENTED)\***

Modeling Parameters	CASE NUMBERS																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21**	22***	23****
Area (acres)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Waste-bed thickness (ft)	15	30	60	120	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	120
Cap thickness (ft)	3.5	3.5	3.5	3.5	2	3.5	5	6	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	6	3.5	2
Weight percent organics (VO) in waste	40	40	40	40	40	40	40	40	10	40	60	90	40	40	40	40	40	40	40	40	10	40	90
Air porosity of fixed waste (%)	25	25	25	25	25	25	25	25	25	25	25	25	5	25	50	75	25	25	25	25	5	25	75
Waste liquid density (g/cm <sup>3</sup> )	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Cap air porosity (%)	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Cap total porosity (%)	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
Temperature beneath cap (°C)	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Typical barometric pressure (mb)	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013
Typical barometric pressure drop (mb)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Air temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

\* Input assumptions:

- 100% of the organics in waste is the constituent of interest
- Weight percent oil in waste = 0.0% (fraction = 0.0)
- Weight percent water in waste = 100%-organics (fraction = 1.0-organics)
- Barometric pumping time = 86,400 sec
- Molecular weight oil = 147

- CHEMDAT6 CC/GVOC conversion factor = 1750
- Active biomass = 0.0 g/cc
- Organics dissolved in water = 0 (i.e., use Raoult's Law)
- Rho liquid density = 1.0 g/cm<sup>3</sup>
- Molecular weight of liquid = 18

\*\* Reasonable Best Case (minimum) Emissions (assuming typical source area)

\*\*\* Typical Emission Conditions (assuming typical source area)

\*\*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical source area)

Note: If actual input values vary significantly from the above scenarios it is recommended that CHEMDAT6 be used to calculate emission estimates directly



**TABLE J-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - CLOSED LANDFILL (VENTED)**

Raoult's Law Surrogate	(Case 1)	(Case 2)	(Case 3)	(Case 4)	(Case 5)	(Case 6)	(Case 7)	(Case 8)
HVHB	2 44E + 01	4 44E + 01	8 44E + 01	1 64E + 02	2 78E + 01	2 44E + 01	2 31E + 01	2 26E + 01
HVMB	2 24E + 01	3 96E + 01	7 40E + 01	1 43E + 02	2 63E + 01	2 24E + 01	2 08E + 01	2 02E + 01
HVLB	4 69E + 01	8 60E + 01	1 64E + 02	3 20E + 02	5 29E + 01	4 70E + 01	4 46E + 01	4 37E + 01
MVHB	4 45E-01	8 24E-01	1 58E + 00	3 10E + 00	4 94E-01	4 45E-01	4 25E-01	4 18E-01
MVMB	3 98E-01	7 46E-01	1 44E + 00	2 83E + 00	4 36E-01	3 98E-01	3 83E-01	3 77E-01
MVLB	8 08E-01	1 51E + 00	2 92E + 00	5 73E + 00	8 88E-01	8 08E-01	7 77E-01	7 64E-01
LVMB	1 55E-05	2 83E-05	5 39E-05	1 05E-04	1 76E-05	1 55E-05	1 47E-05	1 44E-05
VHVHB	1 19E + 02	2 15E + 02	4 09E + 02	7 96E + 02	1 35E + 02	1 19E + 02	1 12E + 02	1 10E + 02
VHVLB	2 64E + 02	4 77E + 02	9 03E + 02	1 76E + 03	3 02E + 02	2 64E + 02	2 49E + 02	2 43E + 02
Raoult's Law Surrogate	(Case 9)	(Case 10)	(Case 11)	(Case 12)	(Case 13)	(Case 14)	(Case 15)	(Case 16)
HVHB	2 44E + 01	2 44E + 01	2 44E + 01	2 44E + 01	8 45E + 00	2 44E + 01	4 44E + 01	6 44E + 01
HVMB	2 24E + 01	2 24E + 01	2 24E + 01	2 24E + 01	8 63E + 00	2 24E + 01	3 96E + 01	5 68E + 01
HVLB	4 68E + 01	4 70E + 01	4 70E + 01	4 70E + 01	1 57E + 01	4 70E + 01	8 60E + 01	1 25E + 02
MVHB	4 45E-01	4 45E-01	4 45E-01	4 45E-01	1 41E-01	4 45E-01	8 25E-01	1 20E + 00
MVMB	3 98E-01	3 98E-01	3 98E-01	3 98E-01	1 20E-01	3 98E-01	7 46E-01	1 09E + 00
MVLB	8 08E-01	8 08E-01	8 08E-01	8 08E-01	2 46E-01	8 08E-01	1 51E + 00	2 21E + 00
LVMB	1 55E-05	1 55E-05	1 55E-05	1 55E-05	5 29E-06	1 55E-05	2 83E-05	4 11E-05
VHVHB	1 18E + 02	1 19E + 02	1 19E + 02	1 19E + 02	4 14E + 01	1 19E + 02	2 15E + 02	3 11E + 02
VHVLB	2 61E + 02	2 64E + 02	2 64E + 02	2 65E + 02	9 40E + 01	2 64E + 02	4 75E + 02	6 85E + 02
Raoult's Law Surrogate	1 Year (Case 17)	5 Years (Case 18)	10 Years (Case 19)	70 Years (Case 20)	(Case 21)	(Case 22)	(Case 23)	
HVHB	2 44E + 01	2 44E + 01	2 44E + 01	2 38E + 01	6 59E + 00	2 44E + 01	4 88E + 02	
HVMB	2 24E + 01	2 24E + 01	2 23E + 01	2 18E + 01	6 47E + 00	2 24E + 01	4 22E + 02	
HVLB	4 70E + 01	4 68E + 01	4 66E + 01	4 45E + 01	1 24E + 01	4 70E + 01	9 51E + 02	
MVHB	4 45E-01	4 45E-01	4 45E-01	4 45E-01	1 14E-01	4 45E-01	9 22E + 00	
MVMB	3 98E-01	3 98E-01	3 98E-01	3 98E-01	9 89E-02	3 98E-01	8 44E + 00	
MVLB	8 08E-01	8 08E-01	8 08E-01	8 08E-01	2 02E-01	8 08E-01	1 70E + 01	
LVMB	1 55E-05	1 55E-05	1 55E-05	1 55E-05	4 15E-06	1 55E-05	3 12E-04	
VHVHB	1 19E + 02	1 18E + 02	1 17E + 02	1 04E + 02	3 22E + 01	1 19E + 02	2 36E + 03	
VHVLB	2 64E + 02	2 60E + 02	2 54E + 02	1 94E + 02	7 21E + 01	2 64E + 02	5 20E + 03	

## **Appendix K**

### **Emission Rate Estimates Open Landfills**

**TABLE K-1  
EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - OPEN LANDFILL \***

Modeling Parameters	CASE NUMBERS																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21**	22***	23****
Area (acres)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Waste-bed thickness (ft)	3	7.5	15	30	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	3	7.5	30
Constituent content of waste (%)	40	40	40	40	10	40	60	90	40	40	40	40	40	40	40	40	40	40	40	40	10	40	90
Air porosity of fixed waste (%)	25	25	25	25	25	25	25	25	5	25	35	50	25	25	25	25	25	25	25	25	5	25	50
Total porosity of fixed waste (%)	50	50	50	50	50	50	50	50	50	50	50	50	10	25	50	75	50	50	50	50	75	50	10
Waste liquid density (g/cm <sup>3</sup> )	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Air temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

\* Input assumptions

- Organic (VO) concentration of waste = 1,000,000 ppmw
- Molecular weight of oil = 147
- Organics dissolved in water = 0 (i.e., no)
- Biodegradation = 0 (i.e., no)

\*\* Reasonable Best Case (minimum) Emissions (assuming typical source area)

\*\*\* Typical Emission Conditions (assuming typical source area)

\*\*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical source area)

**Note:** If actual values vary significantly from the above scenarios it is recommended that CHEMDAT6 be used to calculate emission estimates directly

**TABLE K-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - OPEN LANDFILL**

Raoult's Law Surrogate	(Case 1)	(Case 2)	(Case 3)	(Case 4)	(Case 5)	(Case 6)	(Case 7)	(Case 8)
HVHB	769.2	766.2	781.2	781.2	386.9	766.2	946.5	1149.3
HVMB	841.3	841.3	841.3	841.3	420.7	841.3	1036.6	1250.7
HVLB	817.3	811.3	811.3	841.3	409.4	811.3	991.6	1216.9
MVHB	78.1	75.1	90.1	60.1	37.6	75.1	90.1	101.4
MVMB	60.1	60.1	60.1	60.1	30.0	60.1	67.6	101.4
MVLB	78.1	75.1	90.1	60.1	37.6	75.1	90.1	101.4
LVMB	0.5	0.6	0.6	0.6	0.3	0.6	0.7	0.7
VHVHB	2361.7	2358.7	2373.8	2343.7	1179.4	2358.7	2884.6	3549.4
VHVLB	2518.0	2509.0	2524.0	2524.0	1258.2	2509.0	3087.4	3786.0
Raoult's Law Surrogate	(Case 9)	(Case 10)	(Case 11)	(Case 12)	(Case 13)	(Case 14)	(Case 15)	(Case 16)
HVHB	30.0	766.2	1592.5	3455.5	3846.1	1547.5	766.2	510.8
HVMB	30.0	841.3	1742.8	3786.0	4206.7	1682.7	841.3	555.9
HVLB	30.0	811.3	1697.7	3680.8	4086.5	1637.6	811.3	540.9
MVHB	2.4	75.1	165.3	345.5	375.6	150.2	75.1	45.1
MVMB	2.0	60.1	120.2	270.4	300.5	120.2	60.1	45.1
MVLB	2.3	75.1	150.2	330.5	375.6	150.2	75.1	45.1
LVMB	0.02	0.6	1.1	2.4	2.7	1.1	0.6	0.3
VHVHB	75.1	2358.7	4882.7	10336.4	11297.9	4717.5	2358.7	1577.5
VHVLB	75.1	2509.0	5213.3	10907.3	11853.8	5033.0	2509.0	1682.7
Raoult's Law Surrogate	1 year (Case 17)	5 years (Case 18)	10 years (Case 19)	70 years (Case 20)	(Case 21)	(Case 22)	(Case 23)	
HVHB	766.2	1727.7	2433.9	6445.2	7.9	766.2	25961.1	
HVMB	841.3	1878.0	2659.2	7046.2	8.6	841.3	28395.0	
HVLB	811.3	1832.9	2584.1	6850.9	8.4	811.3	27583.7	
MVHB	75.1	165.3	240.4	646.0	0.8	75.1	2569.1	
MVMB	60.1	135.2	195.3	510.8	0.6	60.1	2028.2	
MVLB	75.1	165.3	240.4	631.0	0.8	75.1	2569.1	
LVMB	0.6	1.2	1.7	4.4	0.01	0.6	17.6	
VHVHB	2358.7	5273.4	7451.8	14558.1	24.1	2358.7	78829.9	
VHVLB	2509.0	5618.9	7917.5	14723.3	25.7	2509.0	83697.6	

## **Appendix L**

### **Emission Rate Estimates Wastepiles**

**TABLE L-1  
EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - WASTEPILES\***

Modeling Parameters	CASE NUMBERS																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21**	22***	23****
Area (acres)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Turnover rate (per year)	730	365	140	52	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	52	140	730
Constituent content of waste (%)	40	40	40	40	10	40	60	90	40	40	40	40	40	40	40	40	40	40	40	40	10	40	90
Air porosity of fixed waste (%)	25	25	25	25	25	25	25	25	5	25	35	50	25	25	25	25	25	25	25	25	5	25	50
Total porosity of fixed waste (%)	50	50	50	50	50	50	50	50	50	50	50	50	10	25	50	75	50	50	50	50	75	50	10
Pile height (m)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Waste liquid density (g/cm <sup>3</sup> )	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Air temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

- \* Input assumptions:
  - Organic (VO) concentration of waste = 1,000,000 ppmw
  - Molecular weight of oil = 147
  - Organics dissolved in water = 0 (i.e., no)
  - Biodegradation = 0 (i.e., no)
- \*\* Reasonable Best Case (minimum) Emissions (assuming typical source area)
- \*\*\* Typical Emission Conditions (assuming typical source area)
- \*\*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical source area)

**Note:** If actual input values vary significantly from the above scenarios it is recommended that CHEMTRAC be used to calculate emission estimates directly.

**TABLE L-2  
EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - WASTEPILE**

Raoult's Law Surrogate	(Case 1)	(Case 2)	(Case 3)	(Case 4)	(Case 5)	(Case 6)	(Case 7)	(Case 8)
HVHB	595.3	421.1	261.4	159.7	130.6	261.4	320.1	391.7
HVMB	651.6	460.9	284.9	174.4	143.1	284.9	350.2	429.1
HVLB	633.7	447.9	277.0	169.5	139.2	277.0	340.3	416.7
MVHB	59.3	41.9	26.0	15.9	13.0	26.0	31.8	38.9
MVMB	47.6	33.6	20.9	12.7	10.4	20.9	25.6	31.3
MVLB	58.3	41.2	25.5	15.6	12.8	25.5	31.3	38.3
LVMB	0.4	0.3	0.2	0.1	0.1	0.2	0.2	0.3
VHVHB	1824.4	1289.4	799.3	487.9	399.7	799.3	981.3	1199.0
VHVLB	1947.9	1378.6	852.1	520.3	426.7	852.1	1044.6	1282.0
Raoult's Law Surrogate	(Case 9)	(Case 10)	(Case 11)	(Case 12)	(Case 13)	(Case 14)	(Case 15)	(Case 16)
HVHB	8.0	261.4	540.8	1173.9	1305.8	522.3	261.4	174.1
HVMB	8.8	284.9	593.5	1284.7	1429.8	572.4	284.9	190.7
HVLB	8.5	277.0	575.1	1247.8	1387.6	556.6	277.0	185.2
MVHB	0.8	26.0	53.8	116.6	129.8	52.0	26.0	17.3
MVMB	0.6	20.9	43.3	93.6	104.2	41.7	20.9	13.9
MVLB	0.8	25.5	53.0	114.8	127.7	51.2	25.5	17.0
LVMB	0.01	0.2	0.4	0.8	0.9	0.4	0.2	0.1
VHVHB	24.5	799.3	659.3	3,587.6	4,009.7	1,598.6	799.3	532.9
VHVLB	26.1	852.1	767.4	3,825.0	4,273.5	1,706.8	852.1	569.8
Raoult's Law Surrogate	(Case 17)	(Case 18)	(Case 19)	(Case 20)	(Case 21)	(Case 22)	(Case 23)	
HVHB	261.4	261.4	261.4	261.4	1.6	261.4	20,061.7	
HVMB	284.9	284.9	284.9	284.9	1.8	284.9	21,944.4	
HVLB	277.0	277.0	277.0	277.0	1.7	277.0	21,327.1	
MVHB	26.0	26.0	26.0	26.0	0.2	26.0	1,993.8	
MVMB	20.9	20.9	20.9	20.9	0.1	20.9	1,601.8	
MVLB	25.5	25.5	25.5	25.5	0.2	25.5	1,959.9	
LVMB	0.2	0.2	0.2	0.2	0.001	0.2	13.7	
VHVHB	799.3	799.3	799.3	799.3	5.0	799.3	61,419.6	
VHVLB	852.1	852.1	852.1	852.1	5.3	852.1	65,431.9	

## **Appendix M**

### **Emission Rate Estimates Fixed Roof Tanks**



**TABLE M-1  
EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - FIXED ROOF TANK**

Modeling Parameters	CASE NUMBERS																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22*	23**	24***
Tank diameter (ft)	10	20	40	60	100	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	20	100	200
Tank height (ft)	40	40	40	40	40	40	10	20	30	40	50	40	40	40	40	40	40	40	40	40	40	40	40	50
Turnovers (per yr)	2674	668	167	74	27	7	107	53	36	27	21	4	21	42	127	212	297	27	27	27	27	668	27	59
Throughput (10 <sup>6</sup> gal/yr)	63	63	63	63	63	63	63	63	63	63	63	10	50	100	300	500	700	63	63	63	63	63	63	700
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

- \* Reasonable Best Case (minimum) Emissions (assuming typical tank size)
- \*\* Typical Emission Conditions (assuming typical tank size)
- \*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical tank size)

**Note:** If actual input values vary significantly from the above scenarios it is recommended that AP-42 be used to calculate emission estimates directly

**TABLE M-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - FIXED ROOF TANK**

Raoult's Law Surrogate	(Case 1)		(Case 2)		(Case 3)		(Case 4)		(Case 5)		(Case 6)		(Case 7)		(Case 8)	
	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working
HVHB*																
HVMB*																
HVLB*																
MVHB	1.6E-02	9.3E-01	9.8E-02	9.3E-01	3.6E-01	1.4E+00	7.3E-01	2.7E+00	1.8E+00	3.9E+00	5.9E+00	3.9E+00	8.7E-01	1.8E+00	1.2E+00	2.7E+00
MVMB	1.6E-02	8.5E-01	9.8E-02	8.5E-01	3.6E-01	1.2E+00	7.3E-01	2.5E+00	1.8E+00	3.5E+00	5.8E+00	3.5E+00	8.7E-01	1.6E+00	1.2E+00	2.5E+00
MVLB	2.9E-02	1.7E+00	1.8E-01	1.7E+00	6.5E-01	2.5E+00	1.3E+00	5.0E+00	3.2E+00	7.1E+00	1.0E+01	7.1E+00	1.6E+00	3.3E+00	2.2E+00	5.0E+00
LVMB	1.4E-05	3.1E-05	8.5E-05	3.1E-05	3.2E-04	4.5E-05	6.4E-04	9.1E-05	1.5E-03	1.3E-04	5.1E-03	1.3E-04	7.6E-04	6.0E-05	1.1E-03	9.1E-05
VHVHB*																
VHVLB*																
Raoult's Law Surrogate	(Case 9)		(Case 10)		(Case 11)		(Case 12)		(Case 13)		(Case 14)		(Case 15)		(Case 16)	
	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working
HVHB*																
HVMB*																
HVLB*																
MVHB	1.5E+00	3.9E+00	1.8E+00	3.9E+00	2.0E+00	3.9E+00	1.8E+00	6.1E-01	1.8E+00	3.1E+00	1.8E+00	4.9E+00	1.8E+00	8.4E+00	1.8E+00	9.2E+00
MVMB	1.5E+00	3.5E+00	1.8E+00	3.5E+00	2.0E+00	3.5E+00	1.8E+00	5.6E-01	1.8E+00	2.8E+00	1.8E+00	4.5E+00	1.8E+00	7.7E+00	1.8E+00	8.4E+00
MVLB	2.7E+00	7.1E+00	3.2E+00	7.1E+00	3.5E+00	7.1E+00	3.2E+00	1.1E+00	3.2E+00	5.7E+00	3.2E+00	9.1E+00	3.2E+00	5.9E+01	3.2E+00	1.7E+01
LVMB	1.3E-03	1.3E-04	1.5E-03	1.3E-04	1.7E-03	1.3E-04	1.5E-03	2.1E-05	1.5E-03	1.0E-04	1.5E-03	1.7E-04	1.5E-03	2.8E-04	1.5E-03	3.1E-04
VHVHB*																
VHVLB*																
Raoult's Law Surrogate	(Case 17)		(Case 18)		(Case 19)		(Case 20)		(Case 21)		(Case 22)		(Case 23)		(Case 24)	
	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working	Breathing	Working
HVHB*																
HVMB																
HVLB*																
MVHB	1.8E+00	1.3E+01	1.8E+00	3.9E+00	1.8E+00	3.9E+00	1.8E+00	3.9E+00	1.8E+00	3.9E+00	9.8E-02	9.3E-01	1.8E+00	3.9E+00	6.6E+00	3.0E+01
MVMB	1.8E+00	1.2E+01	1.8E+00	3.5E+00	1.8E+00	3.5E+00	1.8E+00	3.5E+00	1.8E+00	3.5E+00	9.8E-02	8.5E-01	1.8E+00	3.5E+00	6.5E+00	2.8E+01
MVLB	3.2E+00	2.4E+01	3.2E+00	7.1E+00	3.2E+00	7.1E+00	3.2E+00	7.1E+00	3.2E+00	7.1E+00	1.8E-01	1.7E+00	3.2E+00	7.1E+00	1.2E+01	5.6E+01
LVMB	1.5E-03	4.3E-04	1.5E-03	1.3E-04	1.5E-03	1.3E-04	1.5E-03	1.3E-04	1.5E-03	1.3E-04	8.5E-05	3.1E-05	1.5E-03	1.3E-04	5.7E-03	1.0E-03
VHVHB*																
VHVLB*																

\*This type of tank is not typically used for materials with this high vapor pressure

**Appendix N**  
**Emission Rate Estimates**  
**Floating Roof Tanks**

**TABLE N-1  
EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATION - FLOATING ROOF TANK**

Modeling Parameters	CASE NUMBERS																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26*	27**	28***
Rim seal class (see Table J-3)	A	B	C	D	E	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Shell condition (see Table J-4)	A	A	A	A	A	A	A	A	A	B	C	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	C
Average liquid density (lb/gal)	61	61	61	61	61	61	61	61	61	61	61	56	76	96	116	134	61	61	61	61	61	61	61	61	61	56	61	134
Tank diameter (ft)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	30	60	100	140	180	100	100	100	100	30	100	180
Tank throughput (10 <sup>6</sup> gal/yr)	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	10	70	1	1	1	1

- \* Estimated Best Case (minimum) Emissions (assuming typical tank size)
- \*\* Typical Emission Conditions (assuming typical tank size)
- \*\*\* Estimated Worst Case (maximum) Emissions (assuming typical tank size)

**Note:** If actual input values vary significantly from the above scenarios it is recommended that AP-42 be used to calculate emission estimates directly

**TABLE N-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - FLOATING ROOF TANK**

Raoult's Law Surrogates	Case 1			Case 2			Case 3			Case 4			Case 5			Case 6		
	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting
HVHB*																		
HVMB*																		
HVLB*																		
MVHB	1.3E-02	6.2E-02	3.0E-02	3.5E-02	6.2E-02	3.0E-02	5.5E-02	6.2E-02	3.0E-02	9.6E-02	6.2E-02	3.0E-02	1.8E-01	6.2E-02	3.0E-02	3.3E-01	6.2E-02	3.0E-02
MVMB	1.2E-02	6.2E-02	2.8E-02	3.2E-02	6.2E-02	2.8E-02	5.1E-02	6.2E-02	2.8E-02	8.8E-02	6.2E-02	2.8E-02	1.6E-01	6.2E-02	2.8E-02	3.1E-01	6.2E-02	2.8E-02
MVLB	2.4E-02	6.2E-02	5.6E-02	6.4E-02	6.2E-02	5.6E-02	1.0E-01	6.2E-02	5.6E-02	1.8E-01	6.2E-02	5.6E-02	3.3E-01	6.2E-02	5.6E-02	6.2E-01	6.2E-02	5.6E-02
LVMB	4.4E-07	6.2E-02	1.0E-06	1.2E-06	6.2E-02	1.0E-06	1.9E-06	6.2E-02	1.0E-06	3.2E-06	6.2E-02	1.0E-06	6.0E-06	6.2E-02	1.0E-06	1.1E-05	6.2E-02	1.0E-06
VHVHB*																		
VHVLB*																		
Raoult's Law Surrogates	Case 7			Case 8			Case 9			Case 10			Case 11			Case 12		
	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting
HVHB*																		
HVMB*																		
HVLB*																		
MVHB	6.2E-01	6.2E-02	3.0E-02	1.0E+00	6.2E-02	3.0E-02	1.0E+00	6.2E-02	3.0E-02	1.0E+00	3.1E-01	3.0E-02	1.0E+00	6.2E+00	3.0E-02	1.0E+00	5.7E-02	3.0E-02
MVMB	5.7E-01	6.2E-02	2.8E-02	9.5E-01	6.2E-02	2.8E-02	9.5E-01	6.2E-02	2.8E-02	9.5E-01	3.1E-01	2.8E-02	9.5E-01	6.2E+00	2.8E-02	9.5E-01	5.7E-02	2.8E-02
MVLB	1.1E+00	6.2E-02	5.6E-02	1.9E+00	6.2E-02	5.6E-02	1.9E+00	6.2E-02	5.6E-02	1.9E+00	3.1E-01	5.6E-02	1.9E+00	6.2E+00	5.6E-02	1.9E+00	5.7E-02	5.6E-02
LVMB	2.1E-05	6.2E-02	1.0E-06	3.5E-05	6.2E-02	1.0E-06	3.5E-05	6.2E-02	1.0E-06	3.5E-05	3.1E-01	1.0E-06	3.5E-05	6.2E+00	1.0E-06	3.5E-05	5.7E-02	1.0E-06
VHVHB*																		
VHVLB*																		

\* This type of tank is not typically used for materials with this high vapor pressure

**TABLE N-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) - FLOATING ROOF TANK (CONTINUED)**

Raoult's Law Surrogates	Case 13			Case 14			Case 15			Case 16			Case 17			Case 18		
	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting
HVHB*																		
HVMB*																		
HVLB*																		
MVHB	1.0E+00	7.8E-02	3.0E-02	1.0E+00	9.8E-02	3.0E-02	1.0E+00	1.2E-01	3.0E-02	1.0E+00	1.4E-01	3.0E-02	3.1E-01	2.3E-01	3.0E-02	6.2E-01	1.1E-01	3.0E-02
MVMB	9.5E-01	7.8E-02	2.8E-02	9.5E-01	9.8E-02	2.8E-02	9.5E-01	1.2E-01	2.8E-02	9.5E-01	1.4E-01	2.8E-02	2.9E-01	2.3E-01	2.8E-02	5.7E-01	1.1E-01	2.8E-02
MVLB	1.9E+00	7.8E-02	5.6E-02	1.9E+00	9.8E-02	5.6E-02	1.9E+00	1.2E-01	5.6E-02	1.9E+00	1.4E-01	5.6E-02	5.8E-01	2.3E-01	5.6E-02	1.2E+00	1.1E-01	5.6E-02
LVMB	3.5E-05	7.8E-02	1.0E-06	3.5E-05	9.8E-02	1.0E-06	3.5E-05	1.2E-01	1.0E-06	3.5E-05	1.4E-01	1.0E-06	1.1E-05	2.3E-01	1.0E-06	2.1E-05	1.1E-01	1.0E-06
VHVHB*																		
VHVLB*																		
Raoult's Law Surrogates	Case 19			Case 20			Case 21			Case 22			Case 23			Case 24		
	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting
HVHB*																		
HVMB*																		
HVLB*																		
MVHB	1.0E+00	6.2E-02	3.0E-02	1.5E+00	4.4E-02	3.0E-02	1.9E+00	3.4E-02	3.0E-02	1.0E+00	6.2E-02	3.0E-02	1.0E+00	6.2E-02	3.0E-02	1.0E+00	6.2E-02	3.0E-02
MVMB	9.5E-01	6.2E-02	2.8E-02	1.3E+00	4.4E-02	2.8E-02	1.7E+00	3.4E-02	2.8E-02	9.5E-01	6.2E-02	2.8E-02	9.5E-01	6.2E-02	2.8E-02	9.5E-01	6.2E-02	2.8E-02
MVLB	1.9E+00	6.2E-02	5.6E-02	2.7E+00	4.4E-02	5.6E-02	3.5E+00	3.4E-02	5.6E-02	1.9E+00	6.2E-02	5.6E-02	1.9E+00	6.2E-02	5.6E-02	1.9E+00	6.2E-02	5.6E-02
LVMB	3.5E-05	6.2E-02	1.0E-06	4.9E-05	4.4E-02	1.0E-06	6.3E-05	3.4E-02	1.0E-06	3.5E-05	6.2E-02	1.0E-06	3.5E-05	6.2E-02	1.0E-06	3.5E-05	6.2E-02	1.0E-06
VHVHB*																		
VHVLB*																		

\* This type of tank is not typically used for materials with this high vapor pressure

**TABLE N-2**  
**EMISSION RATE ESTIMATES 10<sup>6</sup> g/yr) - FLOATING ROOF TANK (CONTINUED)**

Raoult's Law Surrogates	Case 25			Case 26			Case 27			Case 28		
	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting	Rim	Withdrawal	Fitting
HVHB*												
HVMB*												
HVLB*												
MVHB	1.0E+00	6.2E-02	3.0E-02	3.1E-01	2.2E-01	3.0E-02	1.0E+00	6.2E-02	3.0E-02	1.9E+00	7.4E+00	3.0E-02
MVMB	9.5E-01	6.2E-02	2.8E-02	2.9E-01	2.2E-01	2.8E-02	9.5E-01	6.2E-02	2.8E-02	1.7E+00	7.4E+00	2.8E-02
MVLB	1.9E+00	6.2E-02	5.6E-02	5.8E-01	2.2E-01	5.6E-02	1.9E+00	6.2E-02	5.6E-02	3.5E+00	7.4E+00	5.6E-02
LVMB	3.5E-05	6.2E-02	1.0E-06	1.0E-05	2.2E-01	1.0E-06	3.5E-05	6.2E-02	1.0E-06	6.3E-05	7.4E+00	1.0E-06
VHVHB*												
VHVLB*												

\* This type of tank is not typically used for materials with this high vapor pressure

**TABLE N-3  
TANK RIM SEAL CLASSES**

DESCRIPTION	CLASS
External Floating Roof Tank:	
Metallic shoe seal	
- primary seal only	E (E)*
- with shoe mounted secondary seal	C (D)*
- with rim mounted secondary seal	A (B)*
Liquid mounted resilient seal	
- primary seal only	C
- with weather shield	B
- with rim mounted secondary seal	A
Vapor mounted resilient seal	
- primary seal only	H
- with weather shield	G
with rim mounted secondary seal	F
Internal Floating Roof Tank:	
Liquid mounted resilient seal	
- primary seal only	A
- with rim mounted secondary seal	A
Vapor mounted resilient seal	
- primary seal only	B
- with rim mounted secondary seal	A

\*For riveted tank

**TABLE N-4  
TANK SHELL CONDITIONS**

CLASS	DESCRIPTION
A	Light rust
B	Dense rust
C	Gunitite lined



## **Appendix O**

### **Emission Rate Estimates Variable Vapor Space Tanks**

**TABLE O-1**  
**EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - VARIABLE VAPOR SPACE TANK**

Modeling Parameters	CASE NUMBERS														
	1	2	3	4	5	6	7	8	9	10	11	12	13*	14**	15***
Throughput (10 <sup>6</sup> gal/yr)	.5	10	24	42	10	10	10	10	10	10	10	10	10	10	40
Transfers into tank(#/yr)	60	60	60	60	3	60	120	250	60	60	60	60	60	60	250
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

\* Reasonable Best Case (minimum) Emissions (assuming typical tank size)

\*\* Typical Emission Conditions (assuming typical tank size)

\*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical tank size)

**Note:** If actual input values vary significantly from the above scenarios it is recommended that AP-42 be used to calculate emission estimates directly.

**TABLE O-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr)-VARIABLE VAPOR SPACE TANK**

Raoult's Law Surrogates	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
HVHB	7.8E-01	3.0E+01	7.7E+01	1.3E+02	3.1E+01	3.0E+01	2.9E+01	2.8E+01
HVMB	6.7E-01	2.6E+01	6.6E+01	1.2E+02	2.7E+01	2.6E+01	2.5E+01	2.4E+01
HVLB	1.5E+00	5.9E+01	1.5E+02	2.6E+02	6.0E+01	5.9E+01	5.8E+01	5.4E+01
MVHB	1.5E-02	5.7E-01	1.5E+00	2.6E+00	5.9E-01	5.7E-01	5.6E-01	5.3E-01
MVMB	1.4E-02	5.3E-01	1.3E+00	2.3E+00	5.4E-01	5.3E-01	5.1E-01	4.8E-01
MVLB	2.7E-02	1.1E+00	2.7E+00	4.7E+00	1.1E+00	1.1E+00	1.0E+00	9.8E-01
LVMB	5.0E-07	1.9E-05	4.9E-05	8.6E-05	2.0E-05	1.9E-05	1.9E-05	1.8E-05
VHVHB	3.8E+00	1.5E+02	3.7E+02	6.5E+02	1.5E+02	1.5E+02	1.4E+02	1.3E+02
VHVLB	8.3E+00	3.2E+02	8.2E+02	1.4E+03	3.3E+02	3.2E+02	3.1E+02	3.0E+02
Raoult's Law Surrogates	Case 9	Case 10	Case 11	Case 12	Case 13	Case 14	Case 15	
HVHB	3.0E+01	3.0E+01	3.0E+01	3.0E+01	3.0E+01	3.0E+01	1.3E+02	
HVMB	2.6E+01	2.6E+01	2.6E+01	2.6E+01	2.6E+01	2.6E+01	1.1E+02	
HVLB	5.9E+01	5.9E+01	5.9E+01	5.9E+01	5.9E+01	5.9E+01	2.5E+02	
MVHB	5.7E-01	5.7E-01	5.7E-01	5.7E-01	5.7E-01	5.7E-01	2.4E+00	
MVMB	5.3E-01	5.3E-01	5.3E-01	5.3E-01	5.3E-01	5.3E-01	2.2E+00	
MVLB	1.1E+00	1.1E+00	1.1E+00	1.1E+00	1.1E+00	1.1E+00	4.4E+00	
LVMB	1.9E-05	1.9E-05	1.9E-05	1.9E-05	1.9E-05	1.9E-05	8.1E-05	
VHVHB	1.5E+02	1.5E+02	1.5E+02	1.5E+02	1.5E+02	1.5E+02	6.1E+02	
VHVLB	3.2E+02	3.2E+02	3.2E+02	3.2E+02	3.2E+02	3.2E+02	1.3E+03	

## **Appendix P**

### **Emission Rate Estimates Particles from Storage Piles**

**TABLE P-1**  
**EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - PARTICLES FROM STORAGE PILES**

Modeling Parameters	CASE NUMBERS																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27*	28**	29***
Area of surface of pile (acres)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Silt content (%)	2	5	10	20	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	5	15	20
% of time windspeed exceeds 12 mph	10	10	10	10	5	10	15	25	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	5	10	25
Days of precipitation ≥ 0.1 inch per year (see Figure P-1)	60	60	60	60	60	60	60	60	20	60	100	120	60	60	60	60	60	60	60	60	60	60	60	60	60	60	100	60	20
Mean windspeed (mph)	10	10	10	10	10	10	10	10	10	10	10	10	6	10	14	10	10	10	10	10	10	10	10	10	10	10	6	10	14
Moisture content (%)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	3	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5	0.5
Vehicle weight (tons) (assume front end loader)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	4	10	4	4	4	4	4	4	4
Number of wheels on loader	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Throughput ( 10 <sup>2</sup> tons/yr)	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Mass fraction of contaminant (ppm)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

- \* Reasonable Best Case (minimum) Emissions (assuming typical surface area)
- \*\* Typical Emission Condition (assuming typical surface area)
- \*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical surface area)

Note. If actual unit specific parameters are significantly different from the cases provided above it is recommended that emission rates be calculated directly based on the methodology presented in AP-42 (4th Edition - Volume I - Supplement B, September 1988)

Table P-2. Emission Rate Estimates (10<sup>6</sup> g/yr) - Particles from Storage Piles\*

Case	Wind Erosion**	Batch Dump***	Vehicle Activity****
1	8.1E-07	1.1E-06	1.4E-07
2	2.0E-06	2.8E-06	3.6E-07
3	4.0E-06	5.6E-06	7.1E-07
4	8.1E-06	1.1E-05	1.4E-06
5	3.1E-06	8.7E-06	1.1E-06
6	6.2E-06	8.7E-06	1.1E-06
7	9.0E-06	8.7E-06	1.1E-06
8	1.5E-05	8.7E-06	1.1E-06
9	6.9E-06	8.7E-06	1.2E-06
10	6.2E-06	8.7E-06	1.1E-06
11	5.2E-06	8.7E-06	9.3E-07
12	5.0E-06	8.7E-06	8.6E-07
13	6.2E-06	5.1E-06	1.1E-06
14	6.2E-06	8.7E-06	1.1E-06
15	6.2E-06	1.2E-05	1.1E-06
16	6.2E-06	8.7E-06	1.1E-06
17	6.2E-06	2.1E-06	1.1E-06
18	6.2E-06	2.3E-07	1.1E-06
19	6.2E-06	5.9E-08	1.1E-06
20	6.2E-06	8.7E-06	6.5E-07
21	6.2E-06	8.7E-06	1.1E-06
22	6.2E-06	8.7E-06	2.1E-06
23	6.2E-06	8.7E-06	1.1E-06
24	6.2E-06	8.7E-06	1.1E-06
25	6.2E-06	8.7E-06	1.1E-06
26	6.2E-06	8.7E-06	1.1E-06
27	8.8E-07	4.2E-07	3.1E-07
28	6.2E-06	8.7E-06	1.1E-06
29	2.3E-05	1.6E-05	1.7E-06

Table P-2 (Cont'd)

\*Particle size of 10 microns assumed (emission rate particle multiplier of 0.5 used, based on pg. 4-7 of Control of Open Fugitive Dust Sources, U.S. EPA, September 1988). Constituent concentration of 1ppm assumed.

\*\*Emission rate estimates for wind erosion based on Equation 3, p. 11.2.3-5 of Compilation of Air Pollutant Emission Factors, Vol.I, (U.S. EPA, September 1985).

\*\*\*Emission rate estimates for batch dump operations were calculated using Equation 1, p. 11.2.3-3 of Compilation of Air Pollutant Emission Factors, Vol. I. (U.S. EPA, September 1985). Drop height of 21.9 feet and dumping device capacity of 6.375 yd<sup>3</sup> assumed.

\*\*\*\*Emission rate estimates for vehicle activity were calculated using Equation 1, p. 11.2.1-1 of Compilation of Air Pollutant Emission Factors, Vol. I, (U.S. EPA, September, 1985) assuming one vehicle in continuous operation for 2,080 hours per year at speed of 3 mph (this low speed assumed to account for loading/unloading in immediate vicinity of the waste pile.) Minor adjustments in emission rates should be implemented if unit-specific vehicle speeds and/or total vehicle miles traveled per year are higher than these assumptions.

MEAN NUMBER OF DAYS WITH 0.01 INCH OR MORE OF PRECIPITATION, ANNUAL

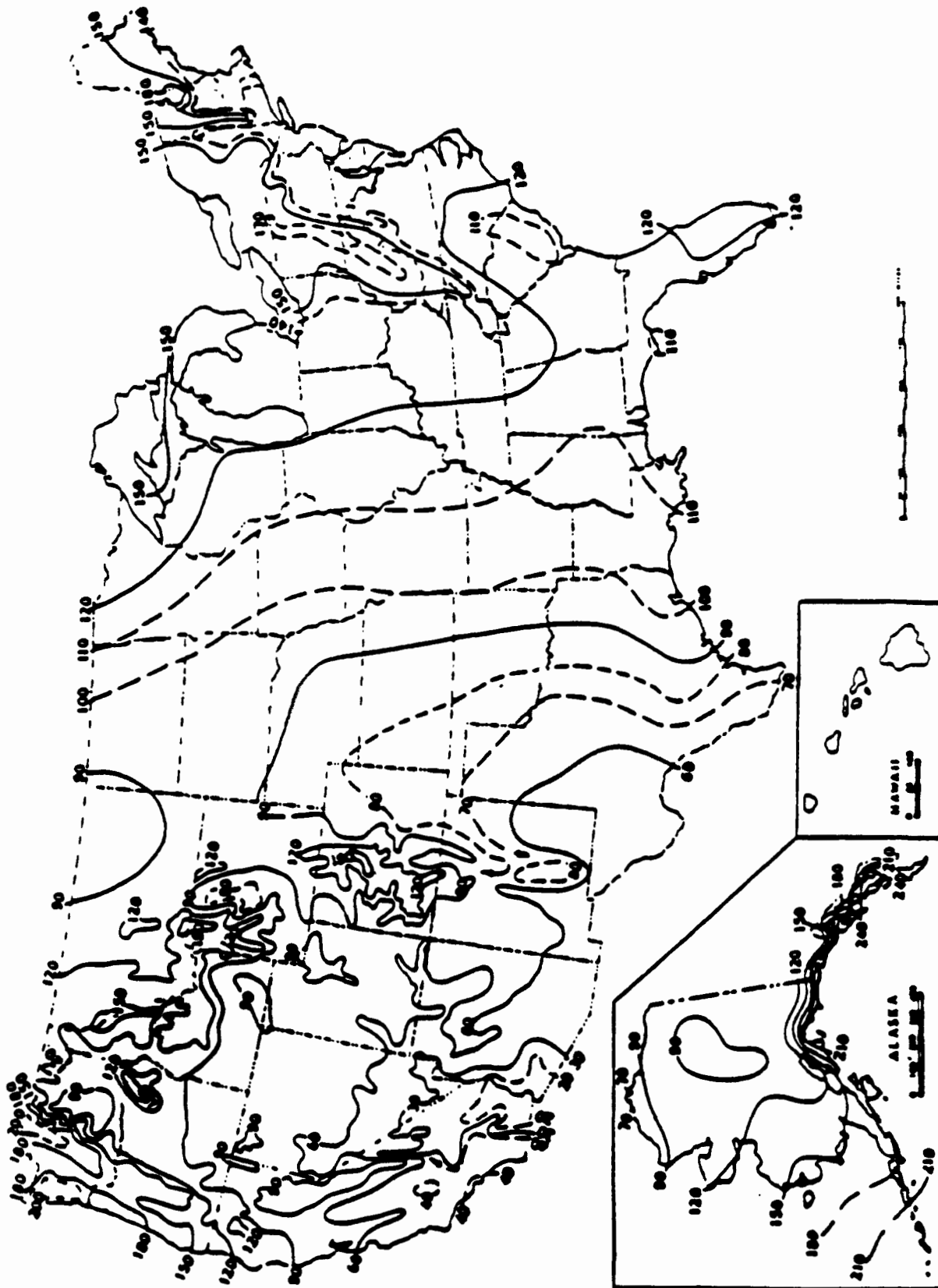


Figure P-1. Map of Precipitation Frequency (AP-42)



## **Appendix Q**

### **Emission Rate Estimates Particles from Exposed, Flat, Contaminated Areas**

**TABLE Q-1**  
**EMISSION RATE MODELING SOURCE SCENARIO CASE SPECIFICATIONS - PARTICLES FROM EXPOSED, FLAT, CONTAMINATED AREAS**

Modeling Parameters	CASE NUMBERS																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23*	24**	25***
Area of exposed area (acres)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Silt content (%)	2	5	10	20	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	5	15	20
Surface erodibility (tons/acre-year)(see Table Q-3)	47	47	47	47	38	56	86	134	220	47	47	47	47	47	47	47	47	47	47	47	47	47	38	47	220
Precipitation-evaporation (PE) Index (see Figure Q-1)	100	100	100	100	100	100	100	100	100	20	60	100	200	300	100	100	100	100	100	100	100	100	120	100	20
% of time wind speed exceeds 12 mph	10	10	10	10	10	10	10	10	10	10	10	10	10	10	5	10	15	25	10	10	10	10	5	10	25
Mass fraction of contaminant (ppm)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Calculational period (yrs)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	10	70	1	1	1

- \* Reasonable Best Case (minimum) Emissions (assuming typical surface area)
- \*\* Typical Emission Conditions (assuming typical surface area)
- \*\*\* Reasonable Worst Case (maximum) Emissions (assuming typical surface area)

**Note:** If actual unit-specific parameters are significantly different from those provided above it is recommended that emission rates be calculated directly using the methodology provided in Control of Open Fugitive Dust Sources (U S EPA, September 1988)

**TABLE Q-2**  
**EMISSION RATE ESTIMATES (10<sup>6</sup> g/yr) PARTICLES FROM EXPOSED AREAS\***

Case	Estimated Emission Rates** (10 <sup>6</sup> g/yr)
1	4.8E-08
2	1.2E-07
3	2.4E-07
4	4.8E-07
5	2.9E-07
6	4.3E-07
7	6.7E-05
8	1.0E-06
9	1.7E-06
10	9.1E-06
11	1.0E-06
12	3.6E-07
13	9.1E-06
14	4.0E-08
15	1.8E-07
16	3.6E-07
17	5.5E-07
18	9.1E-07
19	3.6E-07
20	3.6E-07
21	3.6E-07
22	3.6E-07
23	3.4E-08
24	3.6E-07
25	1.4E-04

\* Particle size of 10 microns assumed (emission rate particle multiplier of 0.5 used, based on p. 6-9 of Control of Open Fugitive Dust Sources, U.S. EPA, September 1988). Constituent concentration of 1 ppm assumed.

\*\* Emission rate estimates for particles from exposed areas were calculated using Equation 8, p. 4-2 of Fugitive Emissions from Integrated Iron and Steel Plants (U.S. EPA, March 1978).

**TABLE Q-3**  
**SOIL ERODIBILITY FOR VARIOUS SOIL TEXTURAL CLASSES\***

Predominant Soil Textural Class	Erodibility, tons/acre/year
Sand	220
Loamy sand	134
Sandy loam	86
Clay	86
Silty clay	86
Loam	56
Sandy clay loam	56
Sandy clay	56
Silt loam	47
Clay loam	47
Silty clay loam	38
Silt	38

\* U.S. Department of Agriculture, July 1964. Guide for Wind Erosion Control on Cropland in the Great Plains States, Soil Conservation Service.

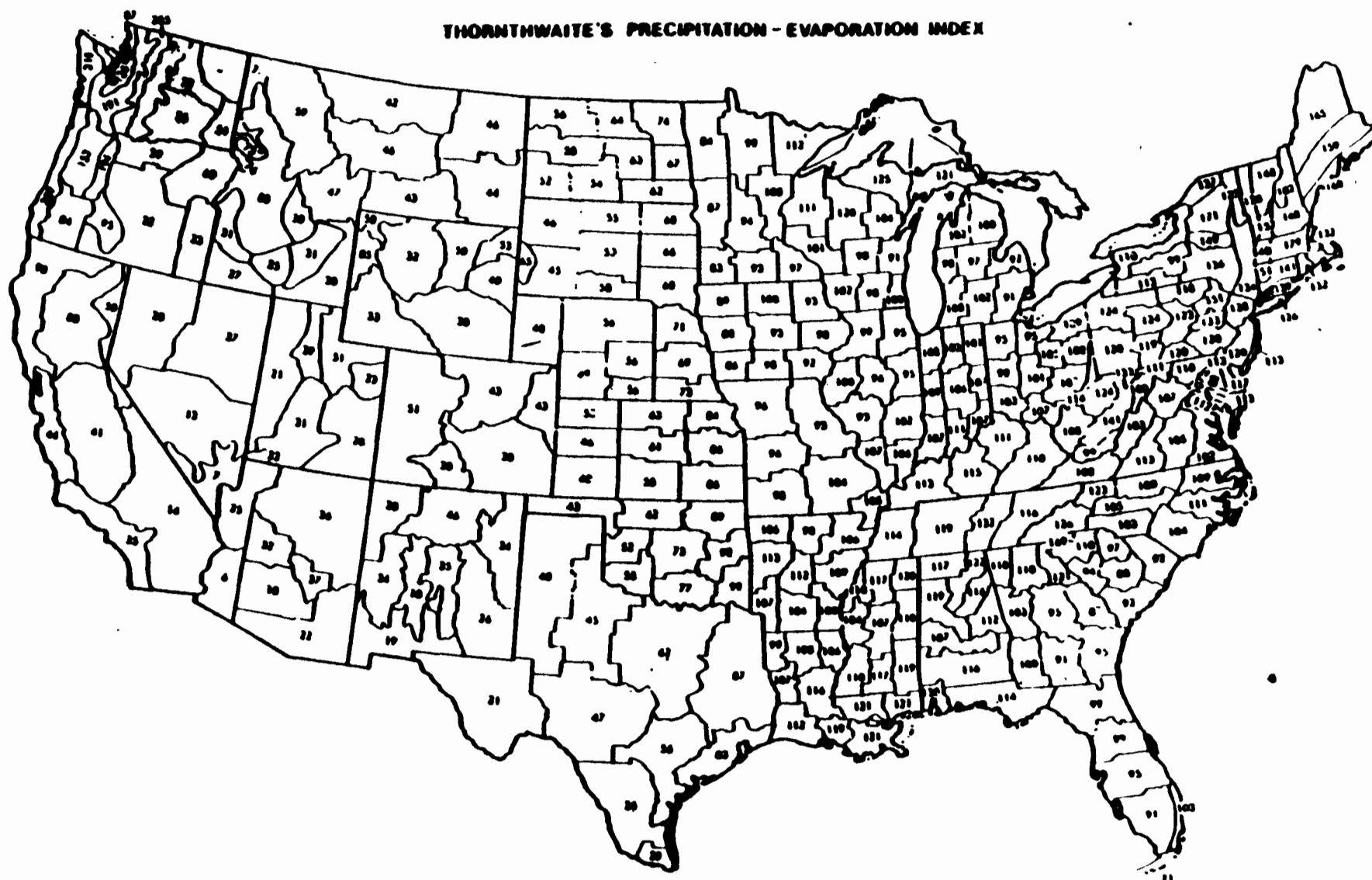


Figure Q-1. Map of PE Index for State Climatic Divisions

**Appendix R**  
**Dispersion Estimates**

**TABLE R-1  
CONCENTRATION ESTIMATION WORKSHEET**

Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 13
Downwind Sector	Instruction A Input Distance to Receptors** (miles)	Instruction B: Determine Dispersion Factor (Figure R-1)	Instruction C: Assume Annual Downwind Frequency of 100% (percent)	<b>Instruction D:</b> Compute Long Term Concentration Estimates ( $\mu\text{g}/\text{m}^3$ ) Based on Equation 1* (select and circle appropriate surrogate subset, Henry's Law Constant or Raoult's Law or particle case)								
				MHLB or HVHB or particle case	HHLB or HVMB	LHMB or HVLB	MHMB or MVHB	HHMB or MVMB	LHHB or MVLB	MHHB or LVMB	HHHB or VHVHB	..... or VHVLB
N												
NNE												
NE												
ENE												
E												
ESE												
SE												
SSE												
S												
SSW												
SW												
WSW												
W												
WNW												
NW												
NNW												
Health Criteria ( $\mu\text{g}/\text{m}^3$ ) Based on RFI Guidance		Toxic Criteria Carcinogenic Criteria										

\* Equation 1 Long-Term Concentration Est ( $\mu\text{g}/\text{m}^3$ ) = Col 3 x Col 4 x (unit/surrogate-specific Emission Rates,  $\text{Mg}/\text{yr}$ , based on Appendix S Worksheets) x (Conversion Factor =  $3.17 \times 10^{-1}$ ) x (Safety Factor = 10)  
 $\text{Mg}/\text{yr} = 10^6 \text{g}/\text{yr}$

\*\* Distance from downward unit boundary

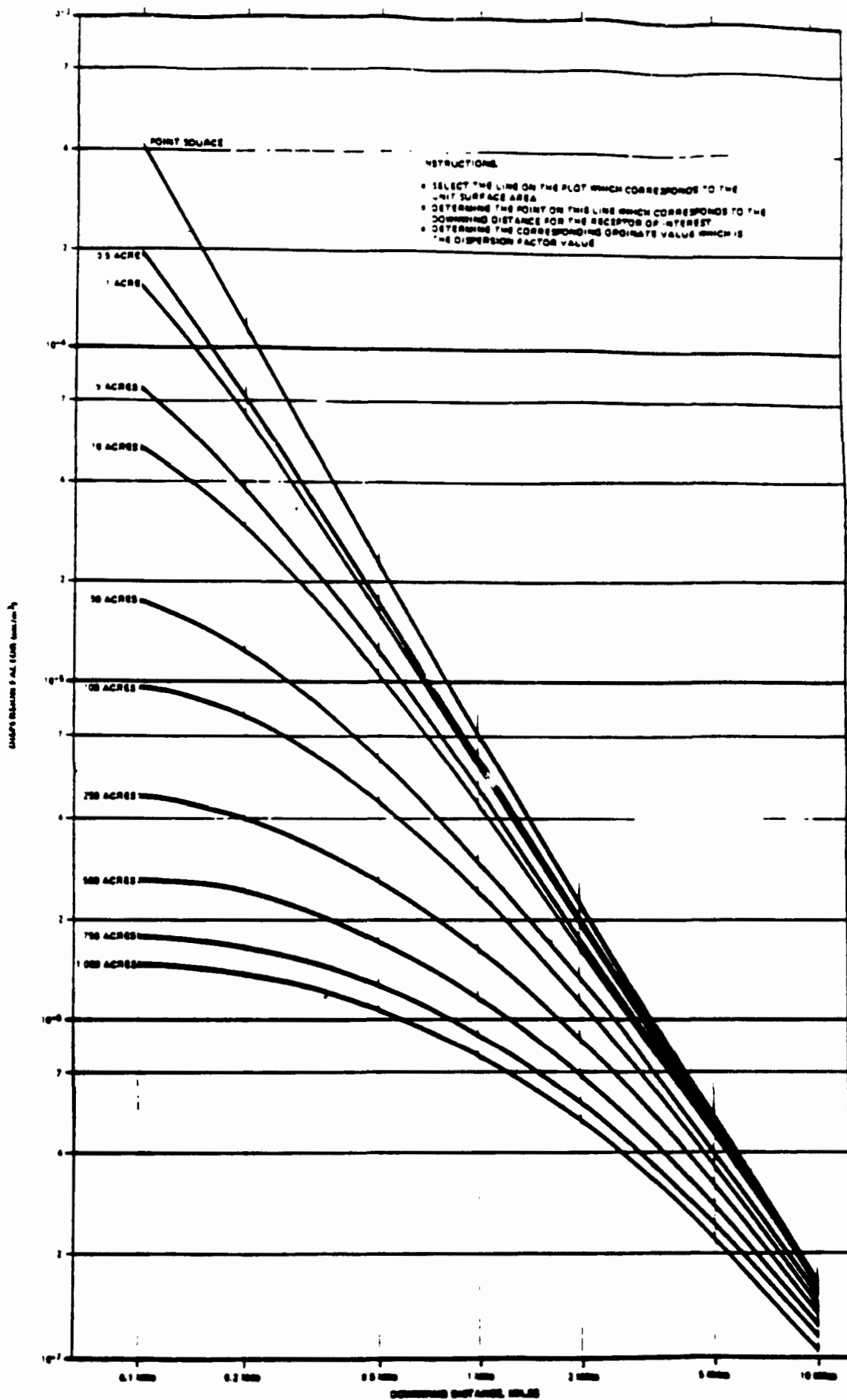


Figure R-1. Atmospheric Dispersion Factors for Typical U.S. Meteorological Conditions (Neutral Stability and 10-MPH Wind Speed)



## **Appendix S**

### **Emission Rate Estimation Worksheets**

**TABLE S-1**  
**EMISSION RATE ESTIMATION WORKSHEET - DISPOSAL IMPOUNDMENT**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11
	<b>Modeling Parameters</b>	<b>Instruction A:</b> Input Unit-Specific Values	<b>Instruction B:</b> Select a Representative Case from Appendix C - Table C-1 (underline selected case)	<b>Instruction C:</b> Determine Surrogate-Specific Scaling Factors**							
				MHLB	HHLB	LHMB	MHMB	HHMB	LHHB	MHHB	HHHB
1	Area*	_____ acres	--	--	--	--	--	--	--	--	--
2	Depth*	_____ m	1,2,3 or 4	_____	_____	_____	_____	_____	_____	_____	_____
3	Turnovers*	_____ /year	5, 6, 7 or 8	_____	_____	_____	_____	_____	_____	_____	_____
4	Constituent Concentration*	_____ ppm	--	--	--	--	--	--	--	--	--
<b>INSTRUCTION D:</b> Complete Lines 5-6 and 8											
				<b><u>SURROGATE-SPECIFIC VALUES</u></b>							
5	Account for Area [unit-specific area/(Case 18 area = 2.2 acres)]			_____	_____	_____	_____	_____	_____	_____	_____
6	Account for Concentration [unit-specific conc./(Case 18 conc. = 1,000 ppm)]			_____	_____	_____	_____	_____	_____	_____	_____
7	Typical Surrogate-Specific Emission Rate (Case 18), 10 <sup>6</sup> g/yr			32.4	32.4	14.1	32.4	32.4	9.4	32.4	32.4
8	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #5 x #6 x #7)			_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2 and 3 from Appendix C - Emission Rate Estimate from Table C-2 divided by Typical Emission Rate defined in Case 18 (see line 7).

**TABLE S-2  
EMISSION RATE ESTIMATION WORKSHEET - STORAGE IMPOUNDMENT**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11
	Modeling Parameters	<u>Instruction A:</u> Input Unit-Specific Values	<u>Instruction B:</u> Select a Representative Case from Appendix D - Table D-1 (underline selected case)	<u>Instruction C:</u> Determine Surrogate-Specific Scaling Factors**							
				MHLB	HHLB	LHMB	MHMB	HHMB	LHHB	MHHB	HHHB
1	Area*	_____ acres	--	--	--	--	--	--	--	--	--
2	Depth*	_____ m	1,2,3 or 4	_____	_____	_____	_____	_____	_____	_____	_____
3	Retention time*	_____ days	5, 6, 7 or 8	_____	_____	_____	_____	_____	_____	_____	_____
4	Constituent Concentration*	_____ ppm	--	--	--	--	--	--	--	--	--
<u>INSTRUCTION D:</u> Complete Lines 5-6 and 8				<u>SURROGATE-SPECIFIC VALUES</u>							
5	Account for Area [unit-specific area/(Case 18 area = 0.4 acres)]			_____	_____	_____	_____	_____	_____	_____	_____
6	Account for Unit-Specific Concentration [unit-specific conc./(Case 18 conc. = 1,000 ppm)]			_____	_____	_____	_____	_____	_____	_____	_____
7	Typical Surrogate-Specific Emission Rate (Case 18), 10 <sup>6</sup> g/yr			34 0	39 24	3 25	38 10	38 40	1 97	38 74	39 24
8	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #5 x #6 x #7)			_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2 and 3 from Appendix D - Emission Rate Estimate from Table D-2 divided by Typical Emission Rate defined in Case 18 (see line 7)

**TABLE S-3  
EMISSION RATE ESTIMATION WORKSHEET - OIL FILM ON STORAGE IMPOUNDMENT**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
	Modeling Parameters	<u>Instruction A:</u> Input Unit-Specific Values	<u>Instruction B:</u> Select a Representative Case from Appendix E - Table E-1 (underline selected case)	<u>Instruction C:</u> Determine Surrogate-Specific Scaling Factors**								
				HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
1	Area*	_____ acres	--	--	--	--	--	--	--	--	--	--
2	Depth of Oil Film*	_____ m	1,2,3 or 4	_____	_____	_____	_____	_____	_____	_____	_____	_____
3	Retention Time*	_____ days	5, 6, 7 or 8	_____	_____	_____	_____	_____	_____	_____	_____	_____
4	Constituent Concentration*	_____ ppm	--	--	--	--	--	--	--	--	--	--
<u>INSTRUCTION D:</u> Complete Lines 5-6 and 8				<u>SURROGATE-SPECIFIC VALUES</u>								
5	Account for Area [unit-specific area/(Case 18 area = 0.4 acres)]			_____	_____	_____	_____	_____	_____	_____	_____	_____
6	Account for Concentration [unit-specific conc./(Case 18 conc. = 200 ppm)]			_____	_____	_____	_____	_____	_____	_____	_____	_____
7	Typical Surrogate-Specific Emission Rate (Case 18), 10 <sup>6</sup> g/yr			0.394	0.394	0.394	0.394	0.389	0.394	1.10E-04	0.394	0.394
8	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #5 x #6 x #7)			_____	_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2 and 3 from Appendix E - Emission Rate Estimate from Table E-2 divided by Typical Emission Rate defined in Case 18 (see line 7)

**TABLE S-4**  
**EMISSION RATE ESTIMATION WORKSHEET - MECHANICALLY AERATED IMPOUNDMENT**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11
	Modeling Parameters	<u>Instruction A:</u> Input Unit-Specific Values	<u>Instruction B:</u> Select a Representative Case from Appendix F - Table F-1 (underline selected case)	<u>Instruction C:</u> Determine Surrogate-Specific Scaling Factors**							
				MHLB	HHLB	LHMB	MHMB	HHMB	LHHB	MHHB	HHHB
1	Area*	_____ acres	--	--	--	--	--	--	--	--	--
2	Depth*	_____ m	1,2,3 or 4	_____	_____	_____	_____	_____	_____	_____	_____
3	Retention Time*	_____ days	5, 6, 7 or 8	_____	_____	_____	_____	_____	_____	_____	_____
4	Constituent Concentration*	_____ ppm	--	--	--	--	--	--	--	--	--
5	Fraction Agitated	_____	13,14,15 or 16	_____	_____	_____	_____	_____	_____	_____	_____
<u>INSTRUCTION D:</u> Complete Lines 6-7 and 9				<u>SURROGATE-SPECIFIC VALUES</u>							
6	Account for Area [unit-specific area/(Case 22 area = 0.4 acres)]			_____	_____	_____	_____	_____	_____	_____	_____
7	Account for Concentration [unit-specific conc./(Case 22 conc. = 1,000 ppm)]			_____	_____	_____	_____	_____	_____	_____	_____
8	Typical Surrogate-Specific Emission Rate (Case 22), 10 <sup>6</sup> g/yr			90 6	98 4	12 3	94 7	98 3	8 5	95 9	98 4
9	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #5 x #6 x #7 x #8)			_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2-3 and 5 from Appendix F - Emission Rate Estimate from Table F-2 divided by Typical Emission Rate defined in Case 22 (see line 8)

**TABLE S-5  
EMISSION RATE ESTIMATION WORKSHEET -**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11
	<b>Modeling Parameters</b>	<b>Instruction A: Input Unit-Specific Values</b>	<b>Instruction B: Select a Representative Case from Appendix G - Table G-1 (underline selected case)</b>	<b>Instruction C: Determine Surrogate-Specific Scaling Factors**</b>							
				<b>MHLB</b>	<b>HHLB</b>	<b>LHMB</b>	<b>MHMB</b>	<b>HHMB</b>	<b>LHHB</b>	<b>MHHB</b>	<b>HHHB</b>
1	Area*	___ acres	--	--	--	--	--	--	--	--	--
2	Depth*	___ m	1,2,3 or 4	_____	_____	_____	_____	_____	_____	_____	_____
3	Retention Time*	___ hours	5, 6, 7 or 8	_____	_____	_____	_____	_____	_____	_____	_____
4	Constituent Concentration*	___ ppm	--	--	--	--	--	--	--	--	--
5	Submerged Air Flow	___ m <sup>3</sup> /sec	13,14,15 or 16	_____	_____	_____	_____	_____	_____	_____	_____
<b>INSTRUCTION D: Complete Lines 6-7 and 9</b>											
				<b><u>SURROGATE-SPECIFIC VALUES</u></b>							
6	Account for Area [unit-specific area/(Case 22 area = $6.7 \times 10^{-3}$ acres)]			_____	_____	_____	_____	_____	_____	_____	_____
7	Account for Concentration [unit-specific conc /(Case 22 conc. = 1,000 ppm)]			_____	_____	_____	_____	_____	_____	_____	_____
8	Typical Surrogate-Specific Emission Rate (Case 22), 10 <sup>6</sup> g/yr			3 9	205 4	0 086	6 4	51 5	0 055	8 1	128 9
9	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #5 x #6 x #7 x #8)			_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2-3 and 5 from Appendix G - Emission Rate Estimate from Table G-2 divided by Typical Emission Rate defined in Case 22 (see line 8)

**TABLE S-6**  
**EMISSION RATE ESTIMATION WORKSHEET - LAND TREATMENT EMISSIONS (AFTER TILLING)**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
	<b>Modeling Parameters</b>	<u><b>Instruction A:</b></u> <b>Input Unit-Specific Values</b>	<u><b>Instruction B:</b></u> Select a Representative Case from Appendix H - Table H-1 (underline selected case)	<u><b>Instruction C:</b></u> <b>Determine Surrogate-Specific Scaling Factors**</b>								
				HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
1	Annual waste throughput* (water & oil)	___ 10 <sup>6</sup> g/yr	--	--	--	--	--	--	--	--	--	--
2	Oil content of waste(%)*	___ percent	1,2,3 or 4	_____	_____	_____	_____	_____	_____	_____	_____	_____
3	Constituent concentration*	___ ppm	5, 6, 7 or 8	_____	_____	_____	_____	_____	_____	_____	_____	_____
4	Soil porosity	___ percent	9, 10, 11 or 12	_____	_____	_____	_____	_____	_____	_____	_____	_____
5	Tilling depth	___ cm	13, 14, 15 or 16	_____	_____	_____	_____	_____	_____	_____	_____	_____
<u><b>INSTRUCTION D:</b></u> Complete Lines 6 and 8				<u><b>SURROGATE-SPECIFIC VALUES</b></u>								
6	Account for Unit-Specific Annual Waste Throughput [unit annual waste throughput/(Case 22 = 1,800 10 <sup>6</sup> g/yr)]			_____	_____	_____	_____	_____	_____	_____	_____	_____
7	Typical Surrogate-Specific Emission Rate (Case 22), 10 <sup>6</sup> g/yr			0.341	0.357	0.359	0.108	0.219	0.338	0.0018	0.356	0.359
8	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #4 x #5 x #6 x #7)			_____	_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2-5 from Appendix H - Emission Rate Estimate from Table H-2 divided by Typical Emission Rate defined in Case 22 (see line 9)

**TABLE S-7**  
**EMISSION RATE ESTIMATION WORKSHEET - OIL FILM SURFACE ON LAND TREATMENT UNIT**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
	Modeling Parameters	<u>Instruction A:</u> Input Unit-Specific Values	<u>Instruction B:</u> Select a Representative Case from Appendix I - Table I-1 (underline selected case)	<u>Instruction C:</u> Determine Surrogate-Specific Scaling Factors**								
				HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
1	Area*	_____ acres	--	--	--	--	--	--	--	--	--	--
2	Depth of Oil Film*	_____ m	1,2,3 or 4	_____	_____	_____	_____	_____	_____	_____	_____	_____
3	Applications per Year	_____ /year	5, 6, 7 or 8	_____	_____	_____	_____	_____	_____	_____	_____	_____
4	Constituent Concentration*	_____ ppm	--	--	--	--	--	--	--	--	--	--
<u>INSTRUCTION D:</u> Complete Lines 5-6 and 8				<u>SURROGATE-SPECIFIC VALUES</u>								
5	Account for Area [unit-specific area/(Case 18 area = 6.2 acres)]			_____	_____	_____	_____	_____	_____	_____	_____	_____
6	Account for Concentration [unit-specific conc./(Case 18 conc. = 200 ppm)]			_____	_____	_____	_____	_____	_____	_____	_____	_____
7	Typical Surrogate-Specific Emission Rate (Case 18), 10 <sup>6</sup> g/yr			131.4	131.4	131.4	30.8	22.0	31.2	1.45E-03	131.4	131.4
8	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #5 x #6 x #7)			_____	_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2 and 3 from Appendix I - Emission Rate Estimate from Table I-2 divided by Typical Emission Rate defined in Case 18 (see line 7).



**TABLE S-8  
EMISSION RATE ESTIMATION WORKSHEET - CLOSED LANDFILL**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
	<b>Modeling Parameters</b>	<b>Instruction A: Input Unit-Specific Values</b>	<b>Instruction B: Select a Representative Case from Appendix J - Table J-1 (underline selected case)</b>	<b>Instruction C: Determine Surrogate-Specific Scaling Factors**</b>								
				HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
1	Area*	_____ acres	--	--	--	--	--	--	--	--	--	--
2	Waste-bed thickness*	_____ ft	1, 2, 3 or 4	_____	_____	_____	_____	_____	_____	_____	_____	_____
3	Cap thickness	_____ ft	5, 6, 7 or 8	_____	_____	_____	_____	_____	_____	_____	_____	_____
4	Constituent content of waste*	_____ percent	9, 10, 11 or 12	_____	_____	_____	_____	_____	_____	_____	_____	_____
5	Air porosity	_____ percent	13, 14, 15 or 16	_____	_____	_____	_____	_____	_____	_____	_____	_____
<b>INSTRUCTION D: Complete Lines 6 and 8</b>												
				<b><u>SURROGATE-SPECIFIC VALUES</u></b>								
6	Account for Area [unit-specific area/(Case 22 area = 3.5 acres)]			_____	_____	_____	_____	_____	_____	_____	_____	_____
7	Typical Surrogate-Specific Emission Rate (Case 22), 10 <sup>6</sup> g/yr			24.4	22.4	47.0	0.445	0.398	0.808	1.55E-05	119	264
8	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #4 x #5 x #6 x #7)			_____	_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2-5 from Appendix J - Emission Rate Estimate from Table J-2 divided by Typical Emission Rate defined in Case 22 (see line 7).

**TABLE S-9  
EMISSION RATE ESTIMATION WORKSHEET - OPEN LANDFILL**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
	<b>Modeling Parameters</b>	<u><b>Instruction A:</b></u> <b>Input Unit-Specific Values</b>	<u><b>Instruction B:</b></u> <b>Select a Representative Case from Appendix K - Table K-1 (underline selected case)</b>	<u><b>Instruction C:</b></u> <b>Determine Surrogate-Specific Scaling Factors**</b>								
				HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
1	Area*	____ acres	--	--	--	--	--	--	--	--	--	--
2	Waste-bed thickness*	____ ft	1, 2, 3 or 4	_____	_____	_____	_____	_____	_____	_____	_____	_____
3	Constituent content of waste*	____ percent	5, 6, 7 or 8	_____	_____	_____	_____	_____	_____	_____	_____	_____
4	Air porosity (fixed waste)	____ percent	9, 10, 11 or 12	_____	_____	_____	_____	_____	_____	_____	_____	_____
5	Total porosity (fixed waste)	____ percent	13, 14, 15 or 16	_____	_____	_____	_____	_____	_____	_____	_____	_____
<u><b>INSTRUCTION D:</b></u> <b>Complete Lines 6 and 8</b>												
				<u><b>SURROGATE-SPECIFIC VALUES</b></u>								
6	Account for Area [unit-specific area/(Case 22 area = 3.5 acres)]			_____	_____	_____	_____	_____	_____	_____	_____	_____
7	Typical Surrogate-Specific Emission Rate (Case 22), 10 <sup>6</sup> g/yr			766.2	841.3	811.3	75.1	60.1	75.1	0.6	2358.7	2509.0
8	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #4 x #5 x #6 x #7)			_____	_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2-5 from Appendix K - Emission Rate Estimate from Table K-2 divided by Typical Emission Rate defined in Case 22 (see line 7).

**TABLE S-10  
EMISSION RATE ESTIMATION WORKSHEET - WASTEPILES**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
	<b>Modeling Parameters</b>	<u><b>Instruction A:</b></u> <b>Input Unit-Specific Values</b>	<u><b>Instruction B:</b></u> Select a Representative Case from Appendix L - Table L-1 (underline selected case)	<u><b>Instruction C:</b></u> <b>Determine Surrogate-Specific Scaling Factors**</b>								
				HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
1	Area*	____ acres	--	--	--	--	--	--	--	--	--	--
2	Turnover rate*	____ per year	1, 2, 3 or 4	_____	_____	_____	_____	_____	_____	_____	_____	_____
3	Constituent content of waste*	____ percent	5, 6, 7 or 8	_____	_____	_____	_____	_____	_____	_____	_____	_____
4	Air porosity (fixed waste)	____ percent	9, 10, 11 or 12	_____	_____	_____	_____	_____	_____	_____	_____	_____
5	Total porosity (fixed waste)	____ percent	13, 14, 15 or 16	_____	_____	_____	_____	_____	_____	_____	_____	_____
<u><b>INSTRUCTION D:</b></u> Complete Lines 6 and 8												
<u><b>SURROGATE-SPECIFIC VALUES</b></u>												
6	Account for Area [unit-specific area/(Case 22 area = 0.1 acres)]			_____	_____	_____	_____	_____	_____	_____	_____	_____
7	Typical Surrogate-Specific Emission Rate (Case 22), 10 <sup>6</sup> g/yr			261.4	284.9	277.0	26.0	20.9	25.5	0.2	799.3	852.1
8	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #4 x #5 x #6 x #7)			_____	_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 2-5 from Appendix L - Emission Rate Estimate from Table L-2 divided by Typical Emission Rate defined in Case 22 (see line 7).

**TABLE S-11**  
**EMISSION RATE ESTIMATION WORKSHEET - FIXED ROOF TANKS**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
	<b>Modeling Parameters</b>	<b>Instruction A:</b> Input Unit-Specific Values	<b>Instruction B:</b> Select a Representative Case from Appendix M - Table M-2 (underline selected case)	<b>Instruction C:</b> Determine Surrogate-Specific Scaling Factors**								
				HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
1	Diameter*	____ ft	1, 2, 3, 4, 5 or 6	Breathing Loss	_____	_____	_____	_____	_____	_____	_____	_____
2				Working Loss	_____	_____	_____	_____	_____	_____	_____	_____
3	Height*	____ ft	7, 8, 9, 10 or 11	Breathing Loss	_____	_____	_____	_____	_____	_____	_____	_____
4				Working Loss	_____	_____	_____	_____	_____	_____	_____	_____
5	Throughput*	____ x10 <sup>6</sup> gal/yr	12, 13, 14, 15, 16 or 17	Working Loss	_____	_____	_____	_____	_____	_____	_____	_____
<b>INSTRUCTION D:</b> Complete Lines 8-10				<b>SURROGATE-SPECIFIC VALUES</b>								
6	Typical Surrogate-Specific Working Loss Emission Rate (Case 23), 10 <sup>6</sup> g/yr				---	---	---	3.9	3.5	7.1	0.0001	---
7	Typical Surrogate-Specific Breathing Loss Emission Rate (Case 23), 10 <sup>6</sup> g/yr				---	---	---	1.8	1.8	3.2	0.0015	---
8	Calculate Unit-Specific Working Loss Emission Rate, 10 <sup>6</sup> g/yr (multiply Lines #2 x #4 x #5 x #6)				_____	_____	_____	_____	_____	_____	_____	_____
9	Calculate Unit-Specific Breathing Loss Emission Rate, 10 <sup>6</sup> g/yr (multiply Lines #1 x #3 x #7)				_____	_____	_____	_____	_____	_____	_____	_____
10	Calculate Total Emission Rate, 10 <sup>6</sup> g/yr (add Lines #8 + #9)				_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 1-5 from Appendix M - Emission Rate Estimate from Table M-2 divided by Typical Emission Rate defined in Case 23 (see lines 7 and 8).

**TABLE S-12**  
**EMISSION RATE ESTIMATION WORKSHEET - FLOATING ROOF TANKS**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
	<b>Modeling Parameters</b>	<b>Instruction A: Input Unit-Specific Values</b>	<b>Instruction B: Select a Representative Case from Appendix N - Table N-1 (underline selected case)</b>	<b>Instruction C: Determine Surrogate-Specific Scaling Factors**</b>								
				HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
1	Rim seal class*	_____	1, 2, 3, 4, 5, 6, 7 or 8	Rim Loss	_____	_____	_____	_____	_____	_____	_____	_____
2	Shell type*	_____	9, 10 or 11	Withdrawal Loss	_____	_____	_____	_____	_____	_____	_____	_____
3	Average liquid density*	_____ lb/gal	12, 13, 14, 15 or 16	Withdrawal Loss	_____	_____	_____	_____	_____	_____	_____	_____
4	Diameter*	_____ ft	17, 18, 19, 20 or 21	RIM Loss	_____	_____	_____	_____	_____	_____	_____	_____
5				Withdrawal Loss	_____	_____	_____	_____	_____	_____	_____	_____
6				Fitting Loss	_____	_____	_____	_____	_____	_____	_____	_____
7	Throughput	_____ x10 <sup>6</sup> gal/yr	---		---	---	---	---	---	---	---	---
<b>INSTRUCTION D:</b>												
Complete Lines 8 and 12-15				<b>SURROGATE-SPECIFIC VALUES</b>								
8	Account for Throughput [unit-specific throughput/(Case 27 throughput = 63x10 <sup>6</sup> gal/yr)]			_____	_____	_____	_____	_____	_____	_____	_____	_____
9	Typical Surrogate-Specific Rim Loss Emission Rate (Case 27), 10 <sup>6</sup> g/yr			---	---	---	1 0	0 95	1 9	0 00004	---	---
10	Typical Surrogate-Specific Withdrawal Loss Emission Rate (Case 27), 10 <sup>6</sup> g/yr			---	---	---	0 062	0 062	0 062	0 062	---	---
11	Typical Surrogate-Specific Fitting Loss Emission Rate (Case 27), 10 <sup>6</sup> g/yr			---	---	---	0 030	0 028	0 056	0 000001	---	---
12	Calculate Unit-Specific Rim Loss Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #1 x #4 x #9)			_____	_____	_____	_____	_____	_____	_____	_____	_____
13	Calculate Unit-Specific Withdrawal Loss Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #2 x #3 x #5 x #8 x #10)			_____	_____	_____	_____	_____	_____	_____	_____	_____
14	Calculate Unit-Specific Fitting Loss Emission Rate, 10 <sup>6</sup> g/yr (multiply lines #6 x #11)			_____	_____	_____	_____	_____	_____	_____	_____	_____
15	Calculate Total Emission Rate, 10 <sup>6</sup> g/yr (add lines #12 + #13 + #14)			_____	_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

**TABLE S-13**  
**EMISSION RATE ESTIMATION WORKSHEET - VARIABLE VAPOR SPACE TANKS**

Line	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
	Modeling Parameters	<u>Instruction A:</u> Input Unit-Specific Values	<u>Instruction B:</u> Select a Representative Case from Appendix O - Table O-1 (underline selected case)	<u>Instruction C:</u> Determine Surrogate-Specific Scaling Factors**								
				HVHB	HVMB	HVLB	MVHB	MVMB	MVLB	LVMB	VHVHB	VHVLB
1	Throughput*	____ x 10 <sup>6</sup> gal/yr	1, 2, 3 or 4	_____	_____	_____	_____	_____	_____	_____	_____	_____
2	Transfers into tank*	____ #/yr	5, 6, 7 or 8	_____	_____	_____	_____	_____	_____	_____	_____	_____
	<u>INSTRUCTION D:</u> Complete Line 4			<u>SURROGATE-SPECIFIC VALUES</u>								
3	Typical Surrogate-Specific Emission Rate (Case 14) 10 <sup>6</sup> g/yr			30	26	59	0.57	0.53	1.1	1.9E-05	150	320
4	Calculate Unit-Specific Emission Rate, 10 <sup>6</sup> g/yr (multiply Lines #1 x #2 x #3)			_____	_____	_____	_____	_____	_____	_____	_____	_____

\* Critical input values

\*\* Scaling Factor determined for Lines 1 and 2 from Appendix O - Emission Rate Estimate from Table O-2 divided by Typical Emission Rate defined in Case 14 (see line 3).

**TABLE S-14**  
**EMISSION RATE ESTIMATION WORKSHEET - PARTICLES FROM STORAGE PILES**

Col 1	Col 2	Col 3	Col 4
Line	Modeling Parameters	<u>Instruction A:</u> Input Unit - Specific Values	<u>Instruction B:</u> Select a Representative Case from Appendix P - Table P-1 (underline selected case)
1	Area	_____ acres	---
2	Silt content*	_____ %	1, 2, 3 or 4      wind erosion
3	Silt content*	_____	batch dump
4	Silt content*	_____	vehicle activity
5	% of time wind speed exceeds 12 mph*	_____ %	5, 6, 7 or 8      wind erosion
6	Days precipitation (≥ .01 inch/day)	_____ days	9, 10, 11 or 12      wind erosion
7	Mean wind speed*	_____ mph	13, 14 or 15      batch dump
8	Moisture content*	_____ %	16, 17, 18 or 19      batch dump
9	Vehicle weight*	_____ tons	20, 21 or 22      vehicle activity
10	Vehicle wheels*	_____ #	---
11	Throughput*	_____ tons/yr	---
12	Mass fraction of contaminant	_____ ppm	---

**INSTRUCTION D:** Complete Lines 13-15 and 19-22

**SURROGATE-SPECIFIC VALUES**

- |    |   |                        |
|----|---|------------------------|
| 13 | Account for Area<br>[unit-specific area/(Case 28 area = 5 acres)]   | _____                  |
| 14 | Account for Vehicle Wheels<br>[square root (vehicle wheels)/square root (Case 28 wheels = √4)]                              | _____                  |
| 15 | Account for Throughput<br>[unit throughput/(Case 28 throughput = 50,000 tons/yr)]   | _____                  |
| 16 | Typical case emission rate - wind erosion<br>(Case 28), 10 <sup>6</sup> g/yr  | 6.2 x 10 <sup>-6</sup> |
| 17 | Typical case emission rate - batch dump<br>(Case 28), 10 <sup>6</sup> g/yr  | 8.7 x 10 <sup>-6</sup> |
| 18 | Typical case emission rate - vehicle activity<br>(Case 28), 10 <sup>6</sup> g/yr  | 1.1 x 10 <sup>-6</sup> |
| 19 | Calculate Unit-Specific Emission Rate - Wind Erosion, 10 <sup>6</sup> g/yr<br>(multiply lines #2 x #5 x #6 x #13 x #16)     | _____                  |
| 20 | Calculate Unit-Specific Emission Rate - Batch Dump, 10 <sup>6</sup> g/yr<br>(multiply lines #3 x #7 x #8 x #15 x #17)       | _____                  |
| 21 | Calculate Unit-Specific Emission Rate - Vehicle Activity, 10 <sup>6</sup> g/yr<br>(multiply lines #4 x #7 x #9 x #14 x #18) | _____                  |
| 22 | Calculate Total Emission Rate, 10 <sup>6</sup> g/yr<br>(add lines #19 + #20 + #21)  | _____                  |

\* Critical input value

\*\* Scaling factor determined for Lines 2-12 from Appendix P - Emission Rate Estimate from Table P-2 divided by Typical Emission Rate defined in Case 28 (see lines 16, 17, and 18).

**TABLE S-15**  
**EMISSION RATE ESTIMATION WORKSHEET - PARTICLES FROM EXPOSED, FLAT, CONTAMINATED AREAS**

Line	Col 1	Col 2	Col 3	Col 4
	<b>Modeling Parameters</b>	<u>Instruction A:</u> Input Unit-Specific Values	<u>Instruction B:</u> Select Representative Case from Appendix Q - Table Q-1 (underline selected case)	<u>Instruction C:</u> Determine Scaling Factor**
1	Area*	_____ acres	--	--
2	Silt Content*	_____ %	1, 2, 3 or 4	_____
3	Surface erodibility*	_____ tons/acre-year	5, 6, 7, 8 or 9	_____
4	% of time windspeed > 12 mph*	_____ %	15, 16, 17 or 18	_____
5	Mass fraction of contaminant*	_____ ppm	--	--
6	$100^2/(\text{PE index})^2$	_____	--	--
<u>INSTRUCTION D:</u> Complete Lines 7-8 and 10				
			<u>SURROGATE-SPECIFIC VALUES</u>	
7	Account for Unit-Specific Area [unit-specific area/(Case 24 area = 5 acres)]		_____	
8	Account for Mass Fraction of Contaminant [unit-specific mass fraction/(Case 24 mass fraction = 1 ppm)]		_____	
9	Typical Case Emission Rate (Case 24), $10^6$ g/yr		$3.6 \times 10^7$	
9	Calculate Unit-Specific Emission Rate, $10^6$ g/yr (multiply line #2 x #3 x #4 x #6 x #7 x #8 x #9)		_____	

\* Critical input values

\*\* Scaling Factor determined for Lines 2-4 from Appendix Q - Emission Rate Estimate from Table Q-2 divided by Typical Emission Rate defined in Case 24 (see line 9)



**APPENDIX H**

**SOIL LOSS CALCULATION**

**EXCERPTED FROM**

**U.S. EPA. Final Draft Superfund Exposure Assessment  
Manual. September, 1987. Office of Emergency and  
Remedial Response, Washington, D.C. 20460**

## APPENDIX H

### SOIL LOSS CALCULATION

#### Introduction

Many of the organic substances of concern found at Superfund sites are relatively nonpolar, hydrophobic substances (Delos et al., 1984). Such substances can be expected to sorb to site soils and migrate from the site more slowly than will polar compounds. As discussed in Haith (1980) and Mills et al. (1982), estimates of the amount of hydrophobic compounds released in site runoff can be calculated using the Modified Universal Soil Loss Equation (MUSLE) and sorption partition coefficients derived from the compound's octanol-water partition coefficient. The MUSLE allows estimation of the amount of surface soil eroded in a storm event of given intensity, while sorption coefficients allow the projection of the amounts of contaminant carried along with the soil, and the amount carried in dissolved form.

#### Soil Loss Calculation

Equation 2-20 is the basic equation for estimating soil loss. Equations 2-21 through 2-24 are used to calculate certain input parameters required to apply Equation 2-20. The modified universal soil loss equation (Williams 1975), as presented in Mills et al. (1982), is:

$$Y(S)_E = a(V_r q_p)^{0.56} KLSCP \quad (2-20)$$

where

$Y(s)_E$	=	sediment yield (tons per event, metric tons per event).
$a$	=	conversion constant, (95 English, 11.8 metric). *
$V_r$	=	volume of runoff, (acre-feet, m <sup>3</sup> ).
$q_p$	=	peak flow rate, (cubic feet per second, m <sup>3</sup> /sec).

---

\* Metric conversions presented in the following runoff contamination equations are from Mills et al. (1982).

- K = the soil erodibility factor, (commonly expressed in tons per acre per dimensionless rainfall erodibility unit). K can be obtained from the local Soil Conservation Service office.
- L = the slope-length factor, (dimensionless ratio).
- S = the slope-steepness factor, (dimensionless ratio).
- C = the cover factor, (dimensionless ratio: 1.0 for bare soil); see the following discussion for vegetated site "C" values).
- P = the erosion control practice factor, (dimensionless ratio: 1.0 for uncontrolled hazardous waste sites).

Soil erodibility factors are indicators of the erosion potential of given soils types. As such, they are highly site-specific. K values for sites under study can be obtained from the local Soil Conservation Service office. The slope length factor, L, and the slope steepness factor, S, are generally entered into the MUSLE as a combined factor, LS, which is obtained from Figures 2-4 through 2-6. The cover management factor, C, is determined by the amount and type of vegetative cover present at the site. Its value is "1" (one) for bare soils. Consult Tables 2-4 through 2-5 to obtain C values for sites with vegetative covers. The factor, P, refers to any erosion control practices used on-site. Because these generally describe the type of agricultural plowing or planting practices, and because it is unlikely that any erosion control would be practiced at an abandoned hazardous waste site, use a worst-case (conservative) P value of 1 (one) for uncontrolled sites.

Storm runoff volume,  $V_r$ , is calculated as follows (Mills et al. 1982):

$$V_r = aAQ_r \quad (2-21)$$

where

- a = conversion constant, (0.083 English, 100 metric).
- A = contaminated area, (acres, ha).
- $Q_r$  = depth of runoff, (in, cm).

Depth of runoff,  $Q_r$ , is determined by (Mockus 1972):

$$Q_r = (R_t - 0.2S_w)^2 / (R_t + 0.8S_w) \quad (2-22)$$

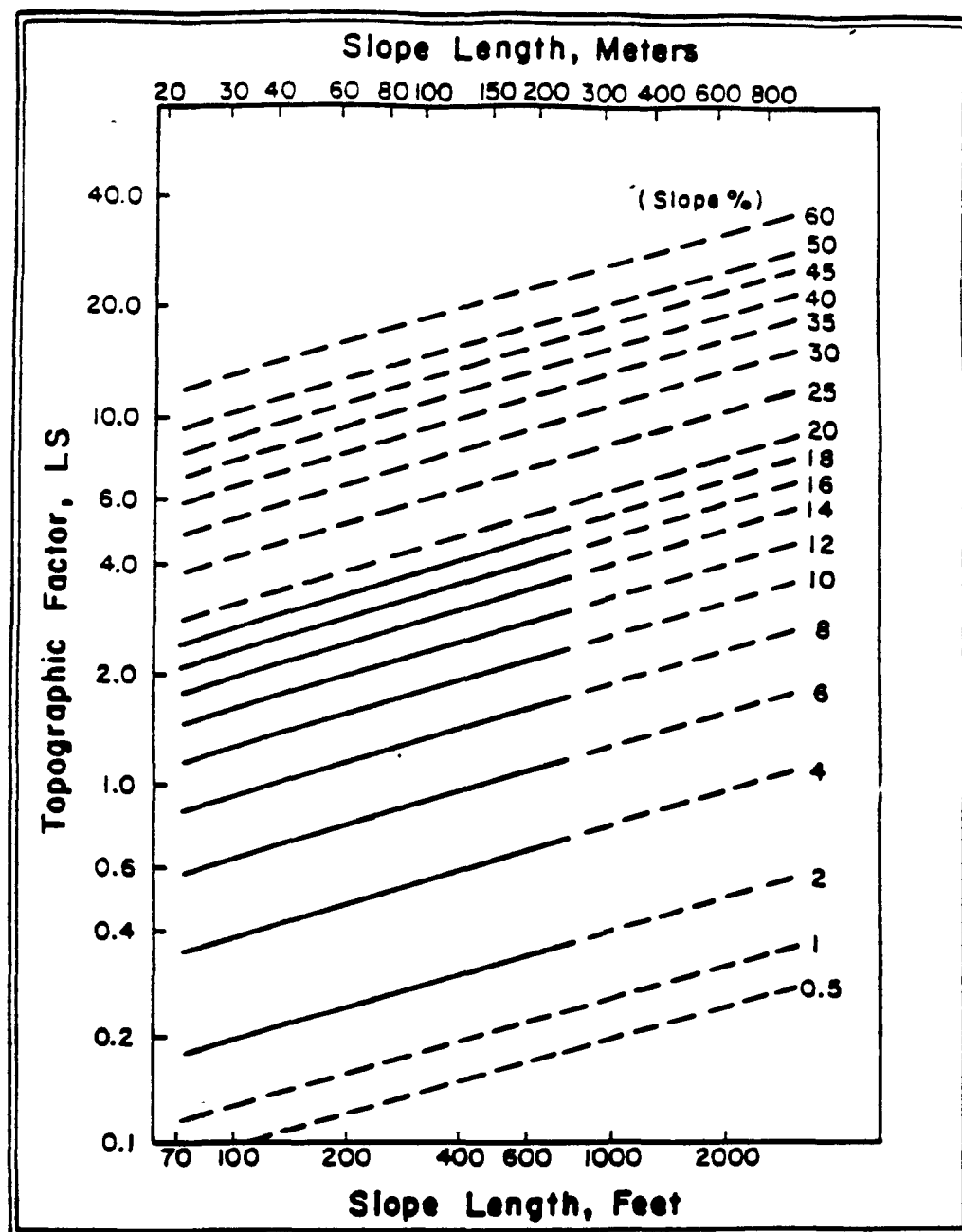


Figure 2-4. Slope Effect chart Applicable to Areas A-1 in Washington, Oregon, and Idaho, and All of A-3: See Figure 3-5 (USDA 1974 as Presented in Mills et al. 1982).

NOTE: Dashed lines are extension of LS formulae beyond values tested in studies.

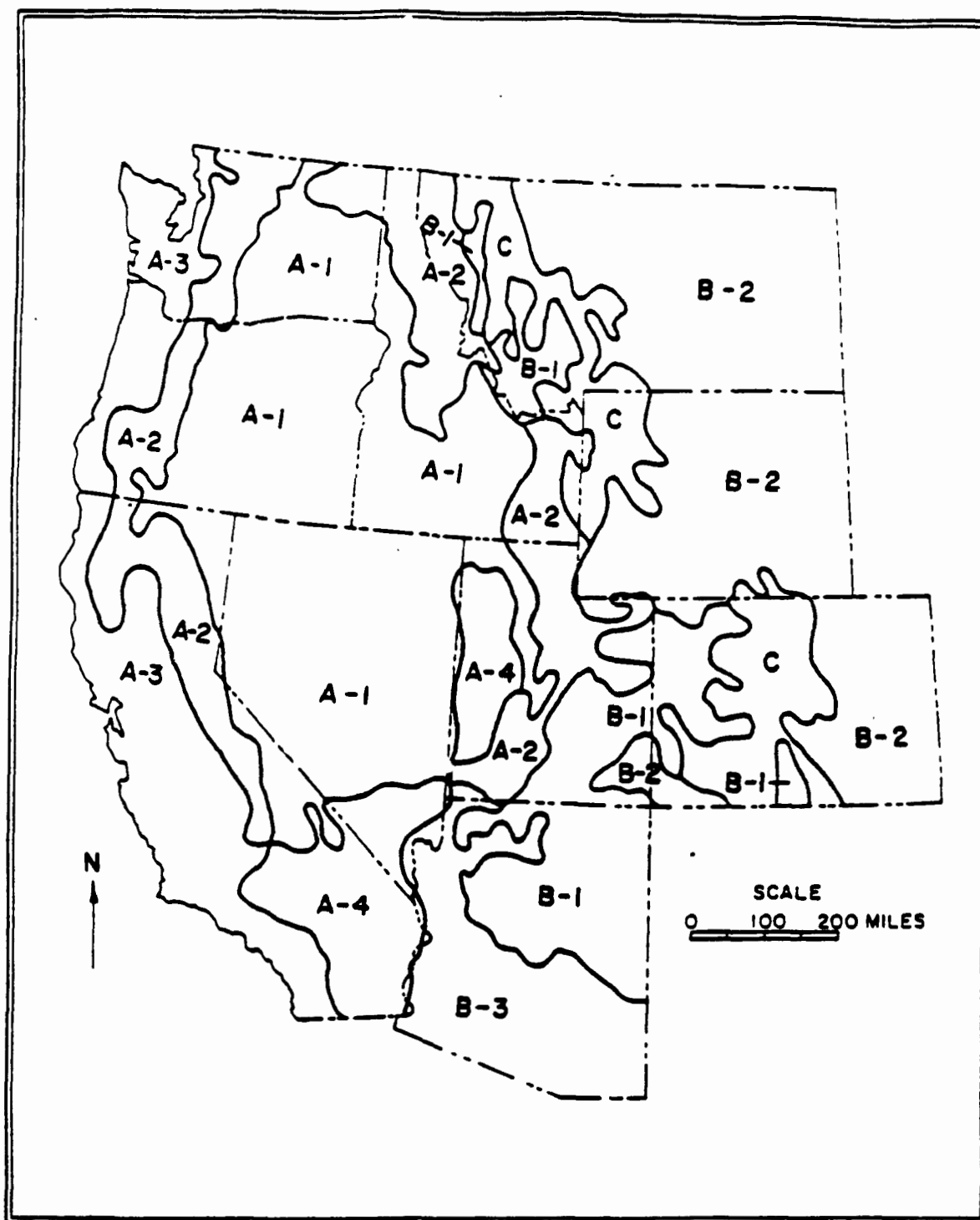


Figure 2-5. Soil Moisture-Soil Temperature Regimes of the Western United States (USDA 1974).

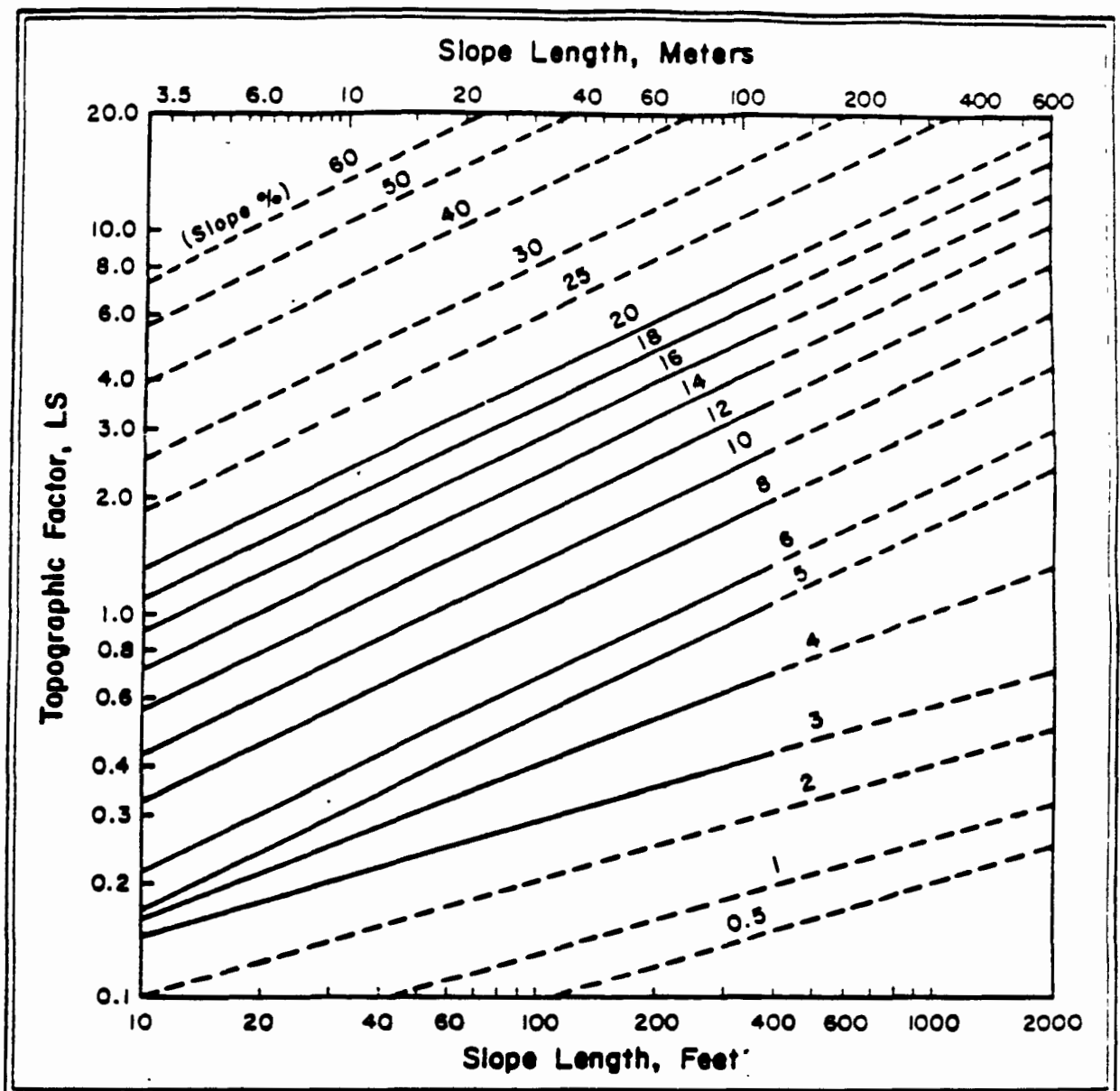


Figure 2-6. Slope Effect Chart for Areas Where Figure 3-5 Is Not Applicable (USDA 1974).

NOTE: The dashed lines represent estimates for slope dimensions beyond the range of lengths and steepnesses for which data are available.

TABLE 2-4

**"C" VALUES FOR PERMANENT PASTURE,  
RANGELAND, AND IDLE LAND**

Vegetal canopy Type and height of raised canopy <sup>b</sup>	Canopy cover <sup>c</sup> (%)	Cover that contacts the surface/Percent groundcover						
		Typed	0	20	40	60	80	95-100
No appreciable canopy		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	0.45	0.24	0.15	0.090	0.043	0.011
Canopy of tall weeds or short brush (0.5 m fall height)	25	G	0.36	0.17	0.09	0.038	0.012	0.003
	50	W	0.36	0.20	0.13	0.082	0.041	0.011
		G	0.26	0.13	0.07	0.035	0.012	0.003
	75	W	0.26	0.16	0.11	0.075	0.039	0.011
		G	0.17	0.10	0.06	0.031	0.011	0.003
		W	0.17	0.12	0.09	0.067	0.038	0.011
Appreciable brush or brushes (2 m fall height)	25	G	0.40	0.18	0.09	0.040	0.013	0.003
	50	W	0.40	0.22	0.14	0.085	0.042	0.011
		G	0.34	0.16	0.085	0.038	0.012	0.003
	75	W	0.34	0.19	0.13	0.081	0.041	0.011
		G	0.28	0.14	0.08	0.036	0.012	0.003
		W	0.28	0.17	0.12	0.077	0.040	0.011
Trees but no appreciable low brush (4 m fall height)	25	G	0.42	0.19	0.10	0.041	0.013	0.003
	50	W	0.42	0.23	0.14	0.087	0.042	0.011
		G	0.39	0.18	0.09	0.040	0.013	0.003
	75	W	0.39	0.21	0.14	0.085	0.042	0.011
		G	0.36	0.17	0.09	0.039	0.012	0.003
		W	0.36	0.20	0.13	0.083	0.041	0.011

Source: Wischemier 1972.

- a All values shown assume: (1) random distribution of mulch or vegetation and (2) mulch of appreciable depth where it exists.
- b Average fall height of waterdrops from canopy to soil surface: m = meters.
- c Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).
- d G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 5 cm (2 in.) deep.  
W: Cover at surface is mostly broadleaf herbaceous plants (as weeds) with little lateral-root network near the surface and/or undecayed residue.

**TABLE 2-5**  
**"C" VALUES FOR WOODLAND**

Stand condition	Tree canopy percent of area <sup>a</sup>	Forest litter percent of area <sup>b</sup>	Undergrowth <sup>c</sup>	"C" factor
Well stocked	100-75	100-90	Managed <sup>d</sup> Unmanaged <sup>d</sup>	0.001 0.003-0.011
Medium stocked	70-40	85-75	Managed Unmanaged	0.002-0.004 0.01-0.04
Poorly stocked	35-20	70-40	Managed Unmanaged	0.003-0.009 0.02-0.09 <sup>e</sup>

Source: Wischemier 1972.

- a When tree canopy is less than 20 percent, the area will be considered as grass land or cropland for estimating soil loss.
- b Forest litter is assumed to be at least 2 in. deep over the percent ground surface area covered.
- c Undergrowth is defined as shrubs, weeds, grasses, vines, etc., on the surface area not protected by forest litter. Usually found under canopy openings.
- d Managed - grazing and fires are controlled.  
Unmanaged - stands that are overgrazed or subjected to repeated burning.
- e For unmanaged woodland with litter cover of less than 75 percent, C values should be derived by taking 0.7 of the appropriate values in Table 3-4. The factor of 0.7 adjusts for much higher soil organic matter on permanent woodland.



where

- $R_t$  = the total storm rainfall, (in, cm).
- $S_w$  = water retention factor, (in, cm).

The value of  $S_w$ , the water retention factor, is obtained as follows (Mockus 1972):

$$S_w = \frac{1000}{CN} - 10a \quad (2-23)$$

where

- $S_w$  = water retention factor, (in, cm).
- CN = the SCS Runoff Curve Number, (dimensionless, see Table 2-6).
- $a$  = conversion constant (1.0 English, 2.54 metric).

The CN factor is determined by the type of soil at the site, its condition, and other parameters that establish a value indicative of the tendency of the soil to absorb and hold precipitation or to allow precipitation to run off the surface. The analyst can obtain CN values of uncontrolled hazardous waste sites from Table 2-6.

The peak runoff rate,  $q_p$ , is determined as follows (Haith 1980):

$$q_p = \frac{aAR_tQ_r}{T_r(R_t - 0.2S_w)} \quad (2-24)$$

where

- $q_p$  = the peak runoff rate, (ft<sup>3</sup>/sec, m<sup>3</sup>/sec).
- $a$  = conversion constant, (1.01 English, 0.028 metric).
- $A$  = contaminated area, (acres, ha).
- $R_t$  = the total storm rainfall, (in, cm).
- $Q_r$  = the depth of runoff from the watershed area, (in, cm).
- $T_r$  = storm duration, (hr).

**TABLE 2-6**  
**RUNOFF CURVE NUMBERS**

Soil Group	Description	Site Type			
		Overall site <sup>a</sup>	Road/right of way	Meadow	Woods
A	Lowest runoff potential: Includes deep sands with very little silt and clay, also deep, rapidly permeable loess (infiltration rate = 8-12 mm/h).	59	74	30	45
B	Moderately low runoff potential: Mostly sandy soils less deep than A, and loess less deep or less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting (infiltration rate = 4-8 mm/h).	74	84	58	66
C	Moderately high runoff potential: Comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below-average infiltration after presaturation (infiltration rate = 1-4 mm/h).	82	90	71	77
D	Highest runoff potential: Includes mostly clays of high swelling percent, but the group also includes some shallow soils with nearly impermeable subhorizons near the surface (infiltration rate = 0-1 mm/h).	86	92	78	83

Source: Adapted from Schwab et al. 1966.

- <sup>a</sup> Values taken from farmstead category, which is a composite including buildings, farmyard, road, etc.

$S_w$  = water retention factor, (in, cm).

### Dissolved/Sorbed Contaminant Release

As discussed in Mills et al. (1985), the analyst can predict the degree of soil/water partitioning expected for given compounds once the storm event soil loss has been calculated with the following equations. First, the amounts of absorbed and dissolved substances are determined, using the equations presented below as adapted from Haith (1980):

$$S_s = [1/(1 + \theta_c/K_d B)] (C_i) (A) \quad (2-25)$$

and

$$D_s = [1/(1 + K_d B/\theta_c)] (C_i) (A) \quad (2-26)$$

where

- $S_s$  = sorbed substance quantity, (kg, lb).
- $\theta_c$  = available water capacity of the top cm of soil (difference between wilting point and field capacity), (dimensionless).
- $K_d$  = sorption partition coefficient, (cm<sup>3</sup>/g).
- $B$  = soil bulk density, (g/cm<sup>3</sup>).
- $C_i$  = total substance concentration, (kg/ha-cm, lb/acre-cm).
- $A$  = contaminated area, (ha-cm, acre-cm). (Actually a volume; assumption is contamination in upper 1 cm is available for release).
- $D_s$  = dissolved substance quantity, (kg, lb).

This model assumes that only the contaminant in the top 1 cm of soil is available for release via runoff.

The ~~soil~~ sorption partition coefficient for a given chemical can be determined from known values of certain other physical/chemical parameters, primarily the chemical's octanol-water partition coefficient, solubility in water, or bioconcentration factor. Lyman et al. (1982) present regression equations that allow the analyst to determine sorption coefficients for specified groups of chemicals (e.g., herbicides, polynuclear aromatics). If parameter values required by the appropriate equations are not available in chemical reference literature, they

can be estimated according to procedures described in Lyman et al. (1982). Initially, the octanol-water partition coefficient can be estimated based on the substance's molecular structure. If necessary, this value can be used, in turn, to estimate either solubility in water or bioconcentration factor.

After calculating the amount of sorbed and dissolved contaminant, the total loading to the receiving waterbody is calculated as follows (adapted from Haith 1980):

$$PX_i = [Y(S)_E / 100 \beta] S_s \quad (2-27)$$

and

$$PQ_i = [Q_r / R_t] D_s \quad (2-28)$$

where

- $PX_i$  = sorbed substance loss per event, (kg, lb).
- $Y(S)_E$  = sediment yield, (tons per event, metric tons).
- $\beta$  = soil bulk density, (g/cm<sup>3</sup>).
- $S_s$  = sorbed substance quantity, (kg, lb).
- $PQ_i$  = dissolved substance loss per event, (kg, lb).
- $Q_r$  = total storm runoff depth, (in, cm).
- $R_t$  = total storm rainfall, (in, cm).
- $D_s$  = dissolved substance quantity, (kg, lb).

$PX_i$  and  $PQ_i$  can be converted to mass per volume terms for use in estimating contaminant concentration in the receiving waterbody by dividing by the site storm runoff volume ( $V_r$ , see Equation 2-21).

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**INTERIM FINAL**  
**RCRA FACILITY INVESTIGATION (RFI) GUIDANCE**  
**VOLUME IV OF IV**

**CASE STUDY EXAMPLES**

**EPA 530/SW-89-031**

**MAY 1989**

**WASTE MANAGEMENT DIVISION**  
**OFFICE OF SOLID WASTE**  
**U.S. ENVIRONMENTAL PROTECTION AGENCY**

## **ABSTRACT**

On November 8, 1984, Congress enacted the Hazardous and Solid Waste Amendments (HSWA) to RCRA. Among the most significant provisions of HSWA are §3004(u), which requires corrective action for releases of hazardous waste or constituents from solid waste management units at hazardous waste treatment, storage and disposal facilities seeking final RCRA permits; and §3004(v), which compels corrective action for releases that have migrated beyond the facility property boundary. EPA will be promulgating rules to implement the corrective action provisions of HSWA, including requirements for release investigations and corrective measures.

This document, which is presented in four volumes, provides guidance to regulatory agency personnel on overseeing owners or operators of hazardous waste management facilities in the conduct of the second phase of the RCRA Corrective Action Program, the RCRA Facility Investigation (RFI). Guidance is provided for the development and performance of an investigation by the facility owner or operator based on determinations made by the regulatory agency as expressed in the schedule of a permit or in an enforcement order issued under §3008(h), §7003, and/or §3013. The purpose of the RFI is to obtain information to fully characterize the nature, extent and rate of migration of releases of hazardous waste or constituents and to interpret this information to determine whether interim corrective measures and/or a Corrective Measures Study may be necessary.

## **DISCLAIMER**

**This document is intended to assist Regional and State personnel in exercising the discretion conferred by regulation in developing requirements for the conduct of RCRA Facility Investigations (RFIs) pursuant to 40 CFR 264. Conformance with this guidance is expected to result in the development of RFIs that meet the regulatory standard of adequately detecting and characterizing the nature and extent of releases. However, EPA will not necessarily limit acceptable RFIs to those that comport with the guidance set forth herein. This document is not a regulation (i.e., it does not establish a standard of conduct which has the force of law) and should not be used as such. Regional and State personnel must exercise their discretion in using this guidance document as well as other relevant information in determining whether an RFI meets the regulatory standard.**

**Mention of company or product names in this document should not be considered as an endorsement by the U.S. Environmental Protection Agency.**



**RCRA FACILITY INVESTIGATION (RFI) GUIDANCE**

**VOLUME IV**

**CASE STUDY EXAMPLES**

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## LIST OF ACRONYMS

AA	-	Atomic Absorption
AI	-	Soil Adsorption Isotherm Test
ASCS	-	Agricultural Stabilization and Conservation Service
ASTM	-	American Society for Testing and Materials
BCF	-	Bioconcentration Factor
BOD	-	Biological Oxygen Demand
CAG	-	EPA Carcinogen Assessment Group
CPF	-	Carcinogen Potency Factor
CBI	-	Confidential Business Information
CEC	-	Cation Exchange Capacity
CERCLA	-	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	-	Code of Federal Regulations
CIR	-	Color Infrared
CM	-	Corrective Measures
CMI	-	Corrective Measures Implementation
CMS	-	Corrective Measures Study
COD	-	Chemical Oxygen Demand
COLIWASA	-	Composite Liquid Waste Sampler
DNPH	-	Dinitrophenyl Hydrazine
DO	-	Dissolved Oxygen
DOT	-	Department of Transportation
ECD	-	Electron Capture Detector
EM	-	Electromagnetic
EP	-	Extraction Procedure
EPA	-	Environmental Protection Agency
FEMA	-	Federal Emergency Management Agency
FID	-	Flame Ionization Detector
Foc	-	Fraction organic carbon in soil
FWS	-	U.S. Fish and Wildlife Service
GC	-	Gas Chromatography
GC/MS	-	Gas Chromatography/Mass Spectroscopy
GPR	-	Ground Penetrating Radar
HEA	-	Health and Environmental Assessment
HEEP	-	Health and Environmental Effects Profile
HPLC	-	High Pressure Liquid Chromatography
HSWA	-	Hazardous and Solid Waste Amendments (to RCRA)
HWM	-	Hazardous Waste Management
ICP	-	Inductively Coupled (Argon) Plasma
ID	-	Infrared Detector
Kd	-	Soil/Water Partition Coefficient
Koc	-	Organic Carbon Adsorption Coefficient
Kow	-	Octanol/Water Partition Coefficient
LEL	-	Lower Explosive Limit
MCL	-	Maximum Contaminant Level
MM5	-	Modified Method 5
MS/MS	-	Mass Spectroscopy/Mass Spectroscopy
NFIP	-	National Flood Insurance Program
NIOSH	-	National Institute for Occupational Safety and Health

## LIST OF ACRONYMS (Continued)

NPDES	-	National Pollutant Discharge Elimination System
OSHA	-	Occupational Safety and Health Administration
OVA	-	Organic Vapor Analyzer
PID	-	Photo Ionization Detector
pKa	-	Acid Dissociation Constant
ppb	-	parts per billion
ppm	-	parts per million
PUF	-	Polyurethane Foam
PVC	-	Polyvinyl Chloride
QA/QC	-	Quality Assurance/Quality Control
RCRA	-	Resource Conservation and Recovery Act
RFA	-	RCRA Facility Assessment
RfD	-	Reference Dose
RFI	-	RCRA Facility Investigation
RMCL	-	Recommended Maximum Contaminant Level
RSD	-	Risk Specific Dose
SASS	-	Source Assessment Sampling System
SCBA	-	Self Contained Breathing Apparatus
SCS	-	Soil Conservation Service
SOP	-	Standard Operating Procedure
SWMU	-	Solid Waste Management Unit
TCLP	-	Toxicity Characteristic Leaching Procedure
TEGD	-	Technical Enforcement Guidance Document (EPA, 1986)
TOC	-	Total Organic Carbon
TOT	-	Time of travel
TOX	-	Total Organic Halogen
USGS	-	United States Geologic Survey
USLE	-	Universal Soil Loss Equation
UV	-	Ultraviolet
VOST	-	Volatile Organic Sampling Train
VSP	-	Verticle Seismic Profiling
WQC	-	Water Quality Criteria

## **14.0 INTRODUCTION**

### **14.1 Use of Case Studies**

This document, Volume IV of the RCRA Facility Investigation (RFI) Guidance, contains case studies selected to illustrate various concepts and procedures presented in Volumes I, II, and III. These case studies are provided to explain, through example, how various tasks can be conducted during RFIs. The case studies also identify some of the potential problems that can occur if the RFI sampling and analytical programs are not carefully designed and executed. The case studies, however, should not be used as the primary source of guidance for RFI program design and conduct. Instead, Volumes I, II and III should be consulted. The studies do not necessarily address details specific to individual facilities, and omission of certain RFI tasks should not be interpreted as an indication that such tasks are unnecessary or of less significance. Most of the case studies are based on actual sites. In some cases, existing data have been supplemented with hypothetical data to illustrate a particular point.

### **14.2 Organization of Volume IV**

The case studies are organized primarily by the order in which the subject matter was presented in Volumes I, II and III. In some cases, individual case studies present materials relevant to more than one topic or media. Table 14-1 lists the points illustrated and identifies the case studies which provide information relevant to these points.

The following general format was used as appropriate for each case study:

- **Title**
- **Identification of points illustrated**
- **Introduction/Background**
- **Facility description**
- **Program design/Data collection**
- **Program results/Data analysis**
- **Case discussion.**

TABLE 14-1

## SUMMARY OF POINTS ILLUSTRATED

POINTS ILLUSTRATED	CASE STUDY NUMBER
<b>SELECTION OF MONITORING CONSTITUENTS</b>	
• Use of 40 CFR Part 261 Listing Background Documents in selecting monitoring constituents	1
• Consideration of degradation as a factor in identifying monitoring constituents	2
<b>SAMPLING SCHEMES</b>	
• Selection of a sampling scheme that appropriately characterizes soil contamination	3
• Evaluation of the effectiveness of a sampling scheme using statistical analyses	3
• Use of release monitoring/leachate collection to characterize wastes when the actual waste stream is inaccessible, as in the case of buried drums	4
<b>QUALITY ASSURANCE AND CONTROL</b>	
• Use of quality assurance and control and data validation procedures	5
<b>DATA PRESENTATION</b>	
• Techniques for presenting data for facility investigations involving multimedia contamination	6
<b>WASTE CHARACTERIZATION</b>	
• Correlation of a contaminant release with a specific waste management unit using ground-water data	7
• Use of site topographic information to select test boring and monitoring well locations at facilities where large volumes of waste have been disposed	8
• Use of waste stream information to select indicator parameters and monitoring constituents in a ground-water monitoring program to minimize the number of constituents that must be monitored	9
• Use of information on possible waste reaction products in designing a ground-water monitoring program	10
<b>CORRECTIVE MEASURES INCLUDING INTERIM MEASURES</b>	
• Use of biodegradation and removal for interim corrective measures	2
• Corrective action and the implementation of interim corrective measures	11
<b>AERIAL PHOTOGRAPHY</b>	
• Use of aerial photographs to identify actual and potential waste migration routes and areas requiring corrective action	12
• Identification of a ground-water contaminant plume using infrared aerial photography	13
• Use of historical aerial photographs and facility maps to identify old waste disposal areas and ground-water flow paths	14

TABLE 14-1

## SUMMARY OF POINTS ILLUSTRATED (continued)

POINTS ILLUSTRATED	CASE STUDY NUMBER
<b>SOIL</b>	
• Use of soil characteristics to estimate mobility of contaminants in soil	15
• Effects of degradation in determining the fate of a contaminant in soil	2
• Use of leaching tests to predict potential impacts of contaminated soils on ground water	16
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## **15.0 CASE STUDIES**

### **CASE STUDY 1: USE OF THE 40 CFR 261 LISTING BACKGROUND DOCUMENTS FOR SELECTING MONITORING CONSTITUENTS**

#### **Point Illustrated**

- The 40 CFR 261 Listing Background Documents can be of direct help in selecting monitoring constituents.

#### **Introduction**

The RCRA Hazardous Waste Listing Background Documents developed for the identification and listing of hazardous wastes under 40 CFR Part 261 represent one source of potential information on waste-specific constituents and their physical and chemical characteristics. The documents contain information on the generation, composition, and management of listed waste streams from generic and industry-specific sources. In addition to identifying hazardous constituents that are present in the wastes, the documents may also provide data on potential decomposition products. In some background documents, migratory potentials are discussed and exposure pathways are identified.

Appendix B of the Listing Document provides more detailed information on the fate and transport of hazardous constituents. Major physical and chemical properties of selected constituents are listed, including molecular weights, vapor pressures and solubilities, octanol-water partition coefficients, hydrolysis rates, biodegradation rates, and volatilization rates. Another section of the appendix estimates the migratory potential and environmental persistence of selected constituents based on a conceptual model of disposal in an unconfined landfill or lagoon.

The appropriate uses and limitations of the Listing Documents are outlined in Table 15-1. A case study on how the Documents may be used in investigating a release follows.

TABLE 15-1

## USES AND LIMITATIONS OF THE LISTING BACKGROUND DOCUMENTS

Uses	Limitations
<ul style="list-style-type: none"> <li>Identifies the hazardous constituents for which a waste was listed</li> </ul>	<ul style="list-style-type: none"> <li>Applicable only for listed hazardous wastes</li> </ul>
<ul style="list-style-type: none"> <li>In some cases, provides information on additional hazardous constituents which may be present in a listed waste</li> </ul>	<ul style="list-style-type: none"> <li>Industry coverage may be limited in scope (e.g., the wood preserving industry). Listing Documents only cover organic preservatives, not inorganics (15 percent of the industry), such as inorganic arsenic salts</li> </ul>
<ul style="list-style-type: none"> <li>In some cases, identifies decomposition products of hazardous constituents</li> </ul>	<ul style="list-style-type: none"> <li>Data may not be comprehensive (i.e., not all potentially hazardous constituents may be identified). Generally, limited to the most toxic constituents common to the industry as a whole</li> </ul>
<ul style="list-style-type: none"> <li>Provides overview of industry; gives perspective on range of waste generated (both quantity and general characteristics)</li> </ul>	<ul style="list-style-type: none"> <li>Data may not be specific. Constituents and waste characteristic data often represent an industry average which encompasses many different types of production processes and waste treatment operations</li> </ul>
<ul style="list-style-type: none"> <li>May provide waste-specific characteristics data such as density, pH, and leachability</li> </ul>	<ul style="list-style-type: none"> <li>Listing Documents were developed from data/reports available to EPA at the time, resulting in varying levels of detail for different documents</li> </ul>
<ul style="list-style-type: none"> <li>May provide useful information on the migratory potential, mobility, and environmental persistence of certain hazardous constituents</li> </ul>	<ul style="list-style-type: none"> <li>Hazardous waste listings are periodically updated and revised, yet this may not be reflected in the Listing Documents</li> </ul>
<ul style="list-style-type: none"> <li>May list physical and chemical properties of selected constituents</li> </ul>	<ul style="list-style-type: none"> <li>Listing Documents for certain industries (e.g., the pesticides industry) may be subject to CBI censorship due to the presence of confidential business information. In such cases, constituent data may be unavailable (i.e., expurgated from the document)</li> </ul>



## Facility Description

The facility is a wood preserving plant located in the southeast. The facility uses a steaming process to treat southern pine and timber. Contaminated vapors from the wood treating process are condensed and transported to an oil/water separator to reclaim free oils and preserving chemicals. The bottom sediment sludge from this and subsequent waste water treatment units is a RCRA listed hazardous waste: K001.

## Use of Listing Background Documents

Due to the presence of small, but detectable, levels of phenolic compounds in the ground water of an adjacent property, a RCRA Facility Assessment (RFA) was conducted and it was determined that a release from the facility had occurred. The owner was instructed to conduct a RCRA Facility Investigation (RFI). Before embarking on an extensive waste sampling and analysis program, the owner decided to explore existing sources of information in order to better focus analytical efforts.

The owner obtained a copy of the Wood Preserving Industry Listing Background Document from the RCRA Docket at EPA Headquarters. He also had available a copy of 40 CFR Part 261, Appendix VII, which identifies the hazardous constituents for which his waste was listed. For K001, he found the following hazardous constituents listed: pentachlorophenol, phenol, 2-chlorophenol, p-chloro-m-cresol, 2,4-dimethylphenyl, 2,4-dinitrophenol, trichlorophenols, tetrachlorophenols, 2,4-dichlorophenol, creosote, chrysene, naphthalene, fluoranthene, benz(b)fluoranthene, benz(a)pyrene, ideno(1,2,3-cd)pyrene, benz(a)anthracene, dibenz(a)anthracene, and acenaphthalene.

From the Summary of Basis for Listing section in the Listing Document, the owner found that phenolic compounds are associated with waste generated from the use of pentachlorophenol-based wood preservatives, and that polynuclear aromatic hydrocarbons (PAHs) (i.e., chrysene through acenaphthalene in Appendix VII) are associated with wastes from the use of creosote-based preservatives. Examining the facility records, he determined that pentachlorophenol had been the

sole preservative used; moreover, it had come from a single manufacturer. Based on a demonstrable absence of creosote use, the owner felt confident in excluding creosote and PAHs.

To help focus on which phenolics might be present in his waste, the owner turned to the Composition section of the Listing Document. In Table 4, he found typical compositions of commercial grade pentachlorophenol. The sample from his manufacturer contained 84.6 percent pentachlorophenol, 3 percent tetrachlorophenol, and ppm levels of polychlorinated dibenzo-p-dioxins and dibenzo-furans. The owner was surprised by the absence of the other phenolics mentioned in Appendix VII, and he was concerned by the presence of dioxins and furans. Reading the text carefully, he discovered that the majority of the phenolic compounds listed as hazardous constituents of the waste are actually decomposition products of penta- and tetrachlorophenol. He also learned that while the Agency had ruled out the presence of tetrachlorodibenzo(p)dioxin (TCDD) in the listed waste (except where incinerated), it had not ruled out the possibility that other chlorinated dioxins might be present: "... chlorinated dioxins have been found in commercial pentachlorophenol and could therefore be expected to be present in very small amounts in some wastes." Due to their extreme toxicity and because his facility had historically used the commercial pentachlorophenol with the highest concentration of dioxins and furans, the owner thought it prudent to include a scan for dioxins in his waste analysis plan.

The owner found no further data in the Composition section to help him narrow the list of phenolics; however, Table 6 gave a breakdown of organic compounds found in different wood preserving plants (i.e., steam process vs. Boneton conditioning), but only two phenolics were listed. A note in the text highlights one of the limitations of using the Listing Document: "The absence in this table (Table 6) of certain components ... probably indicates that an analysis for their presence was not performed rather than an actual absence of the component." It should be kept in mind that the waste analyses in the Listing Background Documents are not comprehensive and that they are based, as the Agency acknowledges, on data available at the time. In the absence of more detailed waste-specific data, the owner decided to include pentachlorophenol, tetrachlorophenol, unsubstituted phenol, and the six listed decomposition-product phenolic compounds in his waste analysis plan.

In reading the Listing Documents, the owner found useful information for other phases of the RFI. In the Migratory Potential Exposure Pathways section, he learned that pentachlorophenol is highly bioaccumulative, with an octanol/water partition coefficient of 102,000. Tetrachlorophenol, tri-chlorophenol, and dichlorophenol are likewise bioaccumulative, with octanol/water coefficients of 12,589, 4,169, and 1,380, respectively. He also learned that the biodegradability of pentachlorophenol is concentration limited.

In Appendix B of the Listing Background Documents; Fate and Transport of Hazardous Constituents, the owner found data sheets for six out of nine phenolic compounds, also some for dioxins and furans. Information on water chemistry, soil attenuation, environmental persistence, and bioaccumulation potential were listed along with chemical and physical properties such as solubility and density.

#### Case Discussion

Although the Listing Background Document did not provide the owner with enough specific data to fully characterize his waste, it did help him refine the list of monitoring constituents, alert him to the potential presence of dioxins, and gave him physical and chemical waste characteristic data which could be useful in predicting contaminant mobility.

## CASE STUDY 2: ESTIMATION OF DEGRADATION POTENTIAL OF CONTAMINANTS IN SOIL

### Point Illustrated

- Degradation, either chemical or biological, can be an important factor in determining the fate of a contaminant in soil, and can also be a factor in identifying constituents to monitor. The degradation rate can also be accelerated as a means of conducting interim or definitive corrective measures.

### Introduction

Degradation of contaminants in the environment can occur through several mechanisms, and can be a factor in identifying monitoring constituents. Under natural conditions, these processes are often very slow, but studies have shown that chemical and biological degradation can be accelerated in the soil by modifying soil conditions. Parameters such as soil moisture content and redox condition can be altered to encourage contaminant degradation in soils.

### Site Description

The site is situated in an arid region that was used during the 1970s by aerial applicators of organochlorine and organophosphate pesticides. The applicators abandoned the site in 1980 and homes were built in the vicinity. The site can be divided into three areas based on past use. The most contaminated area, the "hot zone", is a 125 feet by 50 feet area at the north end of the site that was used for mixing, loading, and unloading the pesticides. Soil samples from this area contained toxaphene, ethyl parathion, and methyl parathion at concentrations up to 15,000 mg/kg. The present residential area was used as a taxiway and an area to rinse tanks and clean planes. Soils from this zone were low in parathions but toxaphene concentrations ranging from 20 to 700 mg/kg were found. This area is approximately 1.7 acres in size and located immediately south and west of the hot zone. The runway itself was approximately 10 acres in size and south of the residential zone. Soil sample results from the runway area had low concentrations of all three pesticides.

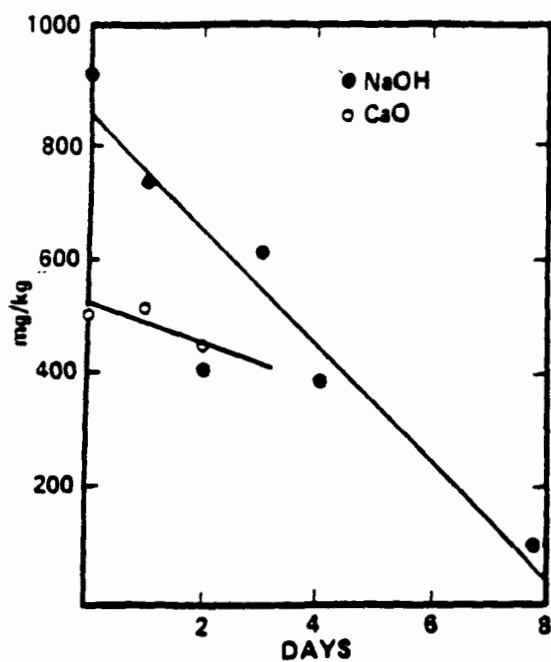
A number of factors influence degradation of organic compounds in soils. These include:

- chemical nature of the compound
- organic matter content of the soil
- soil pH
- oxidation/reduction environment of the soil
- concentrations of the compound.

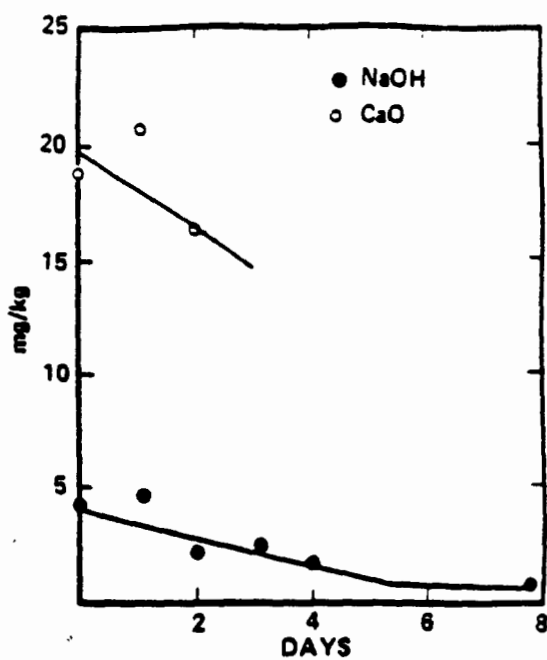
At the subject site, the soils were low in moisture content, were oxidizing, and exhibited soil pH values of 6.8 to 8.0. Under such conditions, parathion can be degraded slowly by alkali catalyzed hydrolysis reactions. The rate of these reactions increases with increasing soil pH. Parathion can also be biodegraded to O,O-Diethyl phosphoric acid. At a nearby site, it was shown that toxaphene will degrade anaerobically if reducing conditions can be achieved in the soil. It has also been observed that the loss of toxaphene by volatilization is enhanced by high soil moisture content. Other data indicated that toxaphene will degrade in the presence of strong alkali, by dechlorination reactions. This information can be used in identifying monitoring constituents and in performing interim and definitive corrective measures.

To test the feasibility of chemically degrading the contaminated soil, in situ, laboratory bench-scale tests were performed. Two treatments were evaluated, application of calcium oxide (quicklime) and sodium hydroxide (lye). Figure 15-1 shows that the pesticides were degraded by both of these strong alkalis.

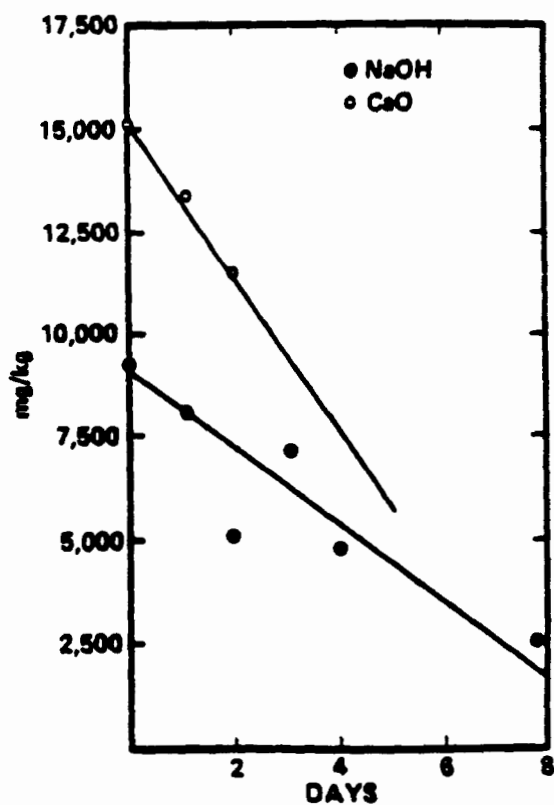
Those responsible for the remedial measures felt that the hot zone was too contaminated for in situ treatment to be effective over reasonable time periods. The upper 2 feet of soil from this area was excavated and transported to an approved landfill for disposal. However, the 1.7-acre residential area was treated in situ. To promote degradation, approximately 200 g/ft<sup>2</sup> of sodium hydroxide was applied using a tractor with a fertilizer-spreading attachment. A plow and disc were used to mix the sodium hydroxide into the soil to a depth of 1.5 feet. At 70 days after the application, concentrations of ethyl parathion had decreased by 76 percent, methyl parathion by 98 percent, and toxaphene by 45 percent.



Laboratory Bench Test, Ethyl Parathion Degradation



Laboratory Bench Test, Methyl Parathion Degradation



Laboratory Bench Test, Toxaphene Degradation

Figure 15-1. Results of Laboratory Bench Test for Pesticide Degradation

### Case Discussion

Knowledge of the properties of a contaminant as well as its environment are important in assessing the potential for degradation, and this information can be used to identify monitoring constituents and conduct interim or definitive corrective measures. It may be possible to alter the site's physical or chemical characteristics to enhance degradation of contaminants. Under appropriate conditions, in situ treatment of contaminated soils can be an effective corrective measures method.

### Reference

King, J., T. Tinto, and M. Ridosh. 1985. In Situ Treatment of Pesticide Contaminated Soils. Proceedings of the National Conference of Management of Uncontrolled Hazardous Waste Sites. Washington, D.C.

## CASE STUDY 3: SELECTION AND EVALUATION OF A SOIL SAMPLING SCHEME

### Points Illustrated

- Sampling methodologies must be properly selected to most appropriately characterize soil contamination.
- Statistical analyses can be used to evaluate the effectiveness of a chosen sampling scheme.

### Introduction

Selection of a sampling scheme appropriate for a soil contamination problem is dependent on the objectives of the sampling program. A grab sampling scheme may be employed; however, grab sampling can produce a biased representation of contaminant concentrations because areas of gross contamination are most often chosen for sampling. Random sampling can provide an estimate of average contaminant concentrations across a site, but does not take into account differences due to the proximity to waste sources and soil or subsurface heterogeneities. A stratified random sampling scheme allows these factors to be considered and, thus, can be appropriate for sampling. Depending on the site, additional sampling using a grid system may be needed to further define the areas of contamination.

### Facility Description

The example facility operated as a secondary lead smelter from World War II until 1984. Principal operations at the smelter involved recovery of lead from scrap batteries. Air emissions were not controlled until 1968, resulting in gross contamination of local soils by lead particulates.

Land use around the smelter is primarily residential mixed with commercial/industrial. A major housing development is located to the northeast and a 400-acre complex of single family homes is located to the northwest. Elevated blood lead levels have been documented in children living in the area.



## Program Design/Data Collection

Initial soil sampling was conducted at the lead smelter and in the surrounding area to document suspected contamination. Sample locations were selected based on suspected areas of deposition of airborne lead and in areas where waste dumping was known to have occurred. High lead concentrations were documented in samples collected from these sources. Because data obtained in the exploratory sampling program (grab sampling) were not adequate to delineate the areal extent of contamination, a stratified random sampling scheme was developed.

Based on wind rose data and the behavior of airborne particulate matter, a sampling area was selected encompassing a 2-mile radius from the smelter. Specific sampling sites were selected using a stratified random sampling scheme. The study area was divided into sectors each 22.5 degrees wide and aligned so that prevailing winds bisected the sectors. Each sector was further divided into approximately one-tenth mile sections. A random number generator was used to select first the direction and then the section. Random numbers generated were subject to the following restrictions: two-thirds of the sites selected had to fall in the major downwind direction; both residential and non-residential sites had to exist in the sector; sampling sections were eligible for repeat selection only if they were geographically within 1/2 mile of the smelter or if the section contained both residential and non-residential sites. Sites that were biased towards lead contamination from other than the lead smelter were not sampled (e.g., gas stations and next to roads). A total of 20 soil sampling locations were selected, 10 at residences and 10 at non-residential sites such as schools, parks, playgrounds and daycare centers.

Sample cores were collected using a 3/4-inch inner diameter stainless steel corer. Total sample depth was 3 inches. A minimum of four and maximum of six samples were collected at each sampling location within a 2 ft radius. Cores were divided into 1 inch increments and the corresponding increments were composited from each depth to make up one sample. This approach provided data on lead stratification in the top 3 inches of soil. All samples were analyzed for total lead.

The results of the stratified random sampling indicated several acres with over 2,000 ppm lead in the soil. To further define the extent of these areas, a grid sampling plan was designed. Seven hundred and fifty foot increments were used. The grid was oriented along the axis of the release. Both residential and non-residential areas were sampled. At each grid point, four 3-inch cores were collected 30 m from the grid point in each major compass direction. The cores were composited by depth as discussed above.

#### Program Results/Data Analysis

Analytical results from the soil sampling program indicated significant lead contamination within the study area. Maximum concentrations observed were 2,000 ppm lead with a background level of 300 ppm. Kriegering of the data from the grid sampling plan was used to develop a contour map as shown in Figure 15-2. Lead concentrations were highest northwest and southwest of the smelter.

#### Case Discussion

Because of the large area potentially affected by lead emissions, development of a sequential sampling plan was necessary to determine the maximum soil lead concentrations surrounding the smelter and the areas having elevated concentrations. A grab sampling scheme was first used to confirm that soil contamination existed. A stratified random sampling scheme was developed to provide representative data throughout the study area. This type of sampling allowed consideration of prevailing wind directions and the need to sample both residential and non-residential areas. To further define areas of contamination, a grid sampling plan was developed. From these data, lead isoconcentrations maps were prepared delineating areas with elevated concentrations.

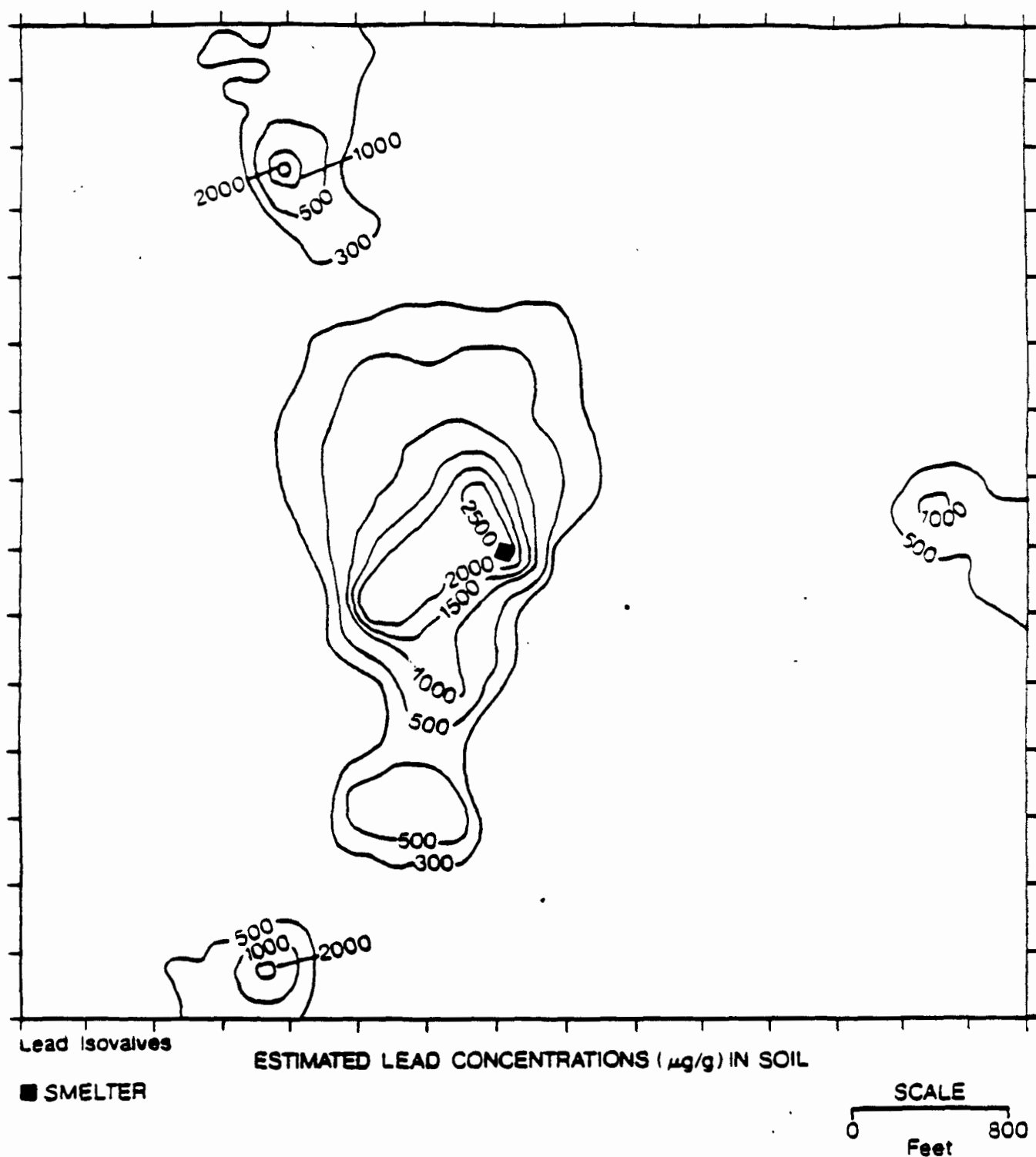


Figure 15-2. Isoconcentration Map of the Lead Concentrations in ppm Around the Smelter

## **CASE STUDY 4: SAMPLING OF LEACHATE FROM A DRUM DISPOSAL AREA WHEN EXCAVATION AND SAMPLING OF DRUMS IS NOT PRACTICAL**

### **Points Illustrated**

- It is not always possible to perform waste characterization prior to establishing the RFI monitoring scheme because the waste may not be directly accessible, as in the case of buried drums.
- When direct waste characterization is not practical, release monitoring should be performed for the constituents listed in Appendix B of Volume I of the RFI Guidance.

### **Introduction**

Insufficient waste characterization data existed for a former drum disposal facility that was suspected of releasing contaminants into the subsurface environment. Leachate within the disposal pit was sampled and analyzed for all constituents listed in Appendix B of Volume I of the RFI Guidance. The resulting information was used to determine the major waste constituents to be monitored during the RFI.

### **Facility Description**

The unit of concern was a pit containing an estimated 15,000 drums. Due to poor recordkeeping by the facility operator, adequate information regarding the contents of the drums was not available. It was also not known if the drums were leaking and releasing contaminants to the environment. Because insufficient data existed regarding the drum contents, it was not known what constituents should be monitored in nearby ground and surface waters. Due to the risk to workers and the potential for causing a multi-media environmental release, excavation and sampling of the drums to determine their contents was not considered practical. Instead, it was decided that leachate around the perimeter of the drum disposal pit would be sampled to identify constituents which may be of concern.

### Program Design/Data Collection

To determine the physical extent of the buried drums, a geophysical survey was conducted using a magnetometer. Borings were located at positions having lower magnetometer readings than surrounding areas in order to minimize the potential for drilling into drums.

Soil borings were drilled around the perimeter of the drum disposal pit, as defined by the magnetometer survey. Drilling was accomplished using a hydraulic rotary drill rig with a continuous cavity pump. Water was used as the drilling fluid. To prevent surface runoff from entering the borehole and to control gaseous releases from the borehole, primary and secondary surface collars were installed. These consisted of 5-foot sections of 4-inch steel pipe set in concrete. A device to control liquid and gaseous releases from the borehole was threaded onto the collars to form a closed system (Figure 15-3).

Drilling was performed using a wireline operated tri-cone roller bit with a diamond tipped casing advancer (Figure 15-4). Water was pumped down inside the casing and out the drill bit, returning up the borehole or entering the formation. The use of water to aid in drilling also helped reduce the escape of gases from the borehole. Air monitoring showed no releases. Split-spoon samples were collected at 5-foot intervals during the drilling and a leachate monitoring well was installed at each boring location.

The soil and leachate samples were analyzed for the compounds contained in Appendix B of Volume I of the RFI Guidance.

### Program Results/Data Analysis

The leachate samples were found to contain high levels of volatile organic compounds including 2-butanone, 4-methyl-2-pentanone, and toluene. Concentrations were higher on the downgradient side of the pit.

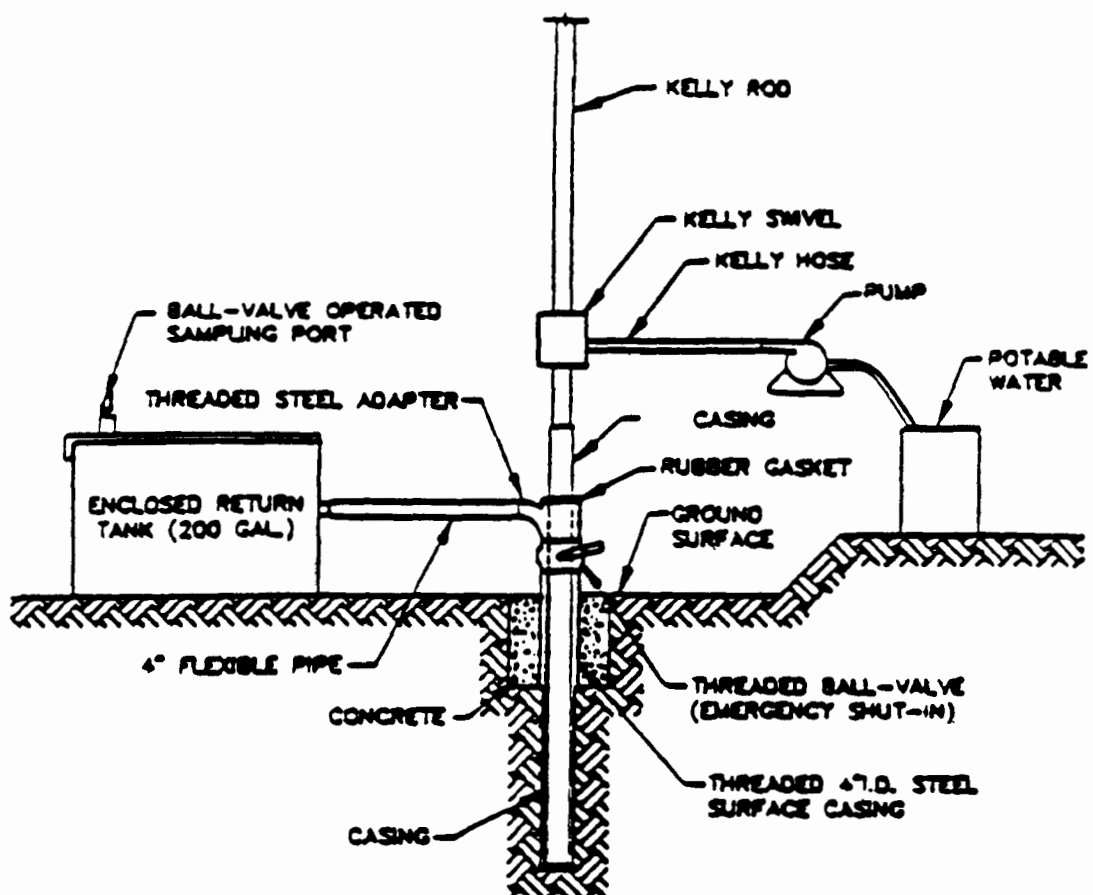


Figure 15-3. Schematic Diagram of Gas Control System Utilized at Pit

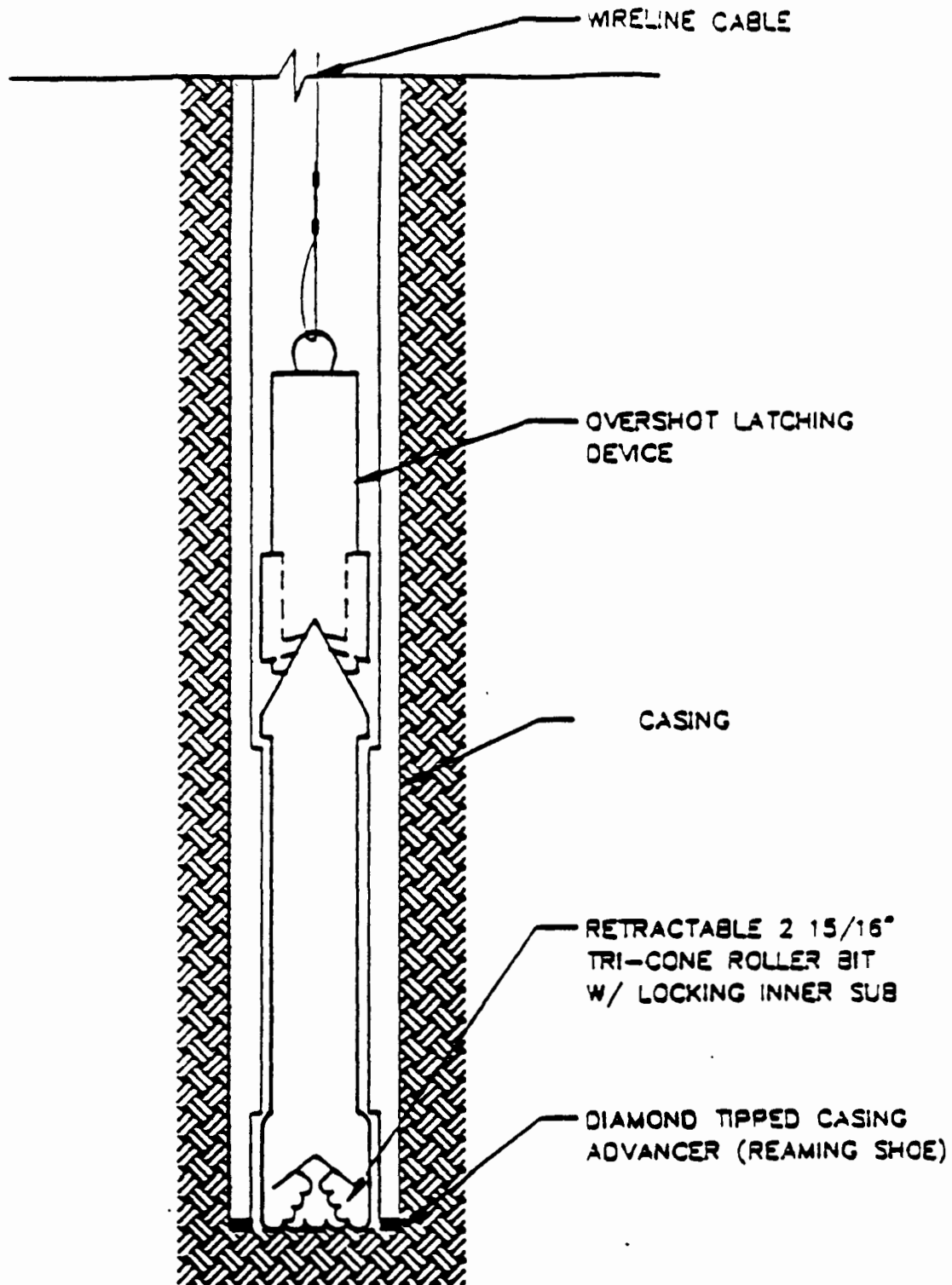


Figure 15-4. Schematic Drawing of Wireline Drill Bit and Reaming Shoe

### Case Discussion

Leachate sampling can be useful in determining whether buried drums are leaking and to identify materials that are being released. This methodology can be safer than excavation and sampling of individual drums. It can also identify the more soil-mobile constituents of the leachate.

The data gathered in this case study were used in designing a monitoring program, and the contaminants found were used as indicator compounds to link downgradient ground-water contamination to this waste disposal unit.



## **CASE STUDY 5: USE OF QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) AND DATA VALIDATION PROCEDURES**

### **Points Illustrated**

- A comprehensive field and laboratory QA/QC program is necessary for assessing the quality of data collected during an RFI.
- Timely validation of laboratory data can uncover problems correctable by reanalysis or by resampling, thus preventing data gaps.

### **Introduction**

A company in the mining and smelting industry sampled domestic wells and surface soils in the vicinity of a tailings pile to monitor possible leaching of metals into the aquifer and possible soil contamination due to wind-blown dust. Because the data would be used to assess corrective measures alternatives and to conduct a health and environmental assessment, the company chose to conduct both its sampling and analysis efforts under a formal QA/QC Project Plan and to subject all laboratory data to rigorous data validation procedures.

### **Facility Description**

At this facility, a tailings pond had received smelter waste for many years. Local water supply wells were potentially at risk due to percolation of water through the pile and possible leaching of heavy metals. Local surface soils in nearby residential areas (e.g., yards, public playgrounds) were also subject to contamination from wind-blown dust originating from the pile during dry windy weather.

### **Sampling Program**

Before sampling began, a set of documents were drafted following U.S. EPA guidelines (U.S. EPA 1978, 1980a, 1980b, 1981, 1982, 1985a, 1985b) that specified in detail sampling sites and parameters to be measured, field and laboratory

procedures, analytical laboratory protocols, and all field and laboratory QC checks including frequencies, and corrective actions. The important elements of each document are described below.

#### **Standard Operating Procedures (SOPs)--**

This document contained step-by-step procedures for the following items:

- Calibration, operation, and maintenance of all instruments used in the field and laboratory.
- Equipment decontamination.
- Ground water and soil sampling, including compositing.
- Use of field notebooks and document control.
- Sample packaging, shipping, and chain-of-custody.

#### **Field Operations Plan (FOP)--**

This document included the following:

- Rationale for choice of sampling locations, sampling frequency, and analytes to be measured
- List of sampling equipment and SOPs to be used for each sampling event.
- List of field QC checks to be used and their frequency for each sampling event.
- Health and safety issues and protective measures for field personnel.
- Sampling schedule.

## **Laboratory Analytical Protocol (LAP)--**

**This document included the following:**

- **Sample size, preservation, and analysis protocol for each analyte.**
- **List of laboratory QC checks, QC statistics to be calculated and their control limits, and corrective actions for QC checks outside control limits.**
- **Detailed list of deliverable documents and their formats.**
- **Procedures for sample custody, independent audits, and general laboratory practices.**

## **QA/QC Project Plan (QAPP)--**

**This document gathered into one place the overall data quality objectives for the sampling and detailed QC procedures needed to attain those objectives. Included were:**

- **Quality assurance objectives in terms of precision, accuracy, completeness, comparability, and representativeness.**
- **Procedures for the screening of existing data.**
- **Data management, reduction, validation, and reporting.**
- **Overview of both field and laboratory QC checks and their frequencies, control limits, and corrective actions.**
- **Data assessment procedures.**

## **Results**

**Five surface soil samples were taken in high traffic areas of two playgrounds and three residential yards. Five tap water samples were collected at two public**

drinking fountains at the playgrounds and at the three private residences. The analysis results, as received from the laboratory, are shown in Table 15-2. The data indicated that a soil hot spot existed for cadmium, that elevated lead occurred at all five soil stations, and that all of the domestic wells showed elevated levels of mercury.

The laboratory data package was subjected to a thorough data validation, as detailed in the QA Project Plan. The following information and QC results were checked by examination of original documents or photocopies of the documents.

#### **Sampling, Sample Shipping, Chain-of-Custody--**

Copies of field and field laboratory notebook pages were examined to insure that all SOPs were correctly followed, that there were no notations of anomalous circumstances (such as sample spillage) that may have affected analysis results, and that the samples were correctly preserved, packaged, and shipped. Copies of all chain-of-custody forms, bills-of-lading, and sample analysis request forms were examined to insure that chain-of-custody was not broken and that samples arrived intact at the laboratory.

#### **Laboratory Raw Data--**

The QAPP had specified that one of the deliverables from the laboratory was copies of all instrument readouts and laboratory notebook pages. The digestion raw data were checked to insure that no holding time violations had occurred. This is important for mercury because the holding time is only 28 days for aqueous samples.

All raw calibration data were recalculated and tested against instrument-calculated sample results. Recoveries of calibration verification standards and continuing calibration standards were checked to insure that all instruments were correctly calibrated, were not drifting out of calibration, and were correctly calculating raw analysis results.

**TABLE 15-2**

**RESULTS OF ORIGINAL SURFACE SOIL AND TAP WATER ANALYSES**

Sample <sup>a</sup>	Cd	Cu	Pb	Hg	Zn
SOIL-1	14	5200	800	NA <sup>b</sup>	1200
SOIL-2	7	2400	400	NA	190
SOIL-3	< 20 <sup>c</sup>	720	4530	NA	70
SOIL-4	19	680	350	NA	350
SOIL-5	1200	1080	460	NA	420
WATER-1	< 50	NA	< 30	1.5	NA
WATER-2	< 50	NA	< 30	1.3	NA
WATER 3	< 50	NA	< 30	1.0	NA
WATER-4	< 50	NA	< 30	1.4	NA
WATER-5	< 50	NA	< 30	1.2	NA

<sup>a</sup> Soils in units of mg/kg, water in µg/L.

<sup>b</sup> Not analyzed.

<sup>c</sup> Undetected at detection limit shown.

Final analysis results were recalculated from raw data using dilution and digestion factors, as summarized in the lab notebooks, and compared to the data summary sheets. No transcription errors were found. However, the cadmium result for SOIL-5 contained a calculation error, and the correct final result was 12 mg/kg instead of the 1200 mg/kg reported.

#### Laboratory QC Checks--

The QAPP had specified that the laboratory had to analyze pre-digestion duplicates and spikes, U.S. EPA laboratory control samples, and reagent blanks. The laboratory QC results are summarized in Table 15-3 and indicated accuracy and precision well within U.S. EPA guidelines. The mercury preparation blank also indicated that the tap water results were not due to laboratory digestion reagents or procedures.

#### Field QC Checks--

As specified in the QAPP and FOP, the following field QC samples were included with each of the soils and tap water samplings: bottle blank, field blank, standard reference material (SRM), triplicate, and an interlaboratory split to a "reference" lab. The results are summarized in Table 15-4.

Although no U.S. EPA control limits or corrective actions exist for field-generated QC checks, the results of their analysis can aid in the overall assessment of data quality. The triplicate, SRM, and interlaboratory split analyses indicated good overall analysis and sampling precision and accuracy. The field blanks indicated the possibility of mercury contamination from one of the four possible sources: the pre-cleaned bottles, the preservation reagent, the distilled water used in the field, or an external contamination source such as dust. The high positive mercury result in the water bottle blank eliminated all of these sources except the first because the bottle blanks remained sealed throughout the sampling effort.

The laboratory was immediately called and, upon personal inspection, the laboratory manager discussed the remnants of a broken thermometer bulb in the plastic tub used to acid-soak the bottles. An unused bottle from the same lot and

**TABLE 15-3**  
**LABORATORY QC RESULTS**

Analyte	Duplicate RPD <sup>a</sup> (%)		Spike Recovery <sup>b</sup> (%)		LCS <sup>c</sup> (%)	Soil Preparation Blank <sup>d</sup>	Water Preparation Blank <sup>e</sup>
	SOIL-2	WATER-4	SOIL-2	WATER-4			
Cd	18	NC <sup>f</sup>	100	98	101	<50 <sup>g</sup>	<50
Cu	5	NA <sup>h</sup>	93	NA	97	<100	NA
Pb	14	NC	110	92	106	<200	<30
Hg	NA	NC	NA	103	NA	NA	<0.20
Zn	7	NA	85	NA	99	<150	NA

a RPD = relative percent difference = (difference/mean) x100. Control limits = ± 35% for solids and ± 20% for aqueous samples.

b Spike Recovery =  $\frac{(\text{spike} + \text{sample result}) - (\text{sample result})}{(\text{spike added})} \times 100$ . Control limit = 75-125%.

c LCS = laboratory control sample. Control limit - 90-110%.

d mg/kg.

e µg/l.

f NC = not calculated due to one or both concentrations below detection limit.

g Undetected at detection limit shown.

h NA = not analyzed.

**TABLE 15-4**  
**FIELD QC RESULTS**

Analyte	Triplicate CV <sup>a</sup> (%)		SRM Recovery <sup>b</sup> (%)		Interlab. RPD <sup>e</sup> (%)		Field Blanks <sup>f</sup>		Bottle Blanks <sup>g</sup>	
	SOIL-1	WATER-1	BCSS-1 <sup>c</sup>	U.S. EPA <sup>d</sup>	SOIL-1	WATER-1	SOIL-1	WATER-1	SOIL-1	WATER-1
Cd	22	NC <sup>h</sup>	83	105	-12	NC	<50 <sup>i</sup>	<50	<0.5	<0.5
Cu	3	NA <sup>j</sup>	94	NA	0	NA	<100	NA	<1	NA
Pb	7	NC	97	101	14	NC	<200	<200	<0.5	<0.5
Hg	NA	18	NA	103	NA	19	NA	1.1	NA	0.8
Zn	1	NA	110	NA	24	NA	<150	NA	<1	NA

<sup>a</sup> CV = coefficient of variation = (mean/standard deviation) X100.

<sup>b</sup> Recovery = (certified value/result) X100.

<sup>c</sup> National Research Council of Canada marine sediment.

<sup>d</sup> U.S. EPA Trace Metals I, Concentration #1.

<sup>e</sup> RPD = relative percent difference = [(analytical lab result - ref. lab. result)/mean] X100.

<sup>f</sup> Distilled water. Units = µg/L.

<sup>g</sup> Empty containers rinsed with digestion reagents at lab. Units = total µg.

<sup>h</sup> NC = not calculated due to at least one sample result below detection limits.

<sup>i</sup> Undetected at detection limit shown.

<sup>j</sup> NA = not analyzed.



still at the laboratory as well as two bottles washed in previous lots were analyzed. The bottles previously washed contained no detectable mercury, and the bottle from the same lot as used in the sampling effort contained 0.75  $\mu\text{g}$ . The water mercury data were rejected, and a second sampling effort using new bottles was conducted. All of the new samples contained no detectable mercury.

### Discussion

This case study demonstrates the need for the establishment of a formal QA/QC program that not only specifies field QC protocols but also incorporates thorough data package validation. In this instance, a potential hot spot was found to be due to a calculation error, and potential mercury contamination of domestic well water was found to be a result of using contaminated sample containers. In the latter case, timely QA/QC review allowed for a speedy resampling effort which could be done at this site. In situations where resampling is not possible, adequate QA is crucial.

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## CASE STUDY 6: PRESENTATION OF DATA COLLECTED DURING FACILITY INVESTIGATIONS

### Point Illustrated

- Techniques for presentation of data for facility investigations involving multimedia contamination.

### Introduction

Data acquisition and interpretation are integral parts of facility investigations. Depending on the size, complexity, and hazards posed at a particular site, significant quantities of meteorologic, hydrologic, and chemical data can be collected. To make the best use of these data, they should be presented in an easily understood and meaningful fashion. This case study focuses on widely used and easily implemented graphical techniques for data presentation.

### Site Description

The site is a former copper smelter that ceased operation in the early 1980s. During the operation of the smelter, large quantities of mine tailings were slurried to tailings ponds that remain today (Figure 15-5). The tailings contain high solid phase concentrations of inorganic contaminants such as copper, zinc, lead, cadmium, and arsenic. In the Smelter Hill area, flue dust and stack emission deposition have contaminated surficial soils. Numerous other units were operated at the complex including an experimental plant designed to leach copper using ammonia. The copper leach plant is shown in Figure 15-6. Three disposal ponds (I, II, and III) received wastes slurried from the plant.

As a result of smelting and waste disposal practices, multimedia contamination of ground water, surface water, and soils has occurred. Also, episodes of air contamination have been documented due to entrainment of tailings during windy periods.

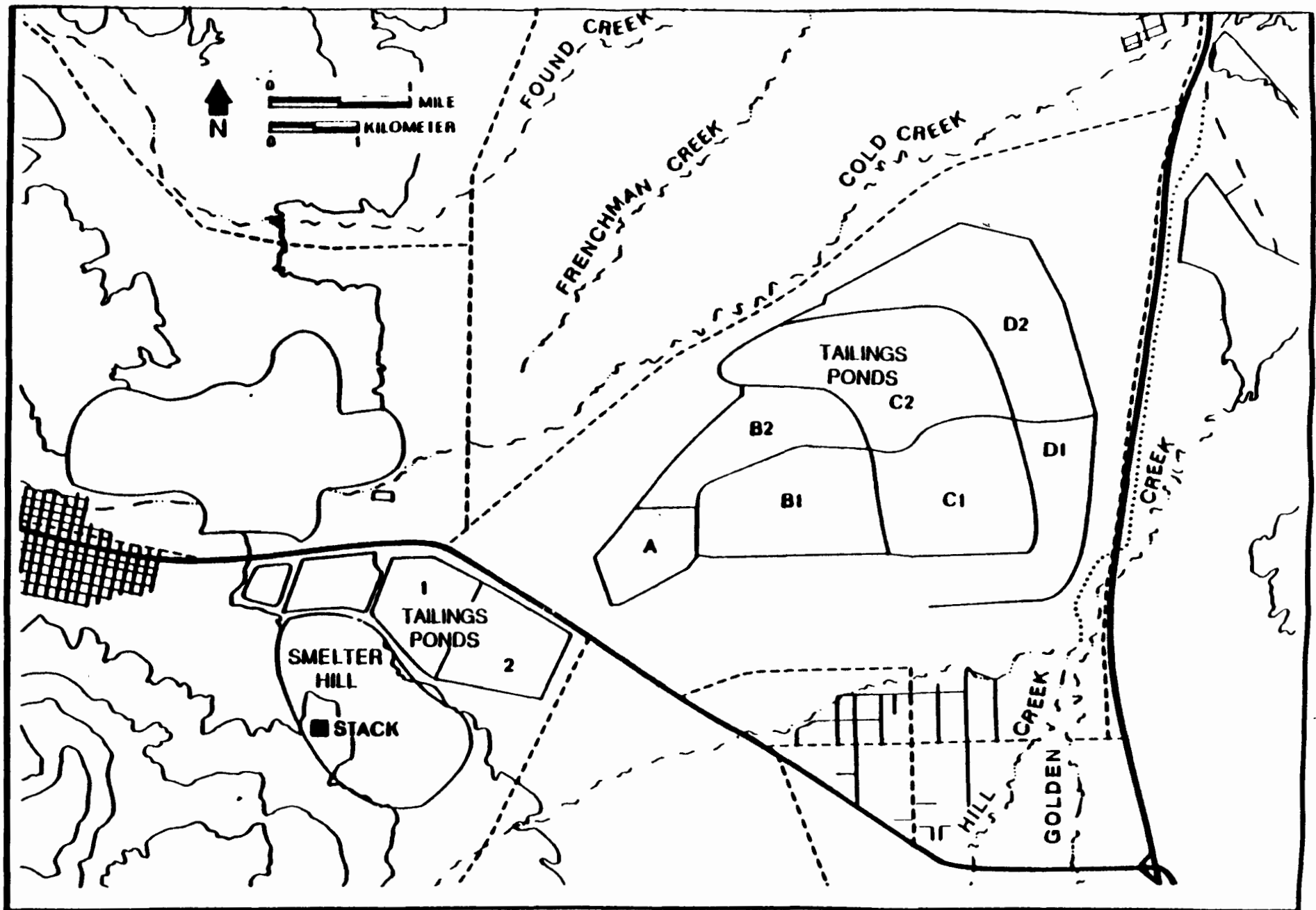


Figure 15-5. Map of the Smelter Site and Associated Tailings Ponds

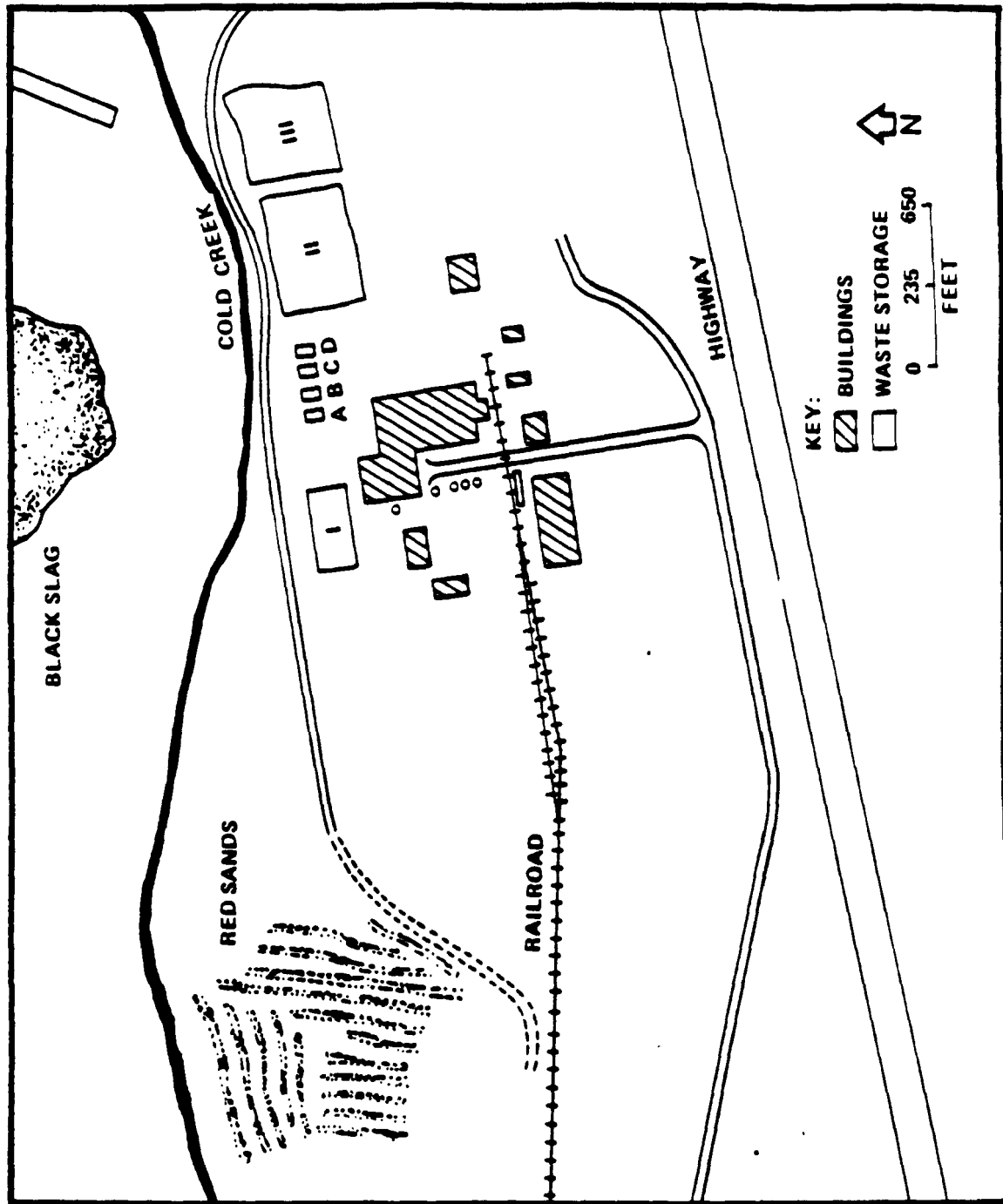


Figure 15-6. Locations of Copper Leach Plant and Waste Storage Ponds

## Field Sampling and Data Collection

Data collection activities at this site were comprehensive. Over 100,000 pieces of data were collected in the categories shown in Table 15-5.

## Data Presentation

This section illustrates a number of graphical techniques that can be used to present data from facility investigations. Graphical presentations are useful for the following general purposes:

- Site feature identification, source identification, and mapping;
- Hydrologic characterization; and
- Water quality characterization.

For large sites, aerial photography is often very useful for defining the locations and boundaries of waste deposits, and for establishing time variability of site characteristics. Figure 15-6, for example, was developed from aerial photographs at a 1:7800 scale. Types of information obtained by comparing this photograph to one taken 10 years earlier include:

- Pond III was originally constructed earlier than Ponds I and II, and was not lined. Ponds I and II were lined.
- The red sands (a slag deposit) shown in Figure 15-6 are present only north of the railroad tracks. Earlier photographs showed that the red sands extended to the highway, but were leveled and covered with alluvium during construction of the copper leach plant.

This type of photographic information is valuable for locating waste deposits, estimating quantities of wastes, and determining waste proximity to sensitive areas.

**TABLE 15-5**  
**SUMMARY OF DATA COLLECTED**

Category	Parameters
Ground Water	Water level elevations, potentiometric heads  Concentration of Al, Sb, As, Ba, Be, Bo, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, K, Se, Ag, Na, Sn, V, Zn, P, Cl, F, SO <sub>4</sub> , pH, O <sub>2</sub> , Ec, Eh, Alkalinity, TDS
Surface Water and Sediment	Flow rates, bed particle size distributions, suspended solids concentrations, dissolved concentrations of same inorganic parameters as ground water
Alluvium <sup>a</sup>	Moisture content, soil, pH, Ec, Sb, As, Cd, Cu, Fe, Pb, Mn, Se, Ag, Zn, particle-size distribution
Soil <sup>a</sup>	Cd, Cu, Fe, Pb, Mn, Ni, Zn, Sb, As, Cd, Cr, Hg, Se, Ag, Zn, particle-size distribution, Eh, S, TOC
Tailings <sup>a</sup>	Sb, Ar, Be, Cd, Cu, Fe, Pb, Mn, Ag, Se, Zn, particle size, moisture, pH, Ec, sulfur, carbonate
Slag and Flue Dust <sup>a</sup>	Sb, As, Cd, Cu, Fe, Pb, Mn, Se, Ag, Zn, SO <sub>4</sub> , Ec, pH, alkalinity
Miscellaneous	Meteorology, aerial photographs and other photographic documentation, well log data, surface topography, volumetric surveys of waste piles

<sup>a</sup> Element data are solid phase.

For sites with complex hydrologic interaction, it is often helpful to graphically represent the flow system. Figure 15-7 illustrates the surface water system at the site. The diagram is useful because it shows the hydrologic interconnections of the drainage system.

For the ground-water system, flow direction and velocities provide information needed for contaminant transport predictions. This information is generated by plotting water levels on a site map, and then drawing contours through points of equal elevation. An example is shown in Figure 15-8. Because the contours form a relatively simple pattern in this case, they were drawn by hand. However, computer-based contour packages exist that could be used to plot more complicated contour patterns.

Inferred flow directions are also shown in Figure 15-8. From a knowledge of the hydraulic gradient, hydraulic conductivity and effective porosity, the average linear velocity can be calculated, as shown in the upper left hand corner of the figure. A velocity of 79 m/yr is calculated, for example, which means that approximately 126 years would be required for conservative solutes to move across the site (approximately 10,000 meters).

Water quality data can be presented as shown in Figure 15-9. This figure shows the spatial distribution of calcium, sulfate, and TDS at key surface water stations. This data presentation method provides a broad areal view of these parameters.

Time series plots are useful for showing temporal variations in water quality. For example, time trends of  $\text{SO}_4$  at three ground-water monitoring locations are shown in Figure 15-10. Well 19 is slightly downgradient from the source, and the high  $\text{SO}_4$  levels reflect that the well is receiving solutes generated within the source. Wells 26 and 24 are further upgradient, and reflect better water quality conditions. The plot indicates that variability between stations generally is more significant than time variability at a given location. One exception is at well 24 where a temporary increase in sulfate levels was noted in 1975-76.



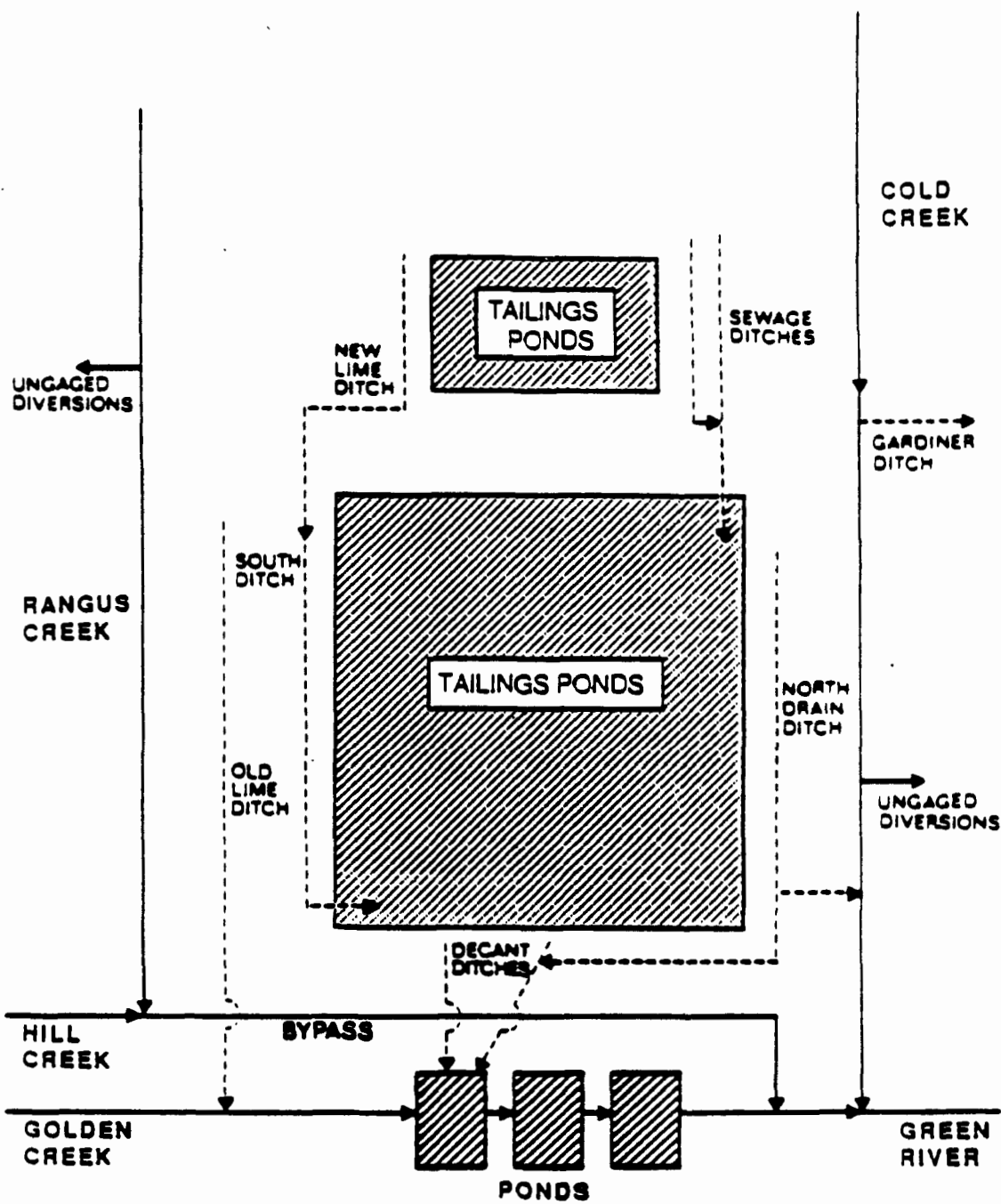
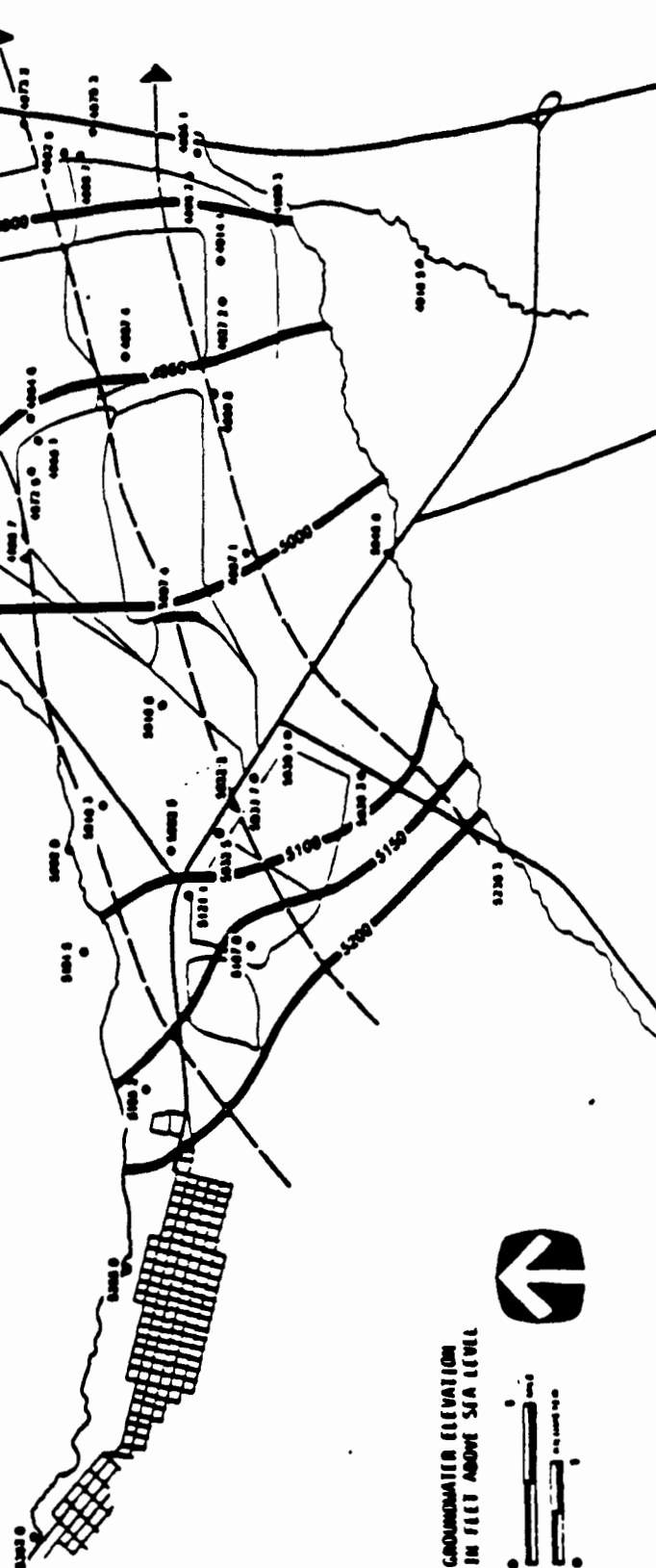


Figure 15-7. Schematic of Surface Water System

$H$  = water level  
 $x$  = distance inflow direction  
 $K_x$  = hydraulic conductivity

**Example:**

 $\Delta M = 300'$  for  $\Delta x = 5 \text{ mi}$ 
$$K_R = 10^{-2} \text{ cm/sec} = 30 \text{ ft/day}$$
$$u_A = 5.75 \text{ m/s}$$
$$s_A = \frac{p_A}{5.15} = \frac{0.08}{5.15} = 0.0155$$


**Figure 15-8. Ground-Water Flowlines Based on Measured Water Levels**

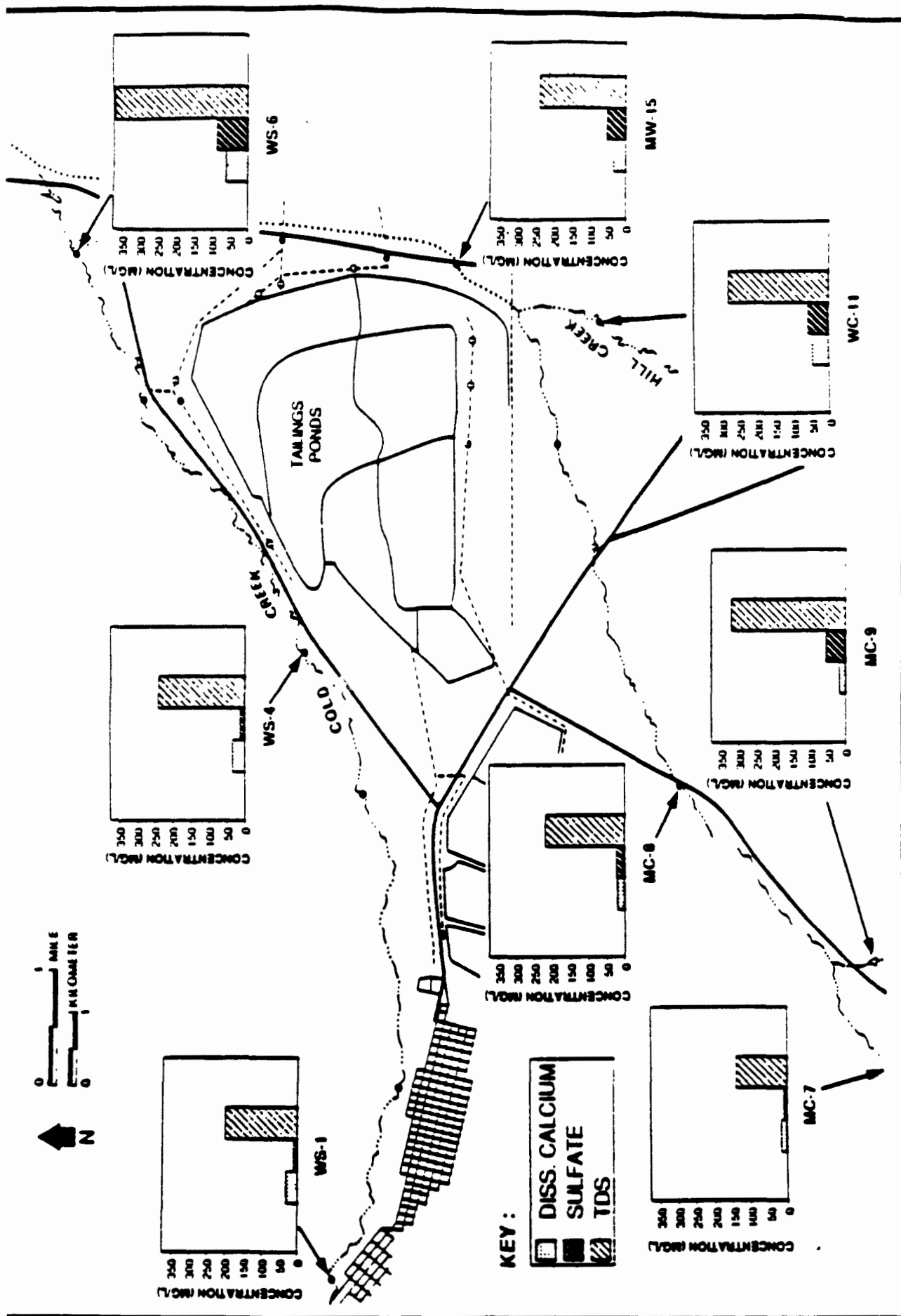


Figure 15-9. Selected Surface Water Quality Parameters at Key Stations

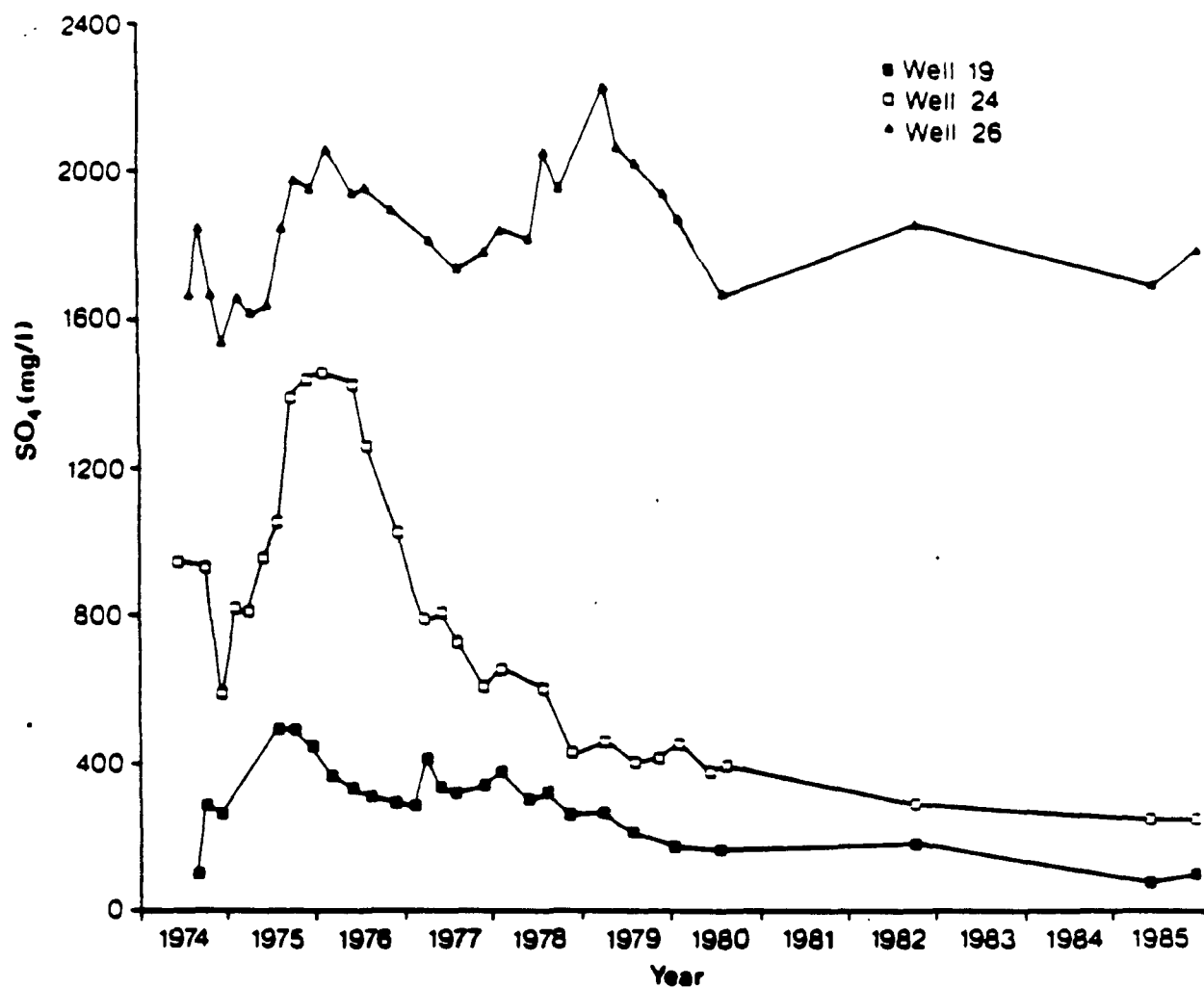


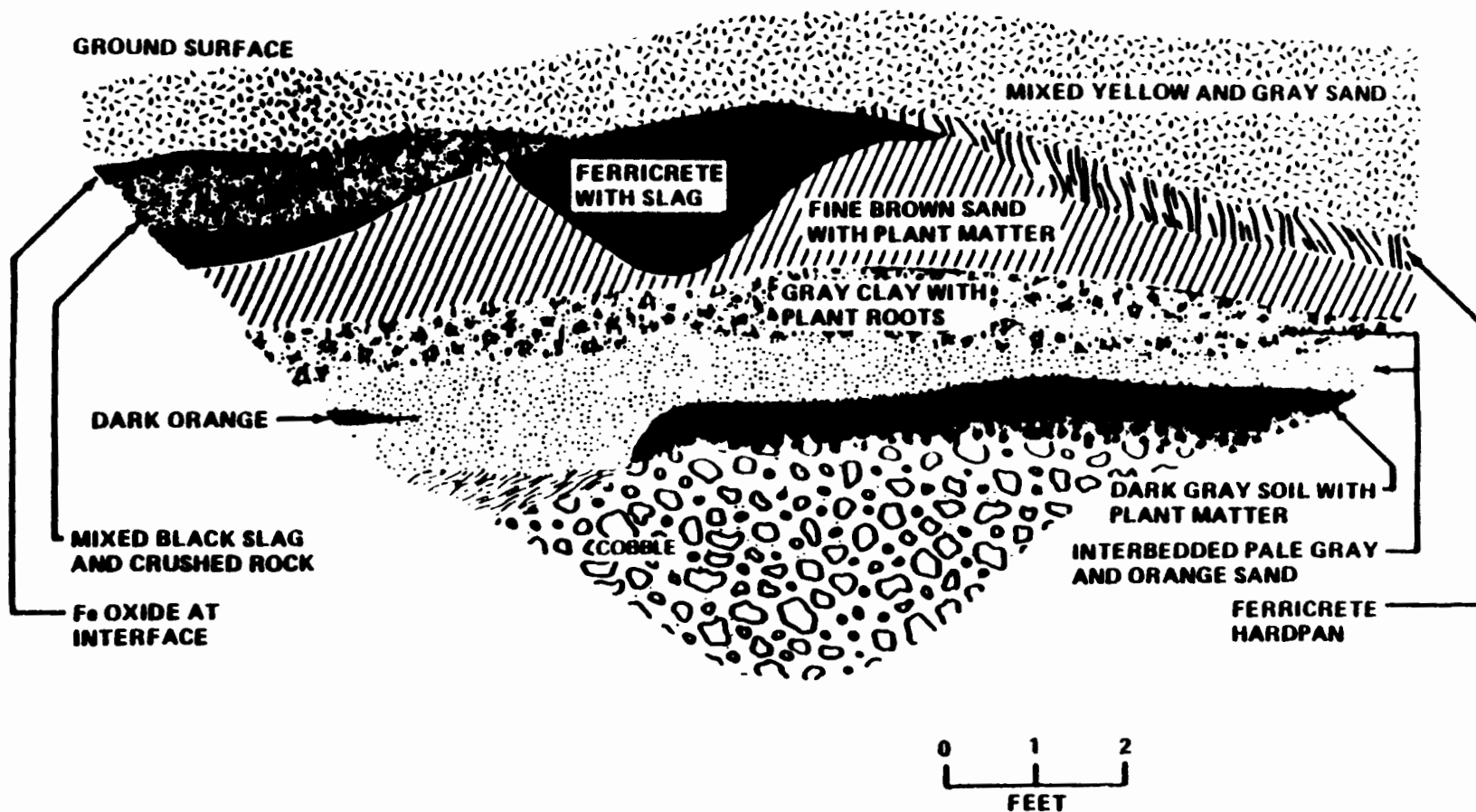
Figure 15-10. Changes in Sulfate Over Time at Selected Wells Located Within the Site

To identify leachate and soil interactions beneath a waste site, trenches may be dug. The trench walls are then logged and photographed. Detailed sampling may be done at closely spaced intervals to confirm that reactions such as precipitation have occurred. Figure 15-11 shows a cross-section of a tailings deposit that was developed based on a trench excavated through the tailings into the underlying alluvium. The plot shows the demarcation between wastes and natural alluvium.

Figure 15-12 shows the details of the chemical composition of one borehole through the tailings and into the underlying alluvium. The chemical composition is shown to vary significantly with depth. These types of plots contain a wealth of chemical information that can help to explain the geochemical processes operative in the tailings. Figure 15-12 also shows the marked contrast between the composition of the tailings (in the top 16 feet) and the underlying alluvium.

### Summary

The graphical presentations illustrated in this case study are a few of the many techniques available. With the proliferation of graphical packages available on microcomputers, scientists and engineers have a wide range of tools available for data presentation. Some of these tools are summarized in Table 15-6.



Notes: A BLUE-GREEN PRECIPITATE FORMED ON THE EXPOSED SURFACE OF TOP 6 INCHES OF ALLUVIUM.  
THIS PRECIPITATE WAS NOT THERE WHEN TRENCH FIRST DUG.

Figure 15-11. Field Sketch of Tailings Trench T-3

**BORE HOLE 88A**  
**C1 Pond**

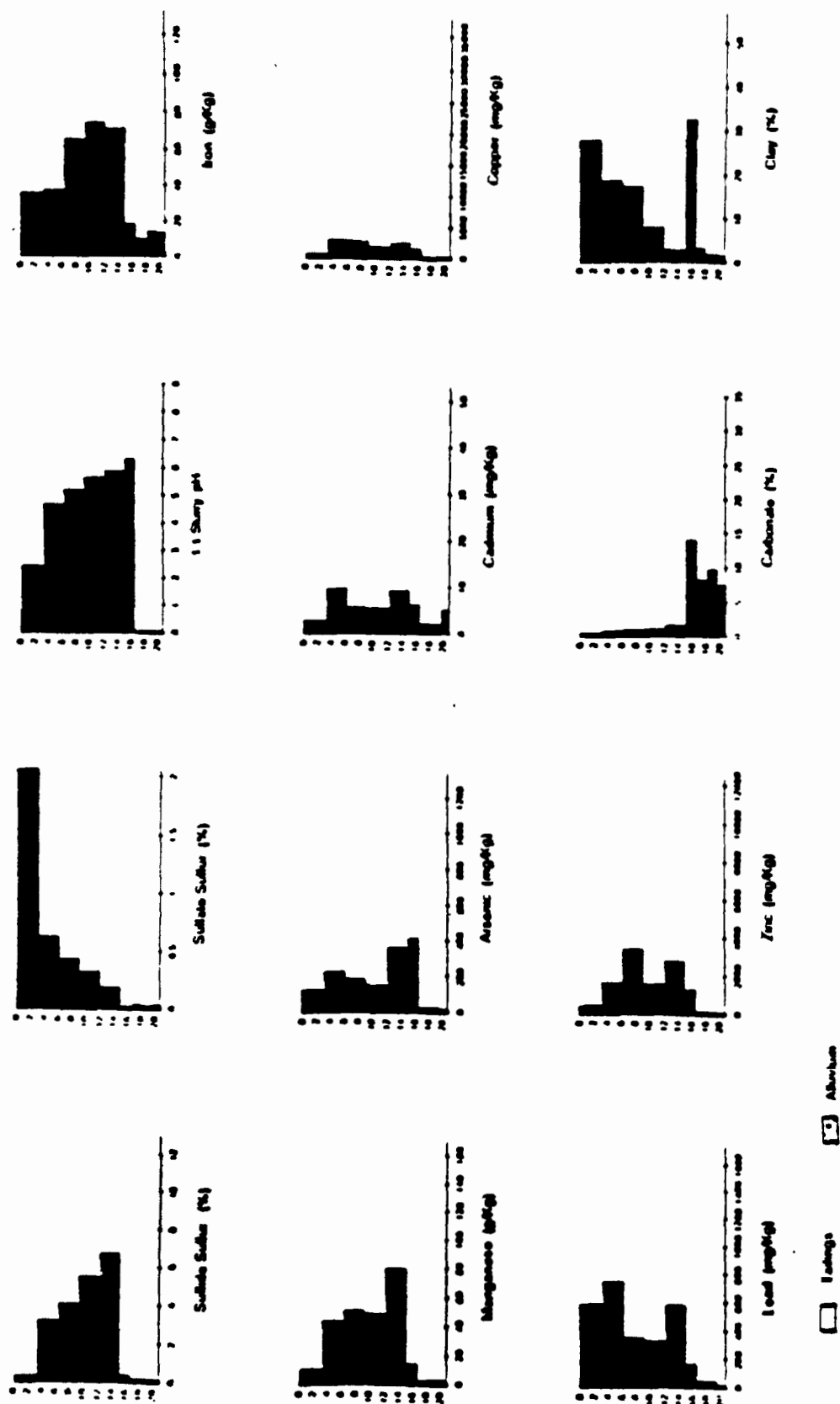


TABLE 15-6

**TYPICAL METHODS FOR GRAPHICALLY PRESENTING DATA COLLECTED  
DURING FACILITY INVESTIGATIONS**

Data	Graphical Presentation Methods
<b>METEOROLOGIC DATA</b>	
Wind speed and direction  Air temperature Precipitation Evaporation	<ul style="list-style-type: none"> <li>● Wind rose showing speed, direction and percent of observations for each 10° increment</li> <li>● Bar chart, by month</li> <li>● Bar chart, by month</li> <li>● Bar chart, by month</li> </ul>
<b>SURFACE WATER DATA</b>	
Flow rates  Water quality	<ul style="list-style-type: none"> <li>● Hydrographs; distance profiles, cumulative frequency distributions, flood frequency plots</li> <li>● Hydrologic network depiction and water budgets</li> <li>● Trilinear diagram</li> <li>● Stiff diagrams</li> <li>● Contour showing vertical concentration or temperature variability in two deep water bodies</li> <li>● Time history plots showing daily/annual variability</li> <li>● Bar charts of major cations/anions or contaminants at multiple locations shown on a single map</li> </ul>
<b>GEOHYDROLOGIC DATA</b>	
	<ul style="list-style-type: none"> <li>● Geologic map of site and vicinity</li> <li>● Stratigraphic cross-sections of site in direction of and perpendicular to ground water flow</li> <li>● Well logs</li> <li>● Cross-sections near waste deposits</li> <li>● Solid phase chemical analyses by depth at borings near waste deposits and into alluvium</li> </ul>
<b>GROUND-WATER DATA</b>	
	<ul style="list-style-type: none"> <li>● Water level contours</li> <li>● Flow directions and velocities</li> <li>● Time history of water table at important locations</li> <li>● Stiff diagrams</li> <li>● Trilinear diagrams</li> <li>● Contaminant plumes, showing isopleths</li> </ul>
<b>MISCELLANEOUS</b>	
	<ul style="list-style-type: none"> <li>● Figures with important site features, including waste sources, storage ponds, disposal areas, buildings, sampling locations, well locations</li> <li>● Operational aspects for special sampling equipment (e.g., lysimeters)</li> </ul>



## **CASE STUDY 7: CORRELATION OF CONTAMINANT RELEASES WITH A SPECIFIC WASTE MANAGEMENT UNIT USING GROUND-WATER DATA**

### **Point Illustrated**

- Development of an effective ground-water monitoring program can tie releases of contaminants to specific waste management units.

### **Introduction**

Documentation of a release from a specific waste management unit may require the development of a comprehensive ground-water monitoring program coupled with an extensive hydrogeologic investigation. Determination of ground-water flow direction and horizontal and vertical gradients are necessary to assess the direction of potential contaminant migration. Historical data on wastes disposed in specific units can provide information on contaminants likely to be detected downgradient.

### **Facility Description**

Chemicals were manufactured at a 1000-acre facility for over 30 years. The facility produced plastics including cellulose nitrate, polyvinyl acetate, polyvinyl chloride and polystyrenes, and other chemicals such as phenols and formaldehyde. Wastes produced in the manufacturing processes were disposed on site in an unlined liquid waste impoundment and in two solid waste disposal areas. Readily combustible materials were incinerated in four burning pits. Ground-water contamination has been documented at the site. Figure 15-13 shows the facility plan and locations of ground-water monitoring wells.

The site is located in a glacial valley and is adjacent to a major river. A minor tributary runs through the southwestern portion of the facility and drains into the river. Approximately 200 dwellings are located downgradient of the site.

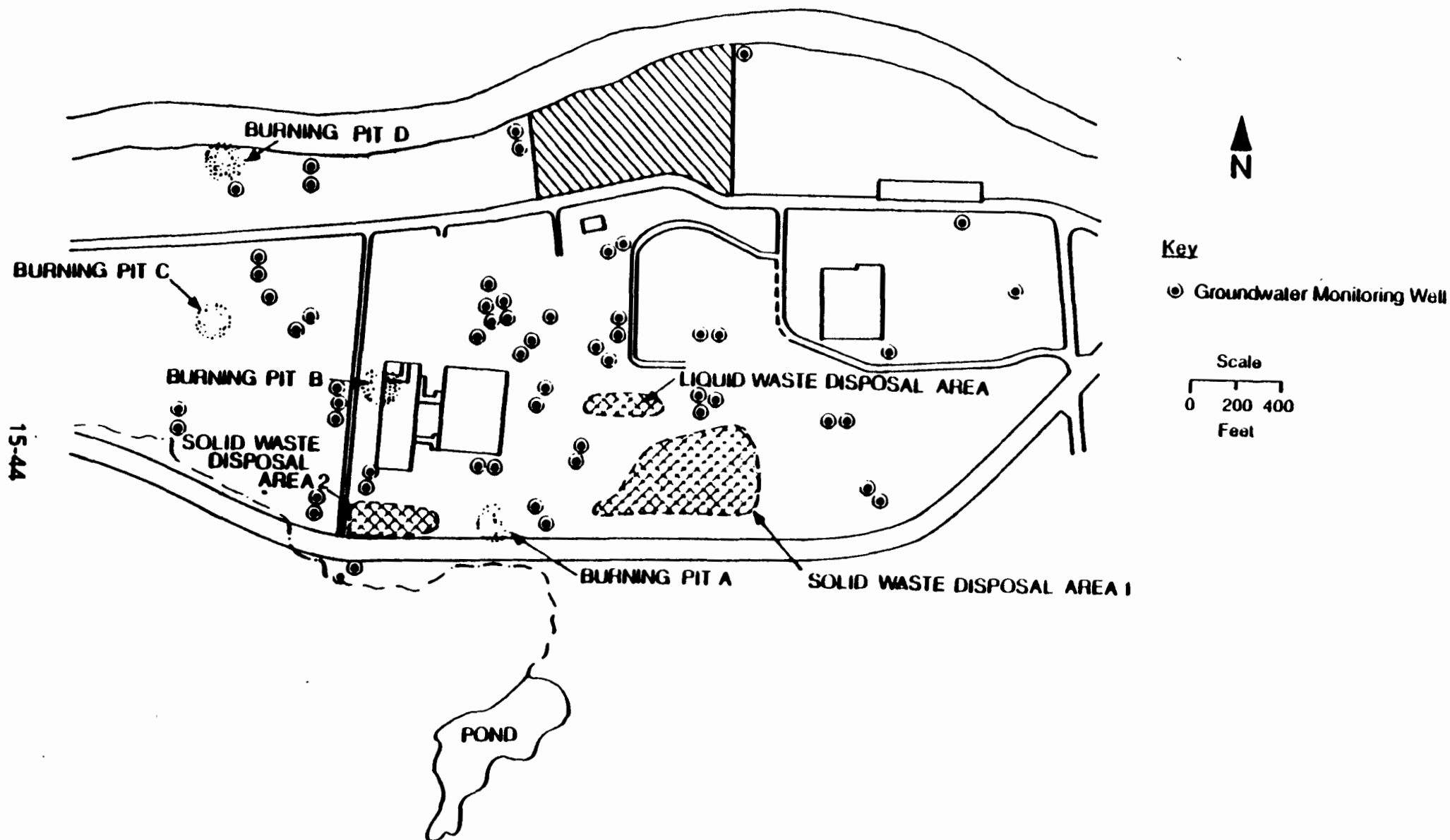


Figure 15-13. Location of Ground-Water Monitoring Wells

## Data Collection

Initial studies to assess the extent of ground-water contamination began in 1981. Studies focused on ground water in the vicinity of various waste disposal units. A limited number of monitoring wells were installed in 1983. These wells provided general data on the direction of ground-water flow and chemical constituents that had entered the ground water. In 1984, a two-phased approach was developed to define the areal and vertical extent of contamination and to identify contaminant releases from specific waste management units. The first phase involved the characterization of facility geologic and hydrogeologic conditions using historical data, determination of the chemical nature of contaminants in the ground water using existing monitoring wells, and development of a contaminant contour map delineating the horizontal boundaries of contamination. Based on this data, 33 soil borings were drilled in Phase 2. The goals of the second phase were to: 1) detail subsurface geologic characteristics, vertical and horizontal water flow patterns, contaminant migration, and site-specific chemical contaminants; and 2) install wells that would be used to monitor contaminants being released from all units of concern at the facility.

Continuous split spoon samples were collected in each boring and headspace analyses for volatile organic compounds (VOC) were conducted on each sample. Chemical constituents were identified using a field gas chromatograph. Confirmational analysis by GC/MS were conducted on selected samples. Geotechnical analyses were also conducted on the split spoon samples.

Chemical and hydrogeologic data (direction of flow, gradients) obtained from the borings were used to select appropriate ground-water monitoring well locations and screen depths. Fifty-two (52) nested monitoring wells were installed at 25 locations upgradient and downgradient of each waste management unit, and near the river and its tributary. Screen depths were determined by the depth of maximum VOC contamination observed in the borings and the permeability of soil layers.

## Data Analysis

Ground-water contamination data from new wells coupled with historical waste disposal data allowed releases from three specific waste management areas to be defined. Sample analyses showed organic solvents in nearly all locations. However, more unusual constituents associated with specific manufacturing processes were detected in some samples, allowing them to be correlated with releases from specific waste management units. The two situations below illustrate how these correlations were accomplished:

- 1) PCBs detected in some samples were correlated with Solid Waste Disposal Area #1. This area received construction debris, resins, plastics, metals, drums, and PCB containing transformers. Records indicated that this unit was the only location where transformers were disposed onsite. PCBs could not be associated with any of the other waste management units.
- 2) The solvent dimethylformamide (DMF) detected in some samples was correlated with Burning Pit B. It was discovered that the building that housed this unit had been used to tint windshields and that DMF is a component of the dye used in this process. DMF could not be tied to any of the other waste management units. A leachfield in which waste dyes had been disposed was discovered under the building and the contamination was traced back to that source.

## Case Discussion

An ~~extensive~~ hydrogeologic investigation of the facility was completed and, in conjunction ~~with~~ historical data, was used to develop a comprehensive ground-water monitoring program. Placement of the monitoring wells and screens was essential in providing data that unequivocally linked contaminant releases to specific waste management units and manufacturing processes.

## CASE STUDY 8: WASTE SOURCE CHARACTERIZATION FROM TOPOGRAPHIC INFORMATION

### Points Illustrated

- Mapping of changes in site topography can support the selection of locations for test borings and monitoring wells.
- This technique is especially useful at sites where large volumes of waste have been disposed of over several years.

### Introduction

Topographic surveys conducted prior to and at different times during the operation of a waste management facility can be used to help characterize the vertical and horizontal extent of waste disposal areas. Because the resolution of this technique is limited, it is most useful when large volumes of waste are involved.

### Facility Description

This facility is the same as discussed in Case Study 7 above.

### Topographic Survey

In 1984, a topographic survey measuring elevations in feet relative to mean sea level was conducted for the areas shown in Figure 15-14. These elevations were plotted on a map of appropriate horizontal scale and contoured in 2-foot intervals. This topography was transferred to an existing site plan (horizontal scale 1" to 200'). Topographic maps from 1935 (showing the natural topography before waste deposition) to 1960 (showing the topography in the earlier stages of the facility operation) were compared to the 1984 map. By examining the changes in elevations which occurred over time, contours were developed showing the estimated changes in vertical and horizontal units of the liquid waste and solid waste disposal areas.

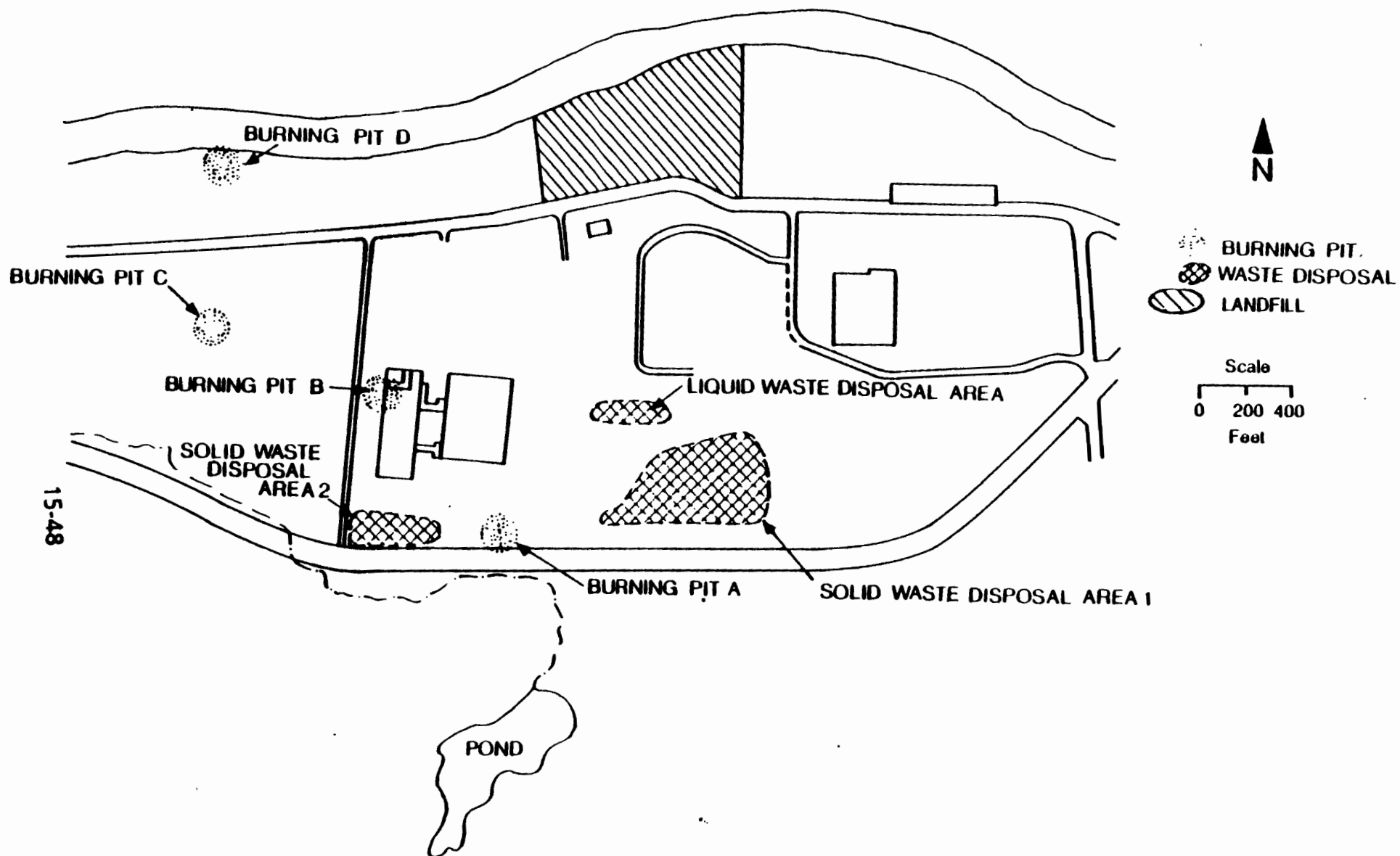


Figure 15-14. Site Map Showing Waste Disposal Areas

## Results

From the analysis, it was apparent that the deepest portion of Solid Waste Disposal Area (SWDA) No. 1 (Figure 15-14) was approximately 48 feet, and the Liquid Waste Disposal Area (LWDA) was approximately 30 feet deep. The horizontal limits of the disposal areas were also defined in part by this review, but other field surveys provided more accurate information on the horizontal boundaries of the waste disposal areas.

## Case Discussion

Topographic surveys can provide useful information for characterizing disposal areas. The results of these studies can facilitate the selection of appropriate test boring locations, and may reduce the number of borings necessary to describe the subsurface extent of contamination. It should be noted that techniques such as infrared aerial photography and topographic surveying are approximate in their findings. They are useful methods in the early phases of an investigation, but do not replace the comprehensive characterization of the environmental setting needed for the full investigation.

## **CASE STUDY 9: SELECTION OF GROUND-WATER MONITORING CONSTITUENTS AND INDICATOR PARAMETERS BASED ON FACILITY WASTE STREAM INFORMATION**

### **Points Illustrated**

- Waste stream information can be used to identify potential contaminants, and thus to select appropriate ground-water monitoring constituents and indicator parameters.
- The number of initial monitoring constituents analyzed may be significantly reduced from the 40 CFR Part 261 Appendix VIII list when detailed waste stream information is available.

### **Introduction**

Hazardous waste treatment, storage, and disposal facilities subject to RCRA are required to identify all waste streams managed the facility, waste volumes, concentrations of waste constituents, and the waste management unit in which each waste type is disposed. Ground-water monitoring programs should be developed to adequately monitor contaminant migration from each unit. Constituents to be analyzed in the ground-water monitoring program should be established prior to sample collection. When waste stream data are not available, the full set of Appendix VIII monitoring constituents may be required to characterize ground-water contamination. Knowledge of the waste streams managed by a facility simplifies the selection of monitoring constituents and indicator parameters because potential contaminants and their likely reaction and degradation products can be more easily identified.

### **Facility Description**

The 600-acre facility is a permitted waste disposal site operated since 1980. Solid waste management units occupy 20 acres of the site and include four surface impoundments and one container storage area subject to RCRA. Until 1985, three units (two surface impoundments and one solids disposal unit) not subject to RCRA were used for geothermal waste disposal. However, the two surface impoundments



were replaced by a RCRA regulated landfill. RCRA wastes managed by the facility include metals, petroleum refining wastes, spent non-halogenated solvents, electroplating wastewater treatment sludge, spent pickle liquor from steel finishing operations, and ignitable, corrosive, and reactive wastes. Ground-water monitoring wells have been installed downgradient of each waste management unit.

#### Program Design

Prior to disposal, each load of waste received is analyzed in an on-site laboratory to provide a complete characterization of waste constituents. Periodic sampling of the waste management units is also conducted to identify waste reaction products and hazardous mixtures. Even though the incoming wastes have been characterized, the facility owner also analyzed initial ground-water samples from each monitoring well for all Appendix VIII constituents. The resulting data were used to establish existing concentrations for each constituent and to select a set of monitoring constituents and indicator parameters to identify migration of waste to the ground-water system. Table 15-7 includes a list of the indicator parameters analyzed at the facility. Rationale for indicator parameter selection are included in this table. A separate list of hazardous constituents to be monitored was also developed based on the waste analysis.

Because the facility accepts only a limited number of 40 CFR Part 261 Appendix VIII constituents and initial monitoring verified the absence of many constituents, the facility owner or operator was able to minimize the total number of constituents monitored in ground water. The process of constituent elimination is dependent on the actual wastes received by the facility and the physical and chemical properties of these constituents that influence their migration potential (e.g., octanol/water partition coefficients, solubility, adsorptivity, susceptibility to biodegradation).

Non-halogenated solvents have relatively low partition coefficients ( $K_{ow}$ : benzene = 100; toluene = 500) and are not readily retained by soils. Conversely, polycyclic aromatic hydrocarbons, constituents of petrochemical wastes, have very high partition coefficients (e.g., chrysene =  $4 \times 10^5$ ) and are generally immobile in soils. Migration rates of metals are also influenced by the exchange

**TABLE 15-7**  
**INDICATOR PARAMETERS**

Parameter	Criteria for Selection
Total Organic Carbon (TOC)	Collective measure of organic substances present
Total Petroleum Hydrocarbons	Indication of petroleum waste products
Total Organic Halogen (TOX)	Halogenated organic compounds are generally toxic, refractory, and mobile
Nitrates	Mobile contaminant, degradation product of nitrogen compounds
Chloride	Plating solution constituent, highly mobile in ground water. Early indicator of plume arrival
Sulfides	Toxic, biodegradation by product, strong reducing agent, may immobilize heavy metals
pH	Good indicator of strongly acidic or alkaline waste leachates close to sources
Total phenols	Collective measure of compounds likely to be in waste. Even small concentrations can cause olfactory problems following water treatment by chlorination

capacity of the soil. Different metal species are sorbed to different extents. Following an assessment of the migration potential of each waste constituent, the need for analysis of that constituent can be prioritized.

#### Case Discussion

Waste stream information was used to determine appropriate monitoring constituents and indicator parameters. The use of the existing initial ground-water quality data and the incoming waste analyses allowed for prediction of contaminants of concern in ground water and reduced the number of constituents requiring analysis.

## CASE STUDY 10: USING WASTE REACTION PRODUCTS TO DETERMINE AN APPROPRIATE MONITORING SCHEME

### Point Illustrated

- It is important to consider possible waste reaction products when developing monitoring procedures.

### Introduction

Volatile organic priority pollutants have been detected in ground water at various areas across the country. These compounds, widely used as solvents, are generally considered environmentally mobile and persistent. Increasing evidence, however, indicates that chlorinated solvents can be degraded under anaerobic conditions by reductive dehydrochlorination. The sequential removal of chlorine atoms from halogenated 1 and 2 carbon aliphatic compounds results in formation of other volatile priority pollutants which can be detected during investigations of solvent contamination.

### Facility Description

The facility is a small municipal landfill sited on a former sand and gravel quarry. In addition to municipal wastes, the landfill accepted trichloroethane and tetrachloroethene contaminated sludge from a local fabrication plant until 1975. In 1983, a municipal well located downgradient of the landfill tested positive for dichloroethane, dichloroethene isomers, and vinyl chloride. This prompted the city to investigate the cause and extent of the problem.

### Site Investigation

According to records kept at the facility, some of the compounds found in the municipal well were not managed at the facility. This prompted the city to request that a monitoring program be developed to determine whether another source was causing well contamination. A careful search of the city records, however, failed to indicate a credible alternative source of the compounds. Suspecting that the landfill was the source of the well contaminants, five monitoring wells were

installed (Figure 15-15) and water samples were analyzed for halogenated compounds using EPA Method 601. The results, given in Table 15-8, show an increase in degradation products of trichloroethane and tetrachloroethene with increasing distance from the landfill. Using these data, supported by hydrogeologic data from the monitoring wells, the municipal landfill was shown to be the source of the observed contamination.

**TABLE 15-8**  
**RESULTS OF MONITORING WELL SAMPLING**

	WELL NUMBER (See Figure 15-15 for well locations)				
	1	2	3	4	5
<b>Chlorinated Ethanes</b>					
(1) Trichloroethanes	10(3)	68	ND(4)	ND	ND
(2) 1,1-Dichloroethane	71	240	130	11	13
1,2-Dichloroethane	ND	12	21	ND	ND
Chloroethane	ND	21	18	160	ND
<b>Chlorinated Ethenes</b>					
(1) Tetrachloroethene	80	13	ND	ND	ND
Trichloroethene	12	100	62	ND	ND
(2) 1,2-Dichloroethenes	ND	990	950	150	ND
1,1-Dichloroethene	ND	ND	ND	ND	ND
Vinyl Chloride	ND	120	59	100	ND

(1) Parent Compounds  
(2) Degradation Products

(3) All Concentrations In Micrograms/L  
(4) ND means < 10 Micrograms/L

### Case Discussion

Based on the compounds found in the municipal well, the city believed that the municipal landfill could not be the source of the contamination. If this reasoning had been followed, then a system of monitoring wells might have been needlessly installed elsewhere in the attempt to find an alternate source of the

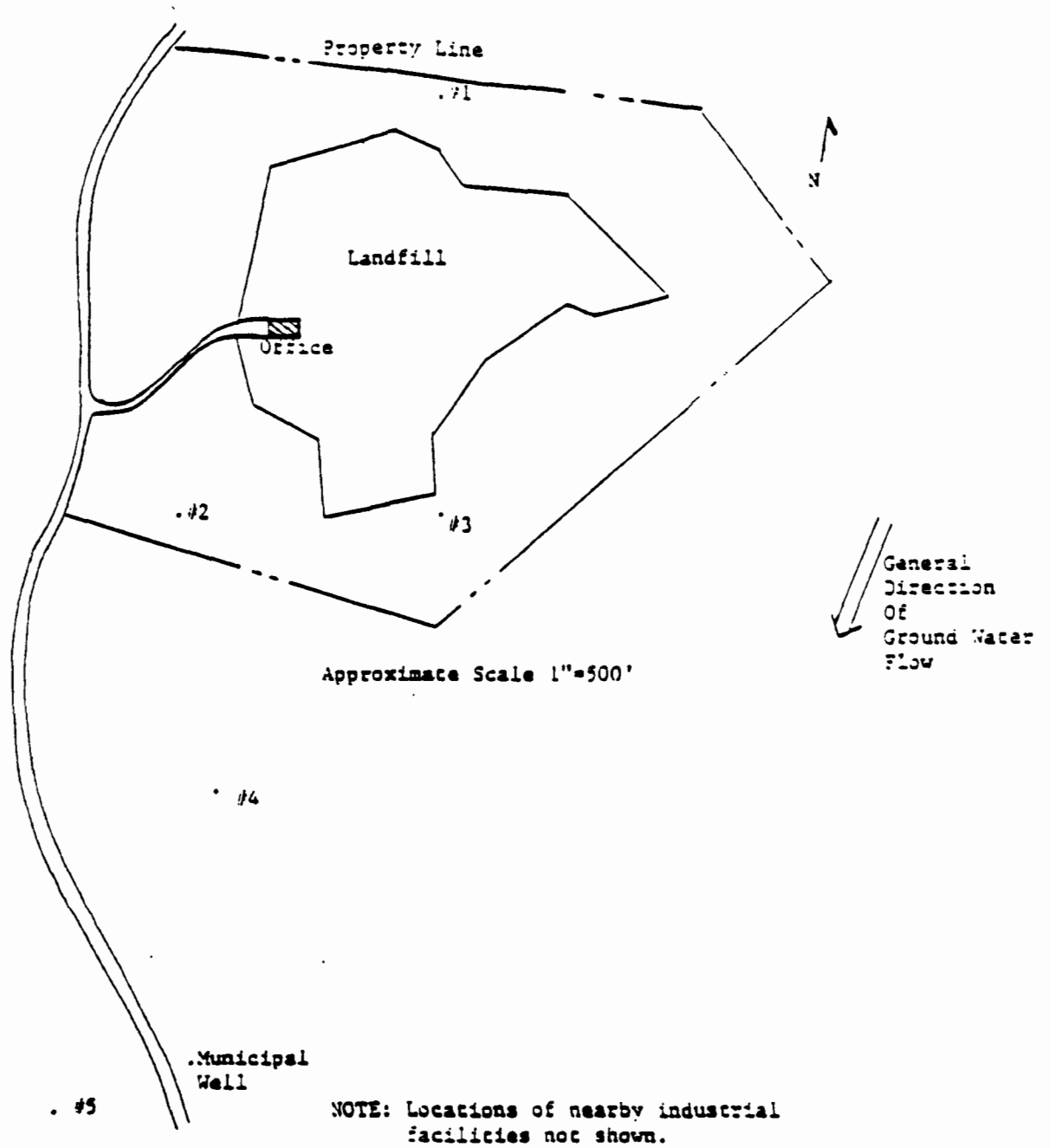


Figure 15-15. Site Map and Monitoring Well Locations

contamination. Instead, after carefully researching local industries, it was determined that the landfill was the most reasonable source of the contamination and that the observed well contaminants were probably degradation products of the landfilled solvents. The progressive dehalogenation of chlorinated ethanes and ethenes, as shown in Table 15-8, is commonly encountered in situations where chlorinated solvents are subjected to anaerobic conditions (Wood, 1981). Different degradation reactions may occur when pesticides are subjected to acidic or alkaline conditions or biological degradation. Therefore, it is important to keep reaction products in mind when designing any monitoring scheme or interpreting contamination data.

### Reference

Wood, P.R., R.F. Lang, I.L. Payan, and J. DeMarco. 1981. Anaerobic Transformation, Transport and Removal of Volatile Chlorinated Organics in Ground Water. First International Conference on Ground Water Quality Research, October 7-10, 1981, Houston, Texas.

## CASE STUDY 11: CORRECTIVE MEASURES STUDY AND THE IMPLEMENTATION OF INTERIM MEASURES

### Points Illustrated

- Interim corrective measures may be necessary to protect human health or the environment.
- The evaluation of the need for definitive corrective measures.

### Introduction

The development and implementation of a comprehensive Corrective Measures Study can be a time-consuming process. Between the time of the identification of a contaminant release and the completion of definitive corrective measures, existing conditions or contaminant migration can endanger human health or the environment. Under such conditions interim measures may be necessary. The case study presented below illustrates the implementation of interim measures to reduce contaminant migration and to remove the imminent threat to the nearby population from exposure to contaminants in drinking water, and also illustrates the decision-making process as to whether definitive corrective measures may be necessary.

### Facility Description

The facility in this case study is an underground tank farm located at a pharmaceutical manufacturing plant. The tank farm encompasses an area approximately 140 feet by 260 feet and contains 30 tanks ranging in size from 12,000 to 20,000 gallons. The tanks are used to store both wastes and raw materials for the various batch manufacturing processes performed at the plant. Typical wastes include carbon tetrachloride, acetonitrile and chloroform. At the time of the release, the tank farm had no cap to prevent the infiltration of rainfall or runoff. It also did not have berms to provide containment for surface spills. No leak detection or leachate collection systems were present.



## Geological and Hydrological Setting

The site is underlain by silty soil overlying limestone. The weathered limestone beneath the site is very permeable (up to 210 ft/day) due to the solution of rock along joints and bedding planes in the limestone. Depth to the limestone varies from 3 to 80 feet beneath the tanks and from 15 to 190 feet downgradient of the site.

The ground-water system beneath the site consists of two aquifers. The upper one, an unconfined limestone aquifer, is about 300 feet below the surface. The deep aquifer is an artesian aquifer in another limestone formation about 1200 feet below the land surface. Ground-water flow in the upper aquifer is controlled by both the regional flow system and local channelized flow through solution conduits. The upper aquifer discharges to a canal 3 miles north of the site. Figure 15-16 shows the ground-water elevation contours in the vicinity of the site. Regional average ground-water flow velocity was estimated at 4 ft/day, but ground-water velocities on the order of 50 ft/day have been measured in some channelized areas. Channelized flow is also responsible for local deviations in flow direction.

## Release Characterization

A contaminant release from the tank farm was discovered when one of the tanks used for waste storage was found to be empty. The waste stored in the tank was predominately carbon tetrachloride (CCl<sub>4</sub>) (a carcinogen with an MCL of 0.005 mg/l, with some acetonitrile (a systemic toxicant with a water-based health criterion of 200 µg/l) and chloroform (a systemic toxicant with a water-based health criterion of 400 µg/l) reference dose (RfD) is 0.4 mg/l). Approximately 15,000 gallons of waste liquids had been routed to the tank before the leak was discovered. Excavation of the tank revealed ruptures in at least three locations. Initial ground-water monitoring after the tank rupture was discovered identified CCl<sub>4</sub> in a well 2500 feet downgradient of the site, at concentrations above the MCL for CCl<sub>4</sub> of 0.005 mg/l.

Contaminants from the leaking tank were found to have dispersed laterally within a two-foot-thick sand bed which underlies the tanks. The contaminated area

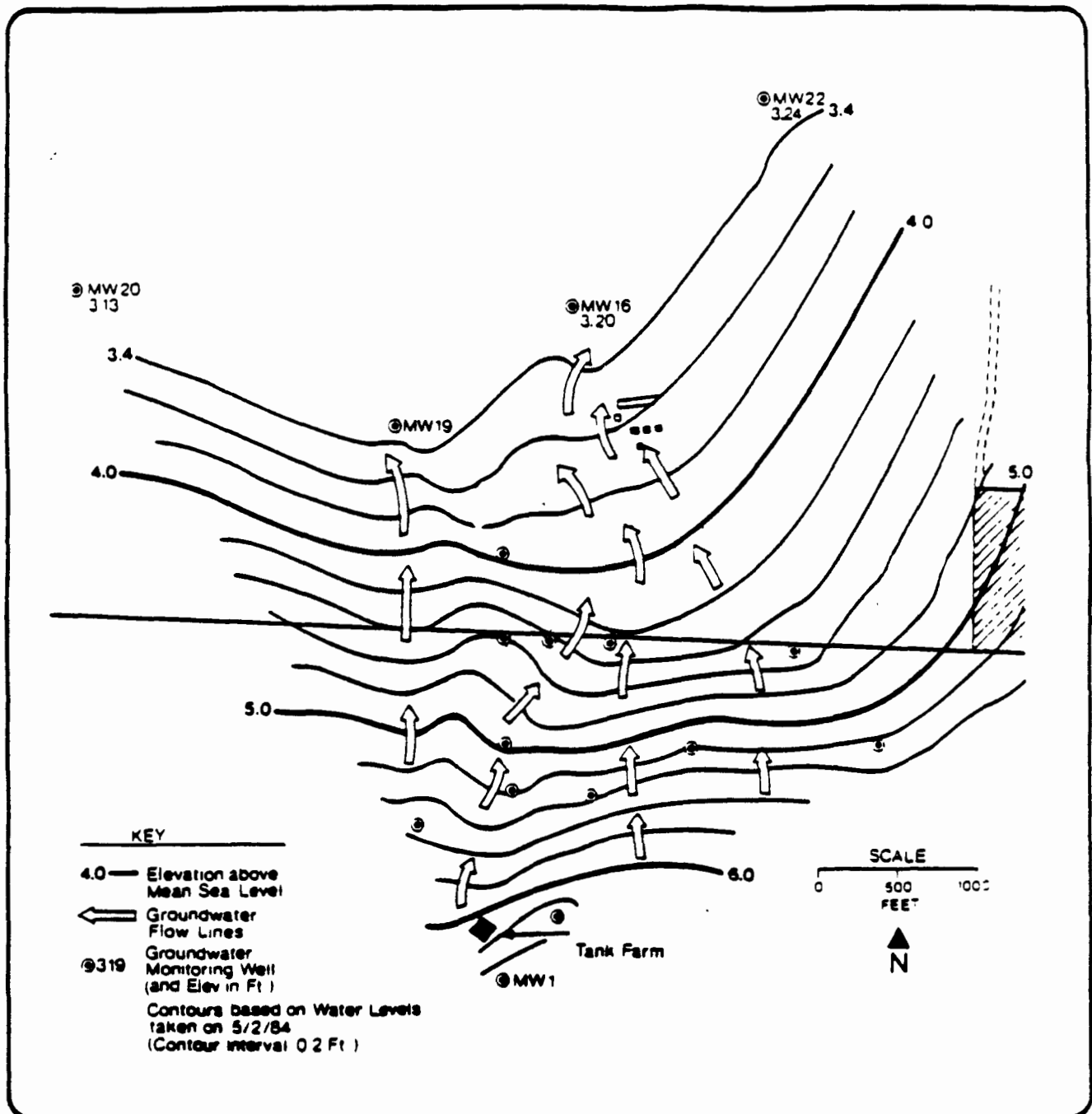


Figure 15-16. Ground-Water Elevations and Flow Directions in Upper Limestone Aquifer

was approximately 5600 ft<sup>2</sup>. High levels of CCl<sub>4</sub> were found throughout the sand layer. Concentrations of CCl<sub>4</sub> in the natural soil ranged between undetected and 2200 mg/kg. Observed concentrations were well above the soil RSD for CCl<sub>4</sub> (2.7 mg/kg). Concentrations generally decreased with depth due to adsorption onto the clay particles in the soil. Carbon tetrachloride apparently moved downward with little lateral dispersion until reaching the soil-limestone interface. Upon reaching the unsaturated limestone, the contaminants then appeared to have rapidly dispersed over an area of about 12 acres before entering the aquifer.

#### Interim Corrective Measures

Immediate action to contain the release in the aquifer was taken. This involved pumping the well where CCl<sub>4</sub> had been found continuously at its full capacity of 450 gpm.

All drinking water in the vicinity of the release was obtained from wells installed in either the shallow or artesian aquifer. Immediately after the detection of the release, all domestic and industrial wells north of the facility were tested for CCl<sub>4</sub> contamination. Test results showed contamination of several shallow water supply wells. Based on this information and the inferred ground-water flow direction to the north-northeast, wells serving two small communities and a nearby motel were closed. The facility operator hired all mobile water tanks available and supplied water for immediate needs until a temporary water supply could be implemented. Water from an unaffected artesian well was then used to supply water to these communities.

The design and operation of the tank farm was altered in an attempt to avoid similar problems in the future. A fiber-reinforced concrete cap was installed over the tank farm to prevent the infiltration of rainfall and runoff, thus minimizing further contaminant migration in the soil. The ruptures were repaired, and a tank monitoring system was also developed and implemented at the site.

#### Definitive Corrective Measures: Saturated and Unsaturated Zones

A comparison of CCl<sub>4</sub> concentrations within the ground water to the MCL for CCl<sub>4</sub> (0.005mg/l) indicated that definitive corrective measures may be necessary.

Due to the high mobility of  $\text{CCl}_4$  within the unsaturated zone, and the potential for continued inter-media transfer from this zone to the ground water, definitive corrective measures for both the saturated (ground water) and unsaturated zones should be evaluated in a Corrective Measures Study (CMS).

#### Case Discussion

The development and implementation of definitive corrective measures at a site may take a substantial length of time. Depending on the nature and severity of the release and the proximity of receptors, interim measures, such as alternative water supplies, were required to minimize the effects on human health and the environment. Comparison of constituent concentrations with health and environmental criteria indicated that definitive corrective measures may be necessary and that a Corrective Measures Study (CMS) should be initiated.

## CASE STUDY 12: USE OF AERIAL PHOTOGRAPHY TO IDENTIFY CHANGES IN TOPOGRAPHY INDICATING WASTE MIGRATION ROUTES

### Points Illustrated

- Aerial photographs can be used to obtain valuable data on facility-related topographic features, including type of waste management activity, distance to residences and surface waters, adjacent land use, and drainage characteristics.
- Detailed interpretation of aerial photographs can identify actual and potential waste migration routes and areas requiring corrective action.

### Introduction

Stereoscopic pairs of historical and current aerial photographs were used to assist in the analysis of waste management practices at a land disposal facility. Stereo viewing enhances the interpretation of aerial photographs because vertical as well as horizontal spatial relationships can be observed, and because the increased vertical resolution aids in distinguishing various shapes, tones, textures, and colors within the study area. Typical items that should be noted include pools of unknown liquid that may have been released from buried materials which could migrate off site through drainage channels. Soil discoloration, vegetation damage, or enhanced vegetation growth can also be indicative of contaminant migration.

### Facility Description

The site contains an active land disposal facility which receives bulk hazardous waste, including sludges and contaminated soil for burial, and liquid wastes for disposal into solar evaporation surface impoundments. Operations at the facility began in 1969. Historical and current aerial photographs were reviewed to assess waste management practices and to identify potential contaminant migration pathways requiring further investigation and corrective action.

### Data Collection and Analysis

Low altitude color aerial photographs of the facility (scale = 1:8400) were obtained in October 1983 and February 1984. The photos were interpreted by an aerial photo analyst at the U.S. EPA Environmental Monitoring and Support Laboratory at Las Vegas, Nevada. Figure 15-17 shows the analyzed photograph. The interpretation code is given in Figure 15-18. Analysis of the photograph indicates several areas of seepage at the base of the surface impoundments. This seepage indicates that either the impoundments are not lined or the liners have failed. Drainage from the western portion of the facility which contains most of the impoundments flows into a drainage reservoir formed by a dam across the main drainage. Drainage from the northeast portion of the facility where seepage was also observed appears to bypass this reservoir and enter the main drainage which flows offsite. Besides possible surface contamination, this seepage also indicates potential subsurface contamination.

The aerial photograph obtained in February 1984 (Figure 15-19) indicates the continued existence of seepage from the surface impoundments. There is evidence of possible discharge from the drainage reservoir to a stream channel, as a pump and piping were observed. Additional material in the solid waste disposal area has altered the drainage pattern. At the south end of this area, seepage is evident in association with damaged vegetation. Drainage from this area enters a drainage system and appears to be diverted offsite.

### Case Discussion







Analysis of aerial photographs of the land disposal facility enabled investigators to identify potential contaminant sources and migration pathways. This information was used by investigators to identify areas for surface water, sediment, soil, and subsurface sampling.



Figure 15-17. October 1983 Aerial Photograph of Land Disposal Facility

## INTERPRETATION CODE





### BOUNDARIES AND LIMITS

	FENCED SITE BOUNDARY
	UNFENCED SITE BOUNDARY
	FENCE
	PROPERTY LINE
	GATE/ACCESS POINT
	SECTION CORNER

### DRAINAGE

	DRAINAGE
	FLOW DIRECTION
	INDETERMINATE DRAINAGE

### TRANSPORTATION/UTILITY

	VEHICLE ACCESS
	RAILWAY
	PIPELINE
	POWERLINE

### SITE FEATURES





	DIKE
	STANDING LIQUID
SL	STANDING LIQUID (SMALL)
	EXCAVATION, PIT (EXTENSIVE)
	MOUNDED MATERIAL (EXTENSIVE)
MM	MOUNDED MATERIAL (SMALL)
CR	CRATES/BOXES
DR	DRUMS
HT	HORIZONTAL TANK
PT	PRESSURE TANK
VT	VERTICAL TANK
CA	CLEARED AREA
OG	DISTURBED GROUND
FL	FILL
IM	IMPOUNDMENT
LG	LAGOON
OD	OPEN DUMP
OF	OUTFALL
SD	SLUDGE
ST	STAIN
SW	SOLID WASTE
TR	TRENCH
WD	WASTE DISPOSAL AREA

Figure 15-18. Aerial Photograph Interpretation Code





## CASE STUDY 13: IDENTIFICATION OF A GROUND-WATER CONTAMINANT PLUME USING INFRARED AERIAL PHOTOGRAPHY

### Point Illustrated

- Infrared photography can assist in identifying contaminant plumes and in locating monitoring wells by showing areas of stressed vegetation and contaminated surface water.

### Introduction

Infrared aerial photography can assist in identifying contaminant plumes at sites where little or no monitoring has been conducted. By identifying areas of stressed vegetation or contaminated surface water, it may be possible to focus on contaminant discharge points and roughly define the extent of a release. Hydrogeologic investigations and surface water sampling can then be performed to further characterize the release. Infrared photography offers the potential to increase the efficiency of a sampling program.

### Facility Description

The facility is a municipal solid waste landfill which has served a population of 22,000 for 30 years. The facility covers an area of 11 acres, holding an estimated 300,000 tons of refuse. The majority of waste in the landfill was generated by the textile industry. Until July 1978, the facility was operated as an open dump with sporadic management. City officials indicated that original disposal occurred in open trenches with little soil cover. After July 1978, the facility was converted to a well-operated sanitary landfill. Figure 15-20 shows the facility.

### Geologic Setting--

The landfill is located on a sandy to silty till varying in thickness from 23 feet at the hill crest to 10 feet on the side slope. A swamp is present at the base of the hill at about 255 feet above sea level. There is a dam at the southern drainage outlet

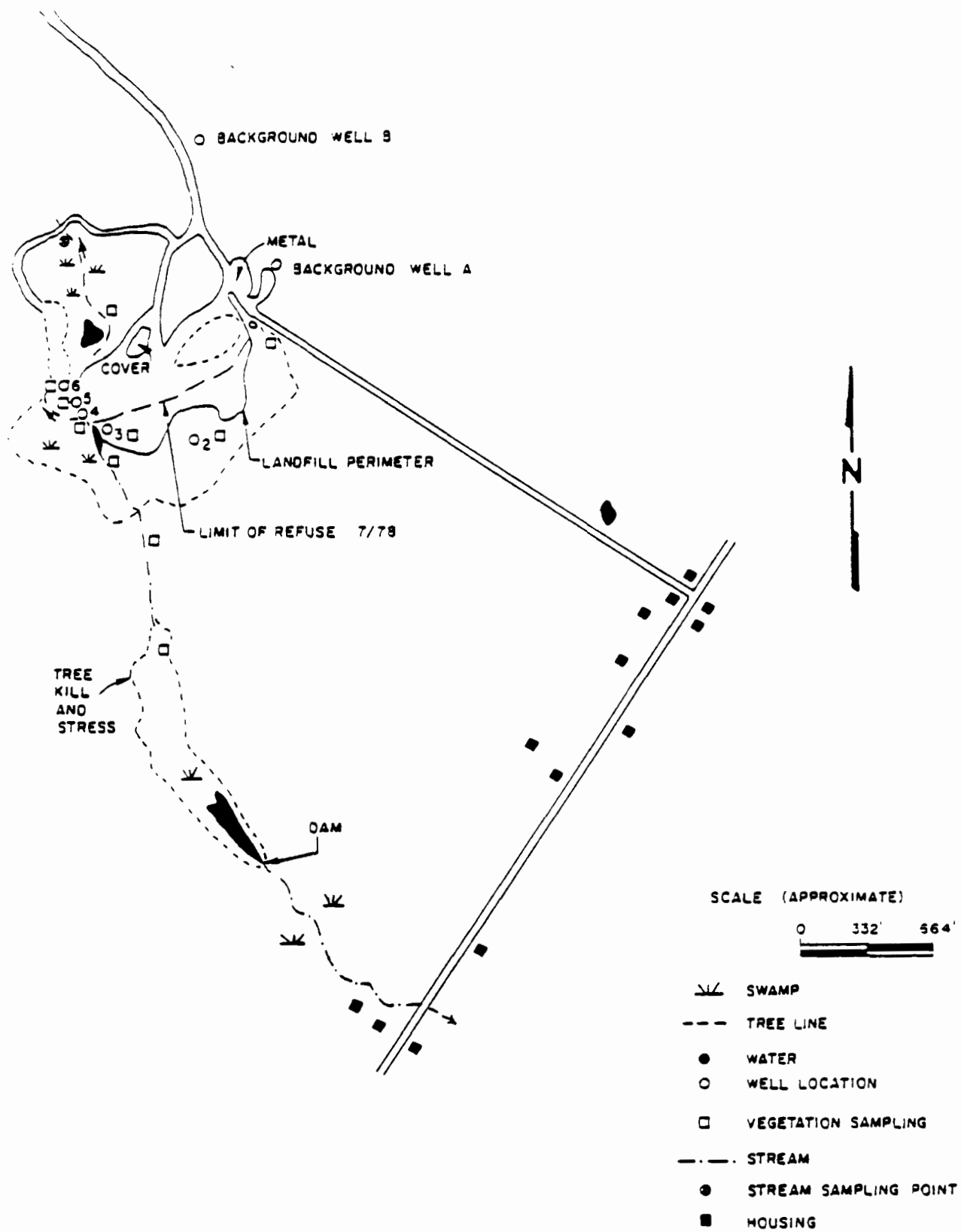


Figure 15-20. Facility Plan View

of the swamp, a distance of 2,500 feet from the landfill. Ground water is approximately 20 feet below the surface at the crest of the hill, while on the slope it is approximately 6 feet below the surface. The swamp at the foot of the hill is the surface expression of the ground water (Figure 15-21).

#### Aerial Photography and Sampling Program

Figure 15-22 shows the infrared aerial image of the site. The landfill corresponds to the light area in the northwest portion of the photograph (Figure 15-21). The dark area to the south of the site is stressed vegetation, and the light area within it is contaminated swamp water. The 33-acre area of tree kill and stress is clearly visible in the original photograph. Plants under stress may be detected by infrared photography because of changes in infrared reflectance.

Ground-water monitoring wells and vegetation sampling points are shown in Figure 15-20. Data collected from the wells indicated elevated levels of chromium, manganese, iron, and total organic carbon (TOC). Table 15-9 lists the average concentrations of the parameters tested. The vegetation study indicated an accumulation of heavy metals.

#### Case Discussion

The vegetative stress apparent in the infrared photography was confirmed by the data from the ground water and vegetation sampling. However, the site requires further characterization to determine the vertical extent of contamination and to assess the potential for impact beyond the present area of stressed vegetation.

It should be emphasized that infrared photography is not a substitute for hydrogeologic characterization. However, it is a useful tool for identifying areas of stressed vegetation that may be associated with releases from waste disposal sites.

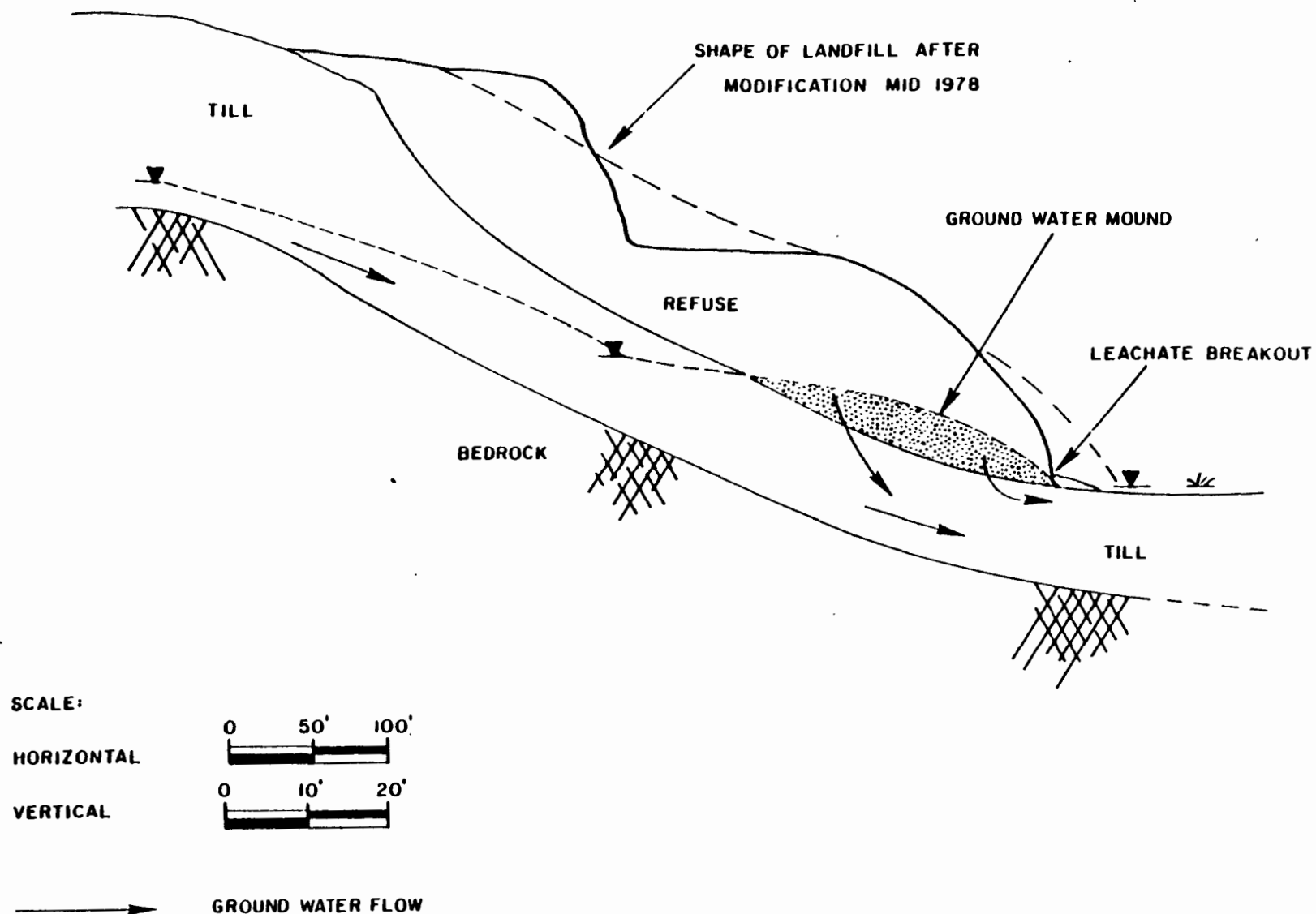
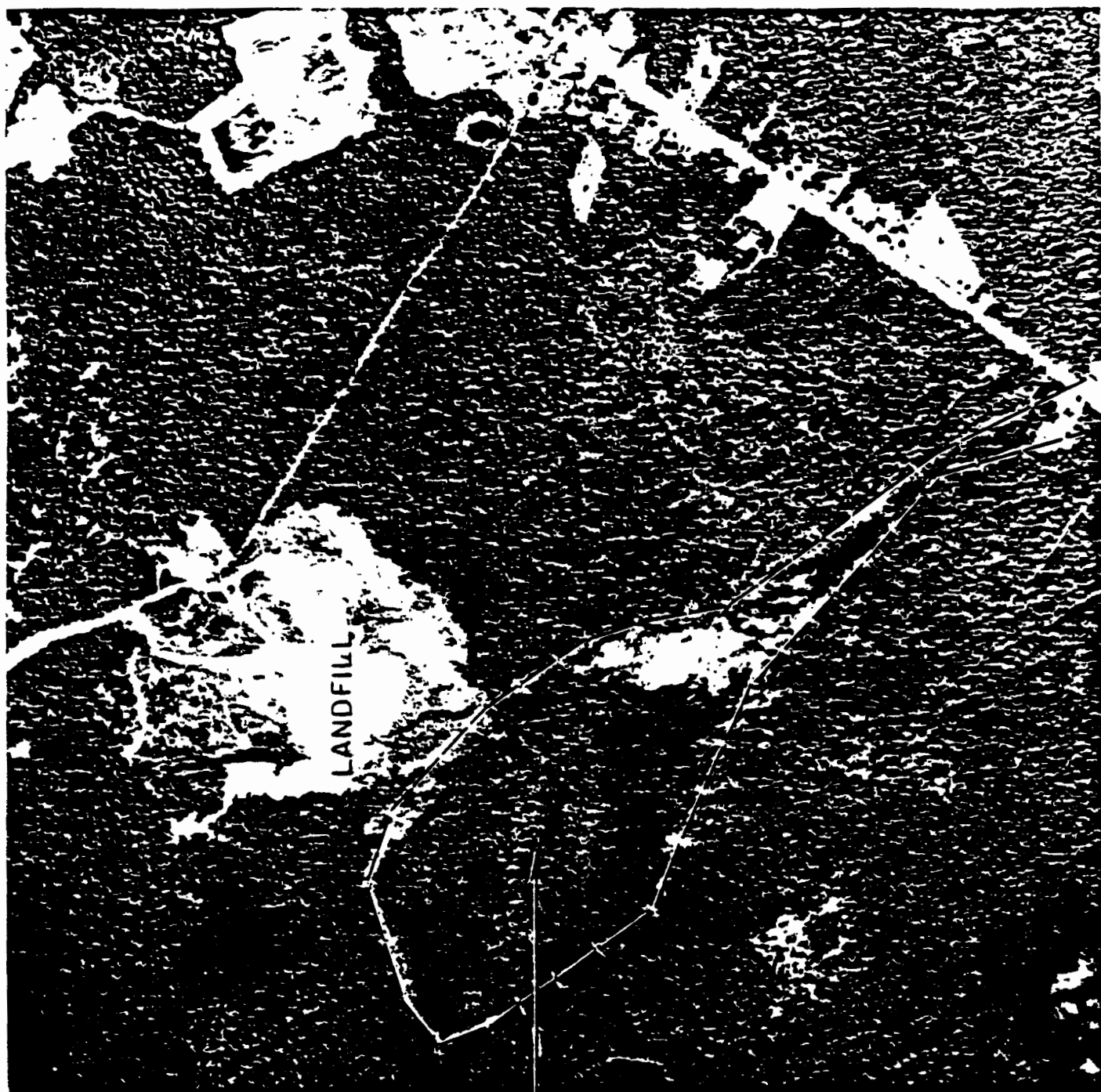


Figure 15-21. Generalized Geologic Cross-Section



LANDFILL

Area of  
Tree kill  
and Stress

Figure 15.22 Infrared Aerial Photograph of the Site

TABLE15-9

AVERAGE VALUES OF PARAMETERS IN GROUND WATER AND STREAM SAMPLES<sup>1</sup>

	BOD <sub>5</sub>	TOC	TKN	NH <sub>3</sub>	NO <sub>3</sub> =	Tot.P	Fe	Mn	Hardness	Cl	CIBD	Cr	TDS	Cd	pH
Background <sup>2</sup>	< 10	/	/	/	/	1.73	2.7	0.4	18.2	5.2	102	/	98	0.05	/
Well #2	< 20	119	1.7	0.54	0.48	0.11	108.8	4.2	525.6	67.3	1000	0.03	828.5	1	2.9
Well #3	< 20	56	5.5	3.9	0.10	0.15	39.6	16.3	414.2	103.5	450	0.02	230	---	5.5
Well #4	/	300	2.5	< 0.01	< 0.01	0.13	27	9.4	1	980		0.02	/	/	5.4
Well #5	20	45.5	0.6	1.22	0.15	0.18	71.6	3.8	353	74.7	240	0.03	863.0	1	5.8
Well #6	19	45.5	3.4	2.47	< 0.1	1.5	177	7.65	659.9	120	1300	0.71	780	/	5.7
Stream	< 20	72.5	43.7	49.7	0.05	0.10	18.4	1.73	230	76.7	1300	0.017	817	/	6.8

<sup>1</sup> All values as mg/l, except conductivity (μmhos) and pH (standard units)<sup>2</sup> Average of background wells A and B

/ = Not Analyzed

## **CASE STUDY 14:     USE OF HISTORICAL AERIAL PHOTOGRAPHS AND FACILITY MAPS TO IDENTIFY OLD WASTE DISPOSAL AREAS AND GROUND-WATER FLOW PATHS**

### **Points Illustrated**

- Aerial photographs taken over many years in the life of a facility can be used to locate old solid waste management units (SWMUs).
- Historical aerial photographs can be used to identify geologic/topographic features that may affect ground-water flow paths.

### **Introduction**

In gathering information pertaining to investigation of a release, historical aerial photographs and facility maps can be examined and compared to current aerial photographs and facility maps. Aerial photographs can be viewed as stereo pairs or individually. Stereo viewing, however, enhances the interpretation because vertical as well as horizontal spatial relationships can be observed. The vertical perspective aids in distinguishing various shapes, tones, textures, and colors within the study area.

Aerial photographs and facility maps can be used for the following:

- Providing evidence of possible buried drums. Historical photographs can show drums disposed of in certain areas where later photographs show no indications of such drums, but may show that the ground has been covered with fill material.
- Showing previous areal extent of landfill or waste management area. Earlier photographs might show a much larger waste management area than later photographs.
- Showing areas that were dry but now are wet, or vice versa, indicating a possible release from an old waste management area.



- Showing changes in land use patterns (e.g., a landfill in an early photograph could now be a park or be covered by buildings).
- Soil discoloration, vegetation damage, or enhanced vegetative growth can sometimes be detected, indicating possible contaminant migration.
- Geologic/hydrologic information, such as faults, fracture or joint systems, old stream courses (channels), and the contact between moraines and outwash plains.

### Facility description

This facility is the same as previously described in Case Studies 7 and 8.

### Data collection and analysis

Over the past 50 years aerial photographs were taken of the facility area. Interpretation of the photographs produced important information that is shown diagrammatically in Figure 15-23. Solid Waste Disposal Area 2 (SWDA-2) was lower in elevation in 1940 than it is now. In fact, the area appears to have been leveled and is now covered by vegetation, making it difficult to identify as a SWMU at ground level. Another area was identified as a possible waste disposal area from a historical review of photos. Further study of photographs, facility maps and facility files revealed this to be a former Liquid Waste Disposal Area (LWDA), designated as LWDA-2 on Figure 15-23.

The use of these historical photographs also revealed geologic features that could affect the ground-water flow system under the facility. In this case, monitoring well data indicated a general northwesterly ground-water flow direction, in addition to a complex flow pattern near LWDA-1 and SWDA-1 (Figure 15-23). Recent photographs were analyzed, but because of construction and other nearby activities (e.g., cut and fill, sand and gravel mining), conclusions could not be drawn. A review and analysis of old photographs revealed the existence of a buried stream channel of the river (Figure 15-23). This buried stream channel was identified as a preferential path for ground water and consequently contaminant

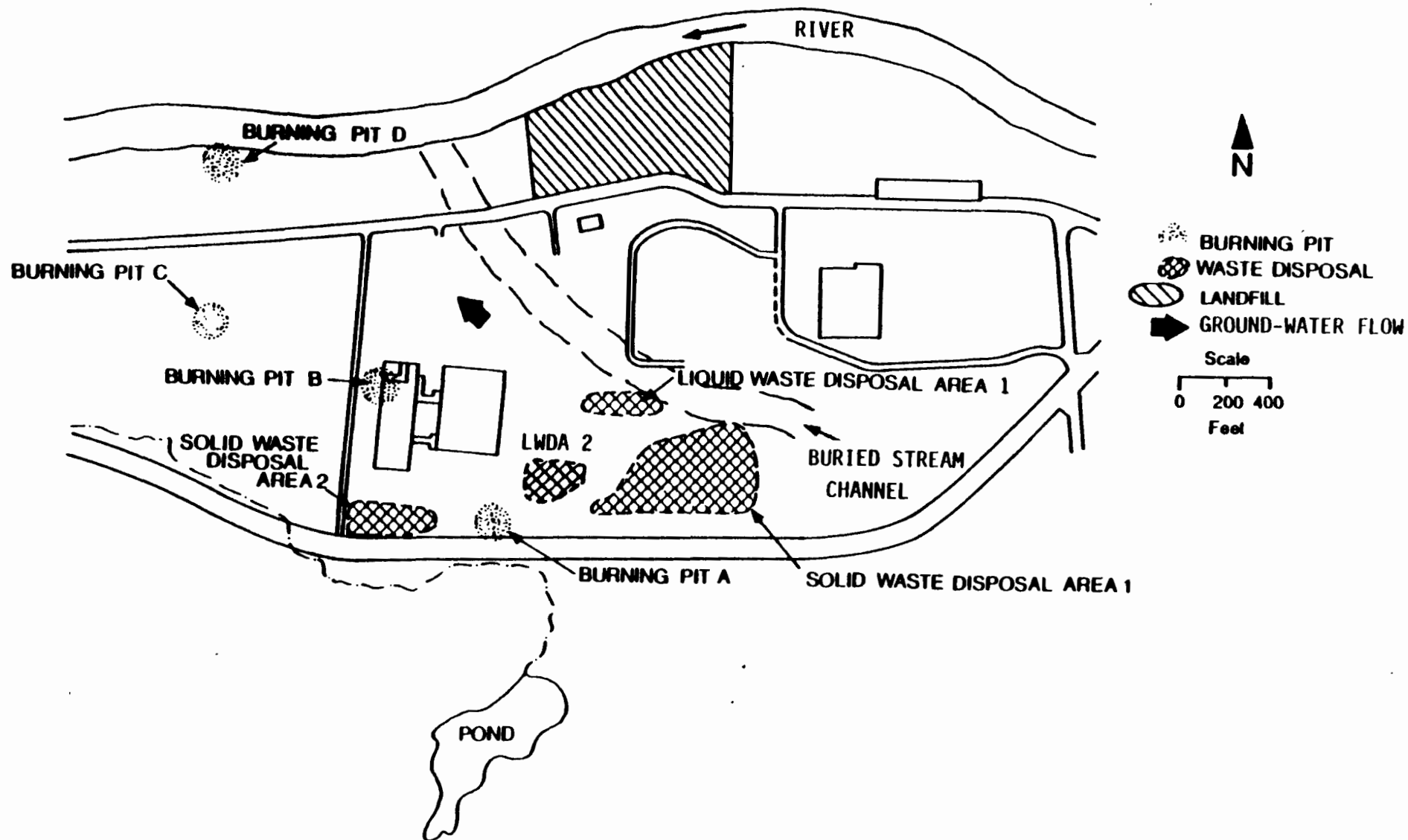


Figure 15-23. Site Layout. LWDA-2, SWDA-2 and Stream Channel Identified Through Use of Aerial Photograph Analysis

migration. Additional monitoring data and further analysis of subsurface geologic data is needed to determine the full impact of the buried stream channel on the ground-water flow regime.

#### Case Discussion

Analysis and interpretation of a series of historical aerial photographs and facility maps spanning a period of over 50 years enabled facility investigators to identify the following:

- (1) Location of waste disposal areas (e.g., old SWMUs);
- (2) Changes in topography (related to earlier disposal activities); and
- (3) Possible preferential pathways (e.g., old stream channel) for migration of ground water and contaminants.

This information was used to identify areas for more detailed sampling and analysis.

Analysis of historical facility maps and historical aerial photographic interpretation can be a very powerful tool in a RCRA Facility Investigation, but should be used in combination with other investigative techniques to result in a thorough characterization of the nature, extent, and rate of contaminant migration.

## CASE STUDY 15: USING SOIL CHARACTERISTICS TO ESTIMATE MOBILITY OF CONTAMINANTS

### Point Illustrated

- Information on soil characteristics can be used to estimate the relative mobility of contaminants in the subsurface environment.

### Introduction

The relative mobility of contaminants can be estimated using soil characteristics and aquifer hydraulic characteristics. Although metals do precipitate at higher concentrations, at the levels encountered in most subsurface environments, sorption is the dominant attenuation process. The degree to which a metal sorbs onto soil particles depends on the soil pH, the percent clay, the percent soil organic matter, the presence of particular coatings (e.g., iron, manganese, and aluminum oxide/hydroxides) and, to a lesser extent, the type of clay present. For organic contaminants, there are several processes which may be important in predicting their fate in soils. These include sorption, biodegradation, hydrolysis and, to a lesser extent, volatilization. The sorption of a given organic compound can be predicted based on its octanol-water partition coefficient, the percent organic carbon in the soil, and the grain-size distribution of the soil.

Determining the relative mobility of contaminants can be helpful in selecting appropriate sampling locations. For example, if wastes containing metals were present in an impoundment, samples to determine the extent of any downgradient metal contamination would normally be collected within a short distance of the impoundment. On the other hand, for fairly mobile waste constituents such as trichloroethylene (TCE), samples could be taken over a much larger downgradient distance. The case study presented below illustrates how contaminant mobility can be estimated.

### Facility Description

A 17-acre toxic waste dump was operated in a mountain canyon for 16 years. The facility received over 32 million gallons of spent acids and caustics in liquid

form. These wastes were placed in evaporation ponds. Other wastes sent to the facility included solvents and wastes from electroplating operations containing chromium, lead, mercury and zinc. Pesticides including DDT had been disposed of in one corner of the site.

### Site Description

The site was underlain by alluvium and granitic bedrock (Figure 15-24). The bedrock, as it was later discovered, was fractured to depths of between 50 and 100 feet. Ground water occurred in the alluvial deposits at depths of 10 to 30 feet. Several springs existed in the upgradient portion of the site. A barrier dam was built across part of the canyon at the downgradient edge of the site in an effort to control leakage. Because of the extensive fracture system, this barrier was not effective. Instead, it appears to have brought the ground-water table up into the wastes and, at the same time, pressurized the underlying fracture system, thereby creating seepage of contaminated water under the dam.

### Estimation of Contaminant Mobility

Because of the variety of constituents accepted at this site, an estimate of their relative mobility was needed prior to designing the remedial investigation. The first step was to estimate the average linear velocity using the following equation:

$$\bar{v} = \frac{Ki}{n_e}$$

where

- $\bar{v}$  = horizontal seepage velocity, ft/day
- $K$  = hydraulic conductivity, ft/day
- $i$  = ground-water gradient
- $n_e$  = effective porosity, decimal fraction.

The hydrogeologic data needed were obtained from existing site assessment reports. The alluvium underlying the site had an average hydraulic conductivity of 0.8 ft/day and an estimated effective porosity of 11 percent. The average ground-

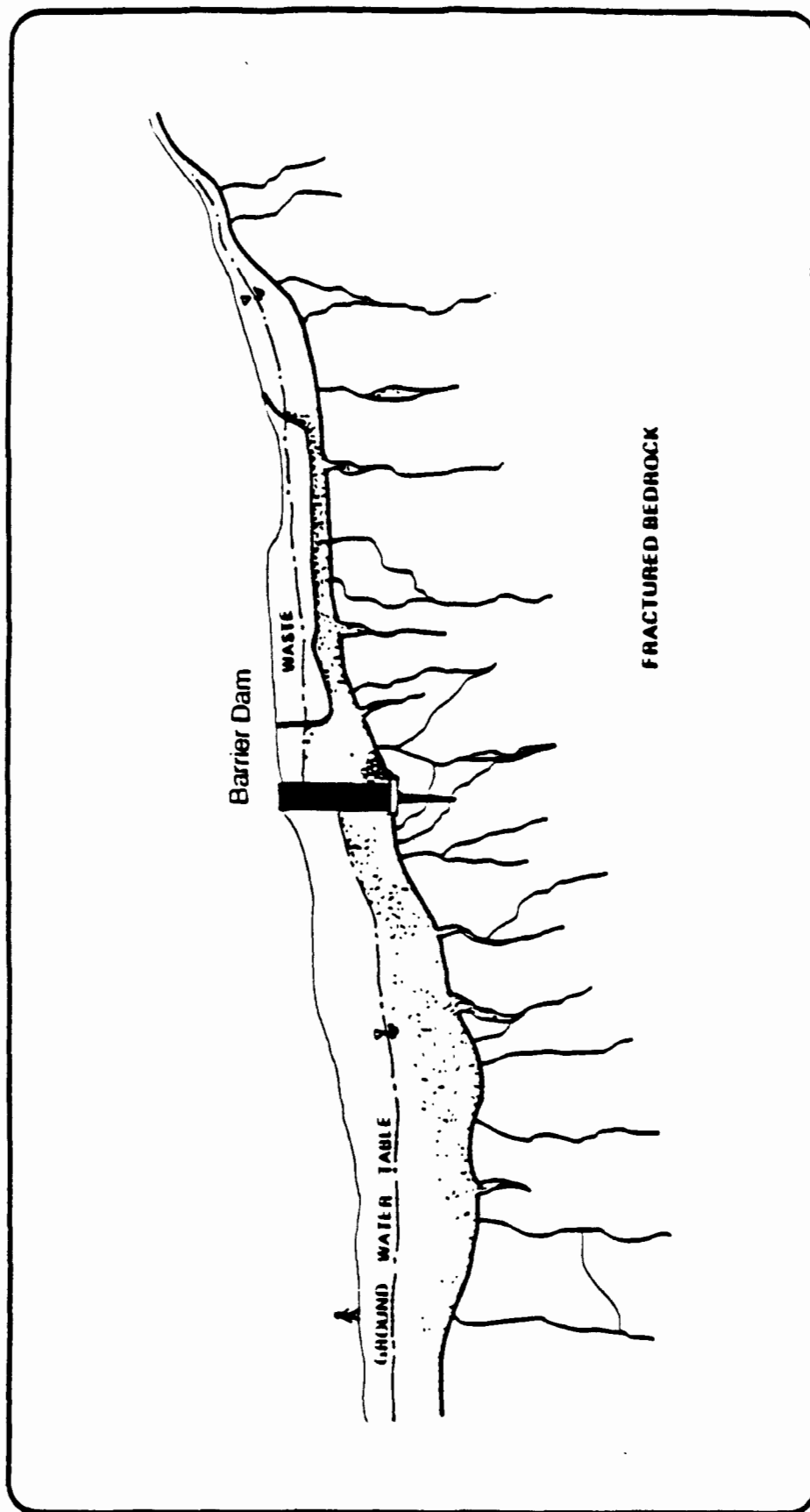


Figure 15-24. Schematic Cross-Section of Waste Disposal Site

water gradient below the site was 0.06. Using the above equation, the average linear velocity was estimated to be 160 ft/yr. This represents the average velocity at which a conservative constituent would migrate downgradient along the centerline of the plume. Examples of such constituents include chloride and bromide. As shown in Table 15-10, nitrate and sulfate also behave conservatively in many cases. Due to the absence of highly weathered, sesquioxide soils, sulfate behaved conservatively at this site. Using the above average linear velocity, an estimate was made of the distance a conservative solute would travel in a given time (T) using  $d = vT$ . Limited water quality data were available for 1980. Wastes were first disposed at this site in 1956. The average extent of plume migration along the centerline was thus estimated to be 3800 feet.

With respect to metals, additional data were needed to estimate their fate including soil pH, presence of carbonates, organic ligands, and percent soil organic matter and clay. At this site, the soil pH varied from less than 3.0 within 400 feet of the acid ponds to 7.2 at a distance 2000 feet downgradient. As shown in Figure 15-25, the partition coefficients for metals are dependent on pH and organic matter content. For example, below a pH of 5.6, for the types of soil encountered at the site, the partition coefficient ( $K_p$ ) for cadmium is about 10 ml/g. At a pH of 7.2,  $K_p$  is about 6500 ml/g (Rai and Zachara, 1985). The relative mobility of attenuated constituents can be estimated as follows (Mills et al., 1985):

$$V_A = v/R_d$$

where

$V_A$  = average velocity of attenuated constituent along centerline of plume, ft/day

$v$  = average linear velocity as defined above, ft/day

$R_d$  = retardation factor (unitless)

and

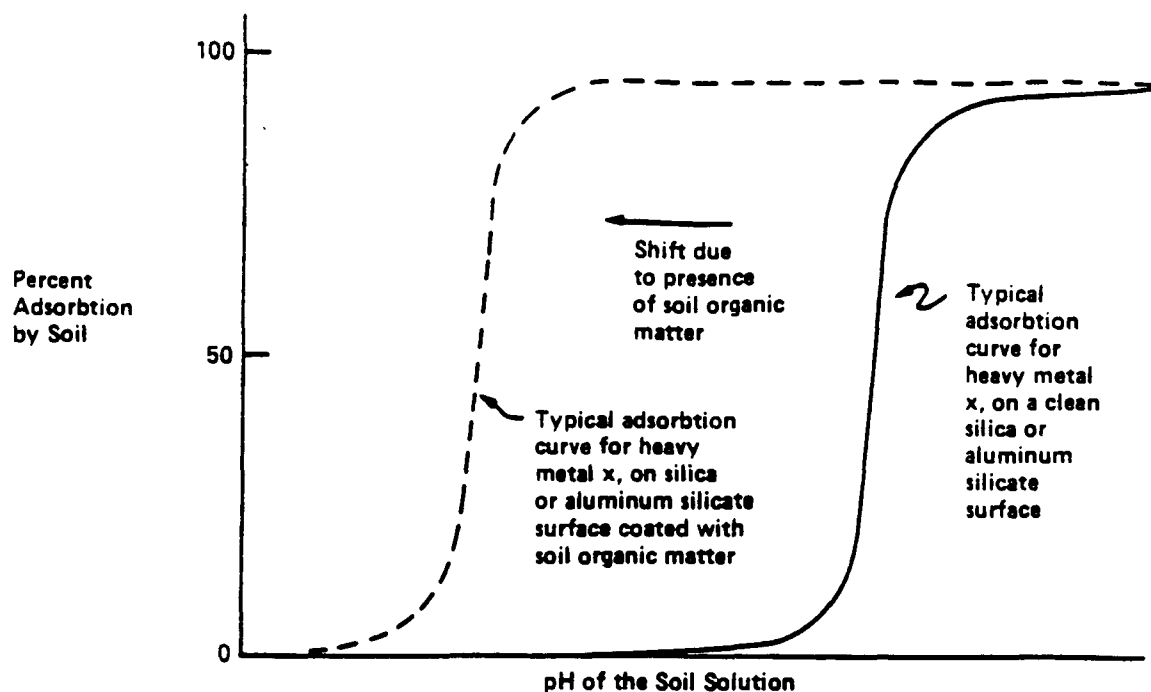
$$R_d = 1 + \frac{K_p \rho_B}{n_e}$$

**TABLE 15-10**  
**RELATIVE MOBILITY OF SOLUTES**

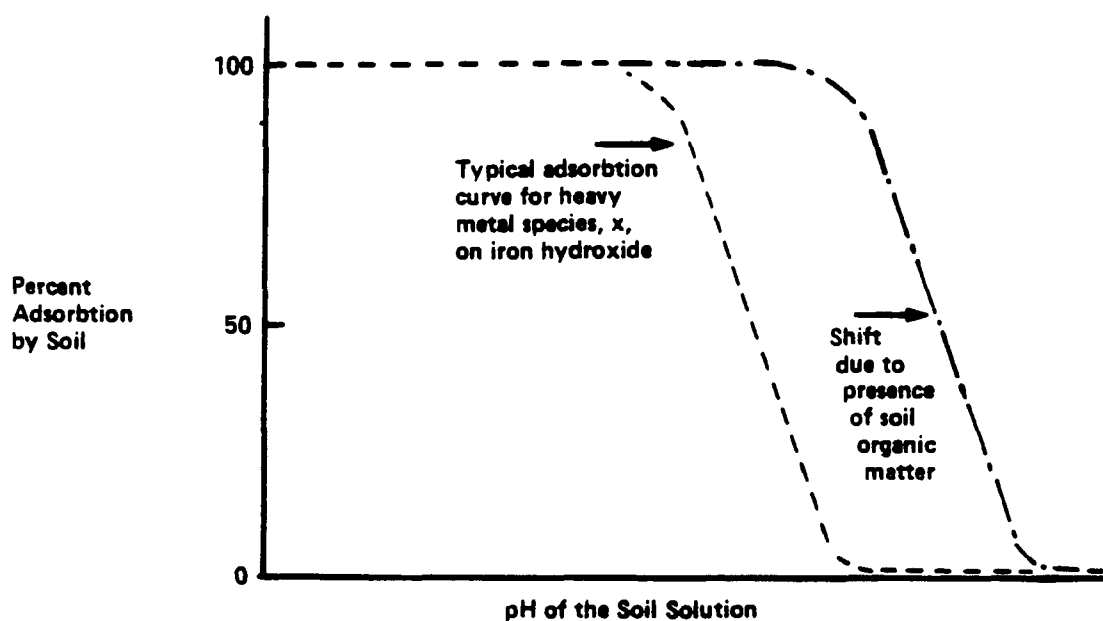
Group	Examples	Exceptions	Master Variables*
Conservative	TDS CL <sup>-</sup> BR <sup>-</sup> NO <sub>3</sub> <sup>-</sup> SO <sub>4</sub> <sup>2-</sup>	Reducing conditions Reducing conditions and in highly weathered soils coated with sesquioxides	v
Slightly Attenuated	B TCE	Strongly acidic systems Anaerobic conditions	v, pH, organic matter v, organic matter
Moderately Attenuated	Se As Benzene		v, pH, Fe hydroxides v, pH, Fe hydroxides v, organic matter
More Strongly Attenuated	Pb Hg Penta- chlorophenol		v, pH, SO <sub>4</sub> <sup>2-</sup> v, pH, Cl v, organic matter

\* Variables which strongly influence the fate of the indicated solute groups.  
Based on data from Mills et al., 1985 and Roi and Zachara, 1984.





a) Generalized Heavy Metal Adsorption Curve for Cationic Species (e.g.,  $\text{CuOH}^+$ )



b) Generalized Heavy Metal Adsorption Curve for Anionic Species (e.g.,  $\text{CrO}_4^{2-}$ )

Source: (Mills et al., 1985).

Figure 15-25. Hypothetical Adsorption Curves for a) Cations and b) Anions Showing Effect of pH and Organic Matter

where

- $K_p$  = soil-water partition coefficient for solute of concern, ml/g  
 $\rho_B$  = soil bulk density, g/ml  
 $n_e$  = effective soil porosity (decimal fraction).

For example, the relative mobility of cadmium at a pH of 7.2 was estimated for this site as shown below:

$$R_d = 1 + \frac{6500(1.7)}{0.11} = 100,456$$

$$V_A = 160/100,000 = 0.002 \text{ ft/yr.}$$

This estimate was consistent with the field data which indicated that the metals migrated only until the pH of the contaminant plume was neutralized, a distance of about 2000 feet. Cadmium concentrations decreased from 1.3 mg/l at a distance of 1400 feet from the ponds to below detection ( $<0.1 \mu\text{g/l}$ ) at a distance of 2000 feet.

Estimates of mobility for organic contaminants which sorb onto soil particles can be made in an analogous manner. The partition coefficient for organic constituents can be calculated using the following equation (Mills *et al.*, 1985):

$$K_p = K_{oc}[0.2(1-f)X^s_{oc} + fX^f_{oc}]$$

where

- $K_p$  = soil-water partition coefficient, ml/g  
 $K_{oc}$  = organic carbon partition coefficient, ml/g  
and  
 $K_{oc}$  =  $0.63 K_{ow}$   
 $K_{ow}$  = octanol-water partition coefficient  
 $f$  =  $\frac{\text{mass of silt and clay}}{\text{mass of silt, clay and sand}}$  ( $0 \leq f \leq 1$ )  
 $X^s_{oc}$  = organic fraction of sand ( $X^s_{oc} \leq 0.01$ )  
 $X^f_{oc}$  = organic fraction of silt-clay ( $0 \leq X^f_{oc} \leq 0.1$ ).

For example, the solvent trichloroethylene (TCE) has a  $K_{ow}$  value of 200. Using the above equation and site data ( $f = 0.1$ ,  $X^s_{oc} = 0.001$ ,  $X^f_{oc} = 0.01$ ), the partition coefficient  $K_p$  was estimated to be 0.2 ml/g. The relative mobility of TCE at the site was then estimated to be approximately 40 ft/yr ( $R_d = 4$  and  $V_A = 40$  ft/yr). Methods for considering additional processes influencing the fate of organics (e.g., hydrolysis and biodegradation) are presented in the manual entitled Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water (Mills et al., 1985).

### Case Discussion

As shown in Figure 15-26, contaminants downgradient of a waste disposal site may migrate at different speeds. Using the methods illustrated above, estimates of the relative mobility of constituents can be made. Such estimates can then be used to locate downgradient monitoring wells and to assist in the interpretation of field data.

### References

Mills, W.B., D.E. Porcella, M.J. Unga, S.A. Gherini, K.V. Summers, L. Mok, G.L. Rupp, and G.L. Bowie. 1985. Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water. EPA/600/6-85/002a, Vol. I, II and III.

Rai, D. and J.M. Zachara. 1984. Chemical Attenuation Studies: Data Development and Use. Presented at Second Technology Transfer Seminar: Solute Migration in Ground Water at Utility Waste disposal Sites. Held in Denver, Colorado, October 24-25, 1985. 63 pp.

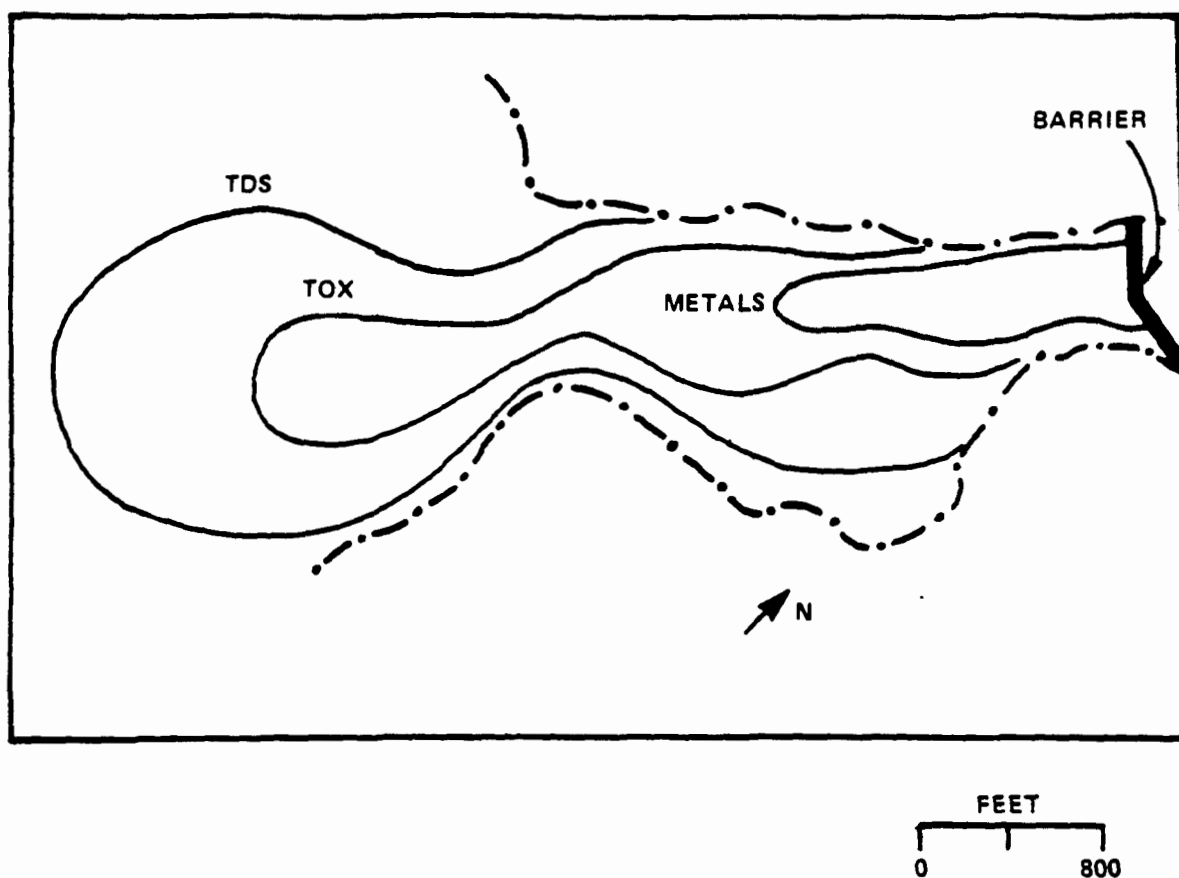


Figure 15-26. Schematic Diagram Showing Plumes of Total Dissolved Solids (TDS), Total Organic Halogens (TOX) and Heavy Metals Downgradient of Waste Disposal Site

## CASE STUDY 16: USE OF LEACHING TESTS TO PREDICT POTENTIAL IMPACTS OF CONTAMINATED SOIL ON GROUND WATER

### Point Illustrated

- o Soil leaching tests can be used in conjunction with waste and site-specific factors to predict potential impacts on ground water.

### Introduction

Contaminated soil, whether deep, or surficial in nature, has the potential to impact ground water, primarily through leaching. In many cases, soil contamination has already lead to contamination of the ground water and decisions can be made regarding clean-up of the contaminated soil and ground water based on the constituent concentrations observed in these media. However, in cases where contaminated soil has not yet resulted in contaminated ground water, but has some potential to do so, decisions need to be made regarding the contaminated soil and whether it should be removed or some other action should be taken because of the soil's potential to contaminate ground water above levels of concern. This evaluation may be especially critical in those cases where only deep soils are contaminated, or where constituent concentrations within surficial soils do not exceed soil ingestion criteria. Both theoretical (mathematical) and physical (leaching test) models can be used in this evaluation, as well as or in conjunction with a qualitative evaluation of release and site-specific factors. This case illustrates the use of leaching tests and consideration of release and site-specific factors to determine whether contaminated soil has the potential to contaminate ground water above levels of concern.

### Facility Description

The facility is an industrial chemical and solvent facility located on a leased 2.5 acre site within the corporate limits of a major city in the north-central United States (see Figure 15-27). Periodic overtopping of the surface impoundment, which is now empty, and suspected contamination of the soil with organic solvents from the surface impoundment, resulted in an RFI in which the facility was directed to characterize the nature, extent and rate of release migration.

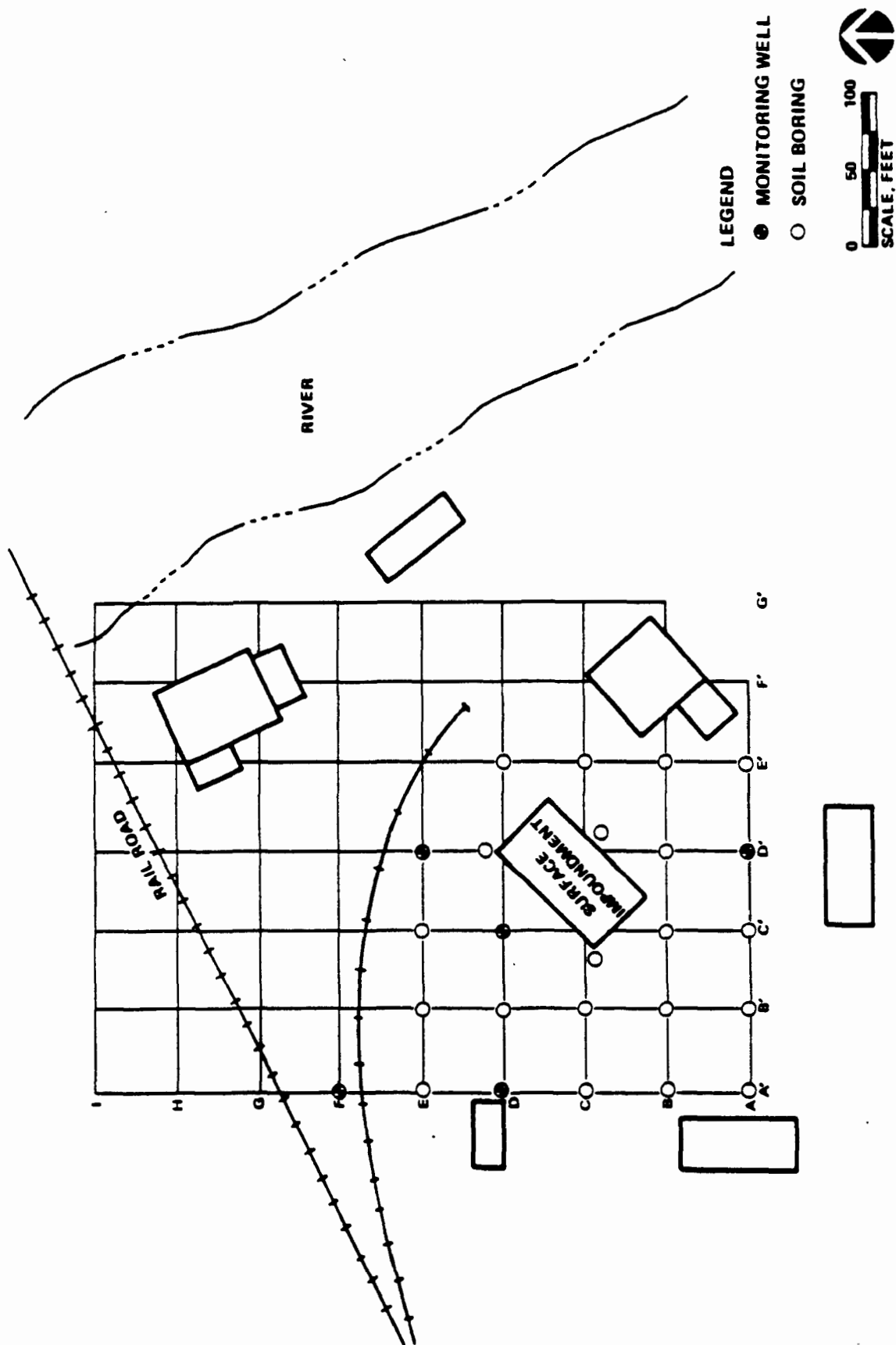


Figure 15-27. Facility Map Showing Soil Boring And Well Installation

Release characterization revealed that the soil surrounding the surface impoundment, which was mostly fine sand and silt with some clay, was contaminated with tetrachloroethylene and 1,1,1-trichloroethane at concentrations ranging from 0.05 to 0.10 and 2 to 20 mg/kg, respectively. This contamination was observed at depths of up to 5 feet, which was approximately 20 feet above the water table (i.e., the water table was approximately 25 feet below the land surface). The soil beneath the site was relatively permeable, with a hydraulic conductivity of approximately  $9 \times 10^{-4}$  cm/sec.

Ground-water monitoring conducted during the RFI showed no current contamination of the ground water, which flows in a northerly direction and eventually intersects the river (Figure 15-28). The river is used for irrigation and drinking at downstream locations. Grab samples taken from the river and river sediments showed no contamination.

The soil in the immediate vicinity of the railroad spur also showed isolated pockets of mercury contamination, ranging in concentration from 1 to 2 mg/kg, and to a depth of 1 foot below the land surface. The source of the mercury contamination could not be determined.

### Contamination Evaluation

The relevant health and environmental (HEA) criteria, the constituent concentrations observed at the site, and selected physical/chemical properties for the three constituents are shown in Table 15-11. Although comparison of the HEA criteria for ingestion with the constituent concentrations observed at the site showed no exceedances, the regulatory agency overseeing the RFI was concerned that leaching of the contaminated soil could lead to eventual contamination of the underlying ground water. This concern was based on the relatively high permeability of the soils beneath the site and the relatively high mobility of the two organic constituents detected. The facility obtained the regulatory agency's approval to conduct a leaching evaluation using EPA's Method 1312 (Synthetic Acid Precipitation Leach Test for Soils).

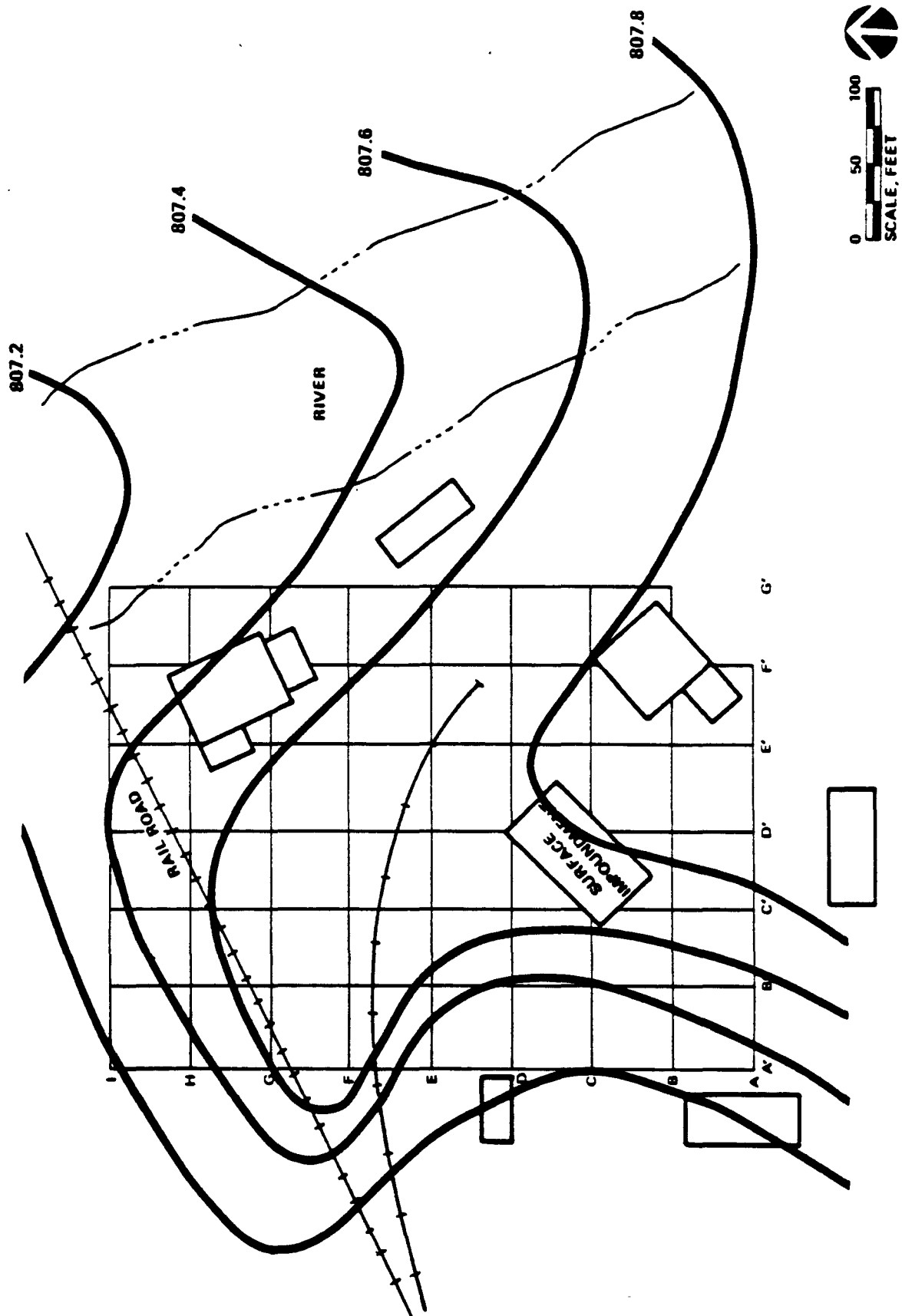


Figure 15-28. Facility Map Showing Ground-Water Contours



TABLE 15-11

**HEA CRITERIA, CONSTITUENT CONCENTRATIONS AND RELEVANT  
PHYSICAL/CHEMICAL PROPERTY DATA FOR CONSTITUENTS OBSERVED AT SITE**

Chemical	CAS No.	HEA Criteria (Ingestion) (mg/kg)	H <sub>2</sub> O Sol (mg/l)	HEA Criteria (Water) (mg/l)	Constit. Conc. (mg/kg)	Koc (mg/l)	Log Kow	Det. Limit* (mg/l)
Tetrachloroethylene	127-18-4	69	150	0.0069	0.10	364	2.6	0.01
1,1,1-Trichloroethane	71-55-6	2,000	1500	0.2	20	152	25	0.01
Mercury	7439-97-6	--	--	0.002	2	Low	--	0.0004

\* Detection limits presented are those for water. Detection limits for soil vary greatly, but may be assumed to be approximately 1 mg/kg.

### Leaching Evaluation

Prior to collecting samples and applying the leaching test, the facility first decided to determine if the contaminated soils could possibly result in leaching test (extract) concentrations that exceed the relevant HEA criteria (See Table 15-11). To do this, the facility calculated the maximum theoretical extract concentration by assuming that 100 percent of the constituents would leach from the soil. The following equation was used:

$$\text{Maximum Theoretical Extract Concentration (mg/l)} = \frac{\text{Concentration of Toxicant in Soil (mg/kg)}}{20}$$

where 20 refers to the liquid to solid ratio applied in EPA Method 1312.

Using this simple equation, the facility determined that the maximum leachate concentration for tetrachloroethylene was, in fact, below the HEA criteria for water (see Table 15-11), and that the level could not possibly be exceeded even if 100 percent of the contaminant leached from the waste. For 1,1,1-trichloroethane and mercury, however, it was determined that the HEA criteria level could be reached if only a portion of the contaminant present leached from the soil, and that application of the leaching test would be necessary. Using this screening-type evaluation, the facility was able to reduce the number of constituents that would need to be analyzed when applying the leaching test, from three to two.

Samples of the contaminated soil were then collected at selected locations (i.e., those expected to produce the more heavily contaminated samples) and Method 1312 applied. Total constituent analyses were also conducted in order to ensure that the samples represented the more heavily contaminated areas of the site. Analyses of the soils and leaching test extract were conducted for 1,1,1-trichloroethane and mercury. The results are shown in Table 15-12.

The leaching test results for 1,1,1-trichloroethane and mercury showed extract concentrations above the respective HEA criteria (action levels) for these

**TABLE 15-12**  
**LEACHING TEST RESULTS (mg/l)\***

Constituent	D-C'	C-C'	C-B'
1,1,1-Trichloroethane	0.3	0.2	0.5
Mercury	0.002	0.002	0.003

\* Resampled at locations close to original sampling point. Samples analyzed are result of composite of three grab-samples. All samples were taken from the top 0-1 ft of the soil surface.

constituents, indicating that there might be a basis to require some sort of corrective action. The facility, however, presented arguments to show that mercury would be attenuated in the soil column as the leachate percolates towards the water table, and that 1,1,1-trichloroethane would be degraded to below the level of concern in the ground water. Below is a synopsis of the two arguments.

Mercury: The facility first examined theoretical Eh-pH fields of stability for the various aqueous mercury species; determined that the predominant mercury species would be elemental mercury, and further predicted (using Eh-pH diagrams) that the maximum equilibrium concentration of elemental mercury in water would be 0.025 mg/l. The facility interpreted the substantially lower leaching test concentration to indicate that attenuation processes such as sorption play a major role in restricting the mobility of elemental mercury. The facility cited high soil/water partition coefficients (i.e., K<sub>d</sub> values), and several scientific studies to further support their contention that mercury would strongly sorb to both organic and inorganic components of the soil before any leachate reached the ground water.

1,1,1-Trichloroethane: The facility recognized that due to its high solubility (1500 mg/l) and low K<sub>d</sub> (0.011 ml/g), 1,1,1-trichloroethane would not be attenuated appreciably as the leachate percolates towards the water table. The facility argued, however, that abiotic hydrolysis would significantly degrade 1,1,1-trichloroethane during leaching. Several environmental half-life studies were cited which indicated that the half life for 1,1,1-trichloroethane ranged between 0.5 and 2.5 years. Based on these studies, the facility predicted that 1,1,1-trichloroethane would be degraded to below levels of concern within one to three years. Using additional site information and simple time of travel calculations, the facility predicted that concentration levels for 1,1,1-trichloroethane would be decreased to below the level of concern well before reaching any potential receptors.

The regulatory agency's evaluation of the facility's arguments is presented below:

Mercury: The facility's argument with respect to mercury is essentially correct if it can be assumed or proven that the mercury originally present at the site is inorganic in nature. If, however, the mercury present is organic in nature (e.g.,

methyl mercury), the potential for migration of the mercury is substantially increased. Organic mercury compounds generally have higher volatility, higher solubility, and much lower Kd values than inorganic mercury compounds. It should also be noted that even if the original release was of inorganic mercury, biotransformation (i.e., biomethylation) of elemental mercury may occur. The facility should be required to determine the actual form(s) of mercury present at the site.

1,1,1-Trichloroethane: The facility's argument with respect to 1,1,1-trichloroethane raises many technical questions. For example, the facility uses published data on the half life of 1,1,1-trichloroethane, which may not be applicable to the facility's soil and ground-water environment. As another example, the half-life degradation rate argument may only be applicable for ground-water transport. The facility does not address degradation in soil or effects on surface water (assuming that contaminated ground-water will eventually migrate to the river). Most important, however, is the fact that the facility did not address the degradation products of 1,1,1-trichloroethane, one of which is 1,1-dichloroethylene, which is also a hazardous constituent. 1,1,1-trichloroethane should be assumed to pose a threat to ground water.

### Conclusions

The next step in the RFI process would be to determine if interim corrective measures or a Corrective Measure Study was warranted for the release. Although none of the soil ingestion HEA criteria were exceeded at the site, application of the leaching evaluation indicated that 1,1,1-trichloroethane could leach to ground water and result in exceedance of the HEA criterion for water. On this basis, the facility should be directed to perform a Corrective Measures Study.

To prevent further contaminant migration, the application of interim corrective measures may also be considered. Construction of a temporary cap over the contaminated area is one option. Perhaps a more appropriate measure would be to remove the contaminated soil. Such an action, taken as an interim corrective measure, may negate the need for a formal Corrective Measures Study.

## Case Discussion

Leaching tests and similar evaluations (e.g., application of validated mathematical leaching models) can be used to identify potential problems due to leaching of contaminated soils. In this case, application of a leaching evaluation was instrumental in identifying a potential threat to ground water as a result of leaching of contaminated soil. This finding was particularly significant as HEA ingestion criteria were not exceeded.

It should be noted, however, that in some cases leaching tests may provide results that are difficult to interpret. For example, consider what would have happened if the soil underlying the facility was predominantly clay with a permeability on the order of  $10^{-8}$  cm/sec. In this case, demonstrating that leaching will most likely occur within the foreseeable future may be difficult. As another example, if the soil underlying the facility were predominantly sand, leaching would be probable. In both these cases, application of a leaching test may not provide any more useful information than is already available. Careful consideration of release and site-specific information is always warranted prior to application of leaching tests.

## CASE STUDY 17: USE OF SPLIT-SPOON SAMPLING AND ON-SITE VAPOR ANALYSIS TO SELECT SOIL SAMPLES AND SCREENED INTERVALS FOR MONITORING WELLS

### Point Illustrated

- HNU and OVA/GC screening can provide a relative measure of contamination by volatile organics. It can be used to select soil sample locations and can assist in the selection of screened intervals for monitoring wells.

### Introduction

On-site vapor screening of soil samples during drilling can provide indications of organic contamination. This information can then be used to identify apparent hot spots and to select soil samples for detailed chemical analyses. In this manner, the use of higher powered laboratory methods can be focused in an effective way on the analysis of samples from critical locations and depths. The vapor analyses on-site can also be helpful in selecting screened intervals for monitoring wells.

### Facility Description and History

Manufacturing of plastics and numerous other chemicals has occurred at the site over the past 30 years. Some of the major products included cellulose nitrate, polyvinyl acetate, phenol, formaldehyde, and polyvinyl chloride. The entire site covers 1,000 acres. The location of the buildings and waste disposal areas are shown in Figure 15-29. This is the same facility as used in Case Studies 7, 8 and 14.

Three disposal methods are known to have been employed at the site. Readily combustible materials were incinerated in four burning pits, while non-combustibles were either disposed of in landfills or in a liquid disposal area. All on-site disposal operations were terminated in 1970, and monitoring programs have been implemented to identify contaminants, define and monitor ground-water contaminant plumes, and assess the resulting environmental impacts.

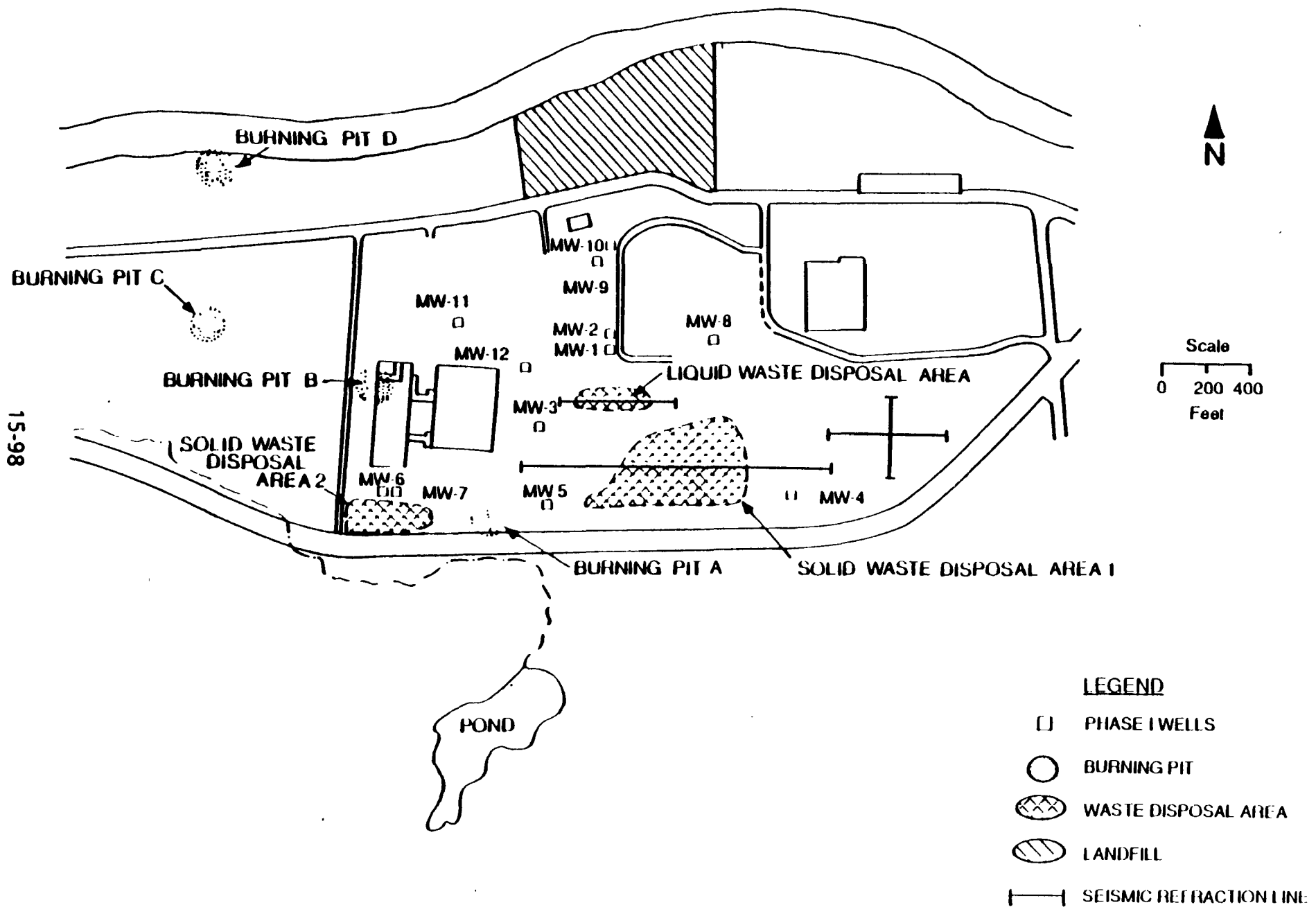


Figure 15-29. Site Plan Showing Disposal Areas and Phase I Well Locations



### Geologic and Hydrologic Setting

The site is located in a well-defined glacial valley, adjacent to a river. Three major units underlie the site, consisting primarily of sand and gravel outwash deposits; fine-grained lacustrine sands; and till. The middle sand unit contains lenses of silt, clay and till. Only the deep till formation appears to be continuous across the site. A geologic cross-section beneath two of the disposal areas is shown in Figure 15-30.

The ground-water flow direction at the site is to the northwest. However, there appears to be a buried stream channel running across the site which strongly influences the local ground-water flow regime (see Figure 15-31). Ground water from the site is thought to discharge to the river. The depth to ground water varies from 10 to 40 feet.

### Sampling Program

As part of the remedial investigation at this site, 33 borings were drilled using a hollow-stem auger rig. Continuous soil samples were collected using split-spoon samplers. Samples for laboratory chemical analysis were selected based on the volatile organic concentrations detected by initial vapor screening of the soil samples in the field.

This field screening was achieved by placing a portion of each sample core in a 40 ml glass headspace vial. An aliquot of gas was extracted from the vial and injected directly into a portable OVA gas chromatograph (OVA/GC). The chromatograph was equipped with a flame ionization detector to identify hydrocarbons. Each sample was also screened using an HNU photoionization detector because of its sensitivity to aromatic hydrocarbons, particularly benzene, toluene and the xylenes. Following completion of drilling, gamma logs were run on all boreholes.

An example of the vapor screening results (HNU and OVA/GC) and geological and gamma logs for one of the boreholes are shown in Figure 15-32. The data shown demonstrate the differential sensitivity of the HNU and OVA/GC detectors. Because the OVA/GC is more sensitive to the organics of interest (aliphatics),

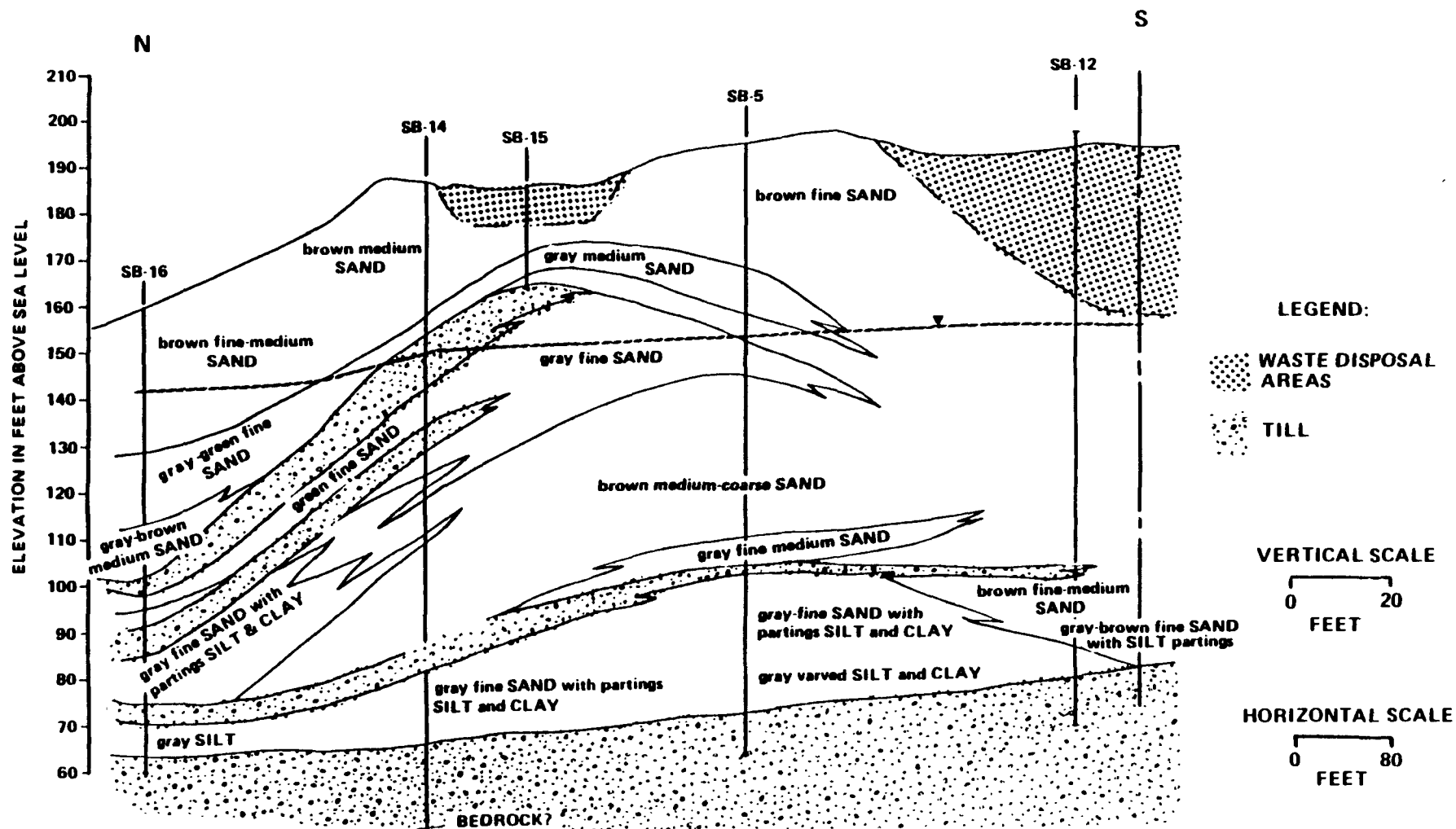


Figure 15-30. Geologic Cross-Section Beneath Portion of Site

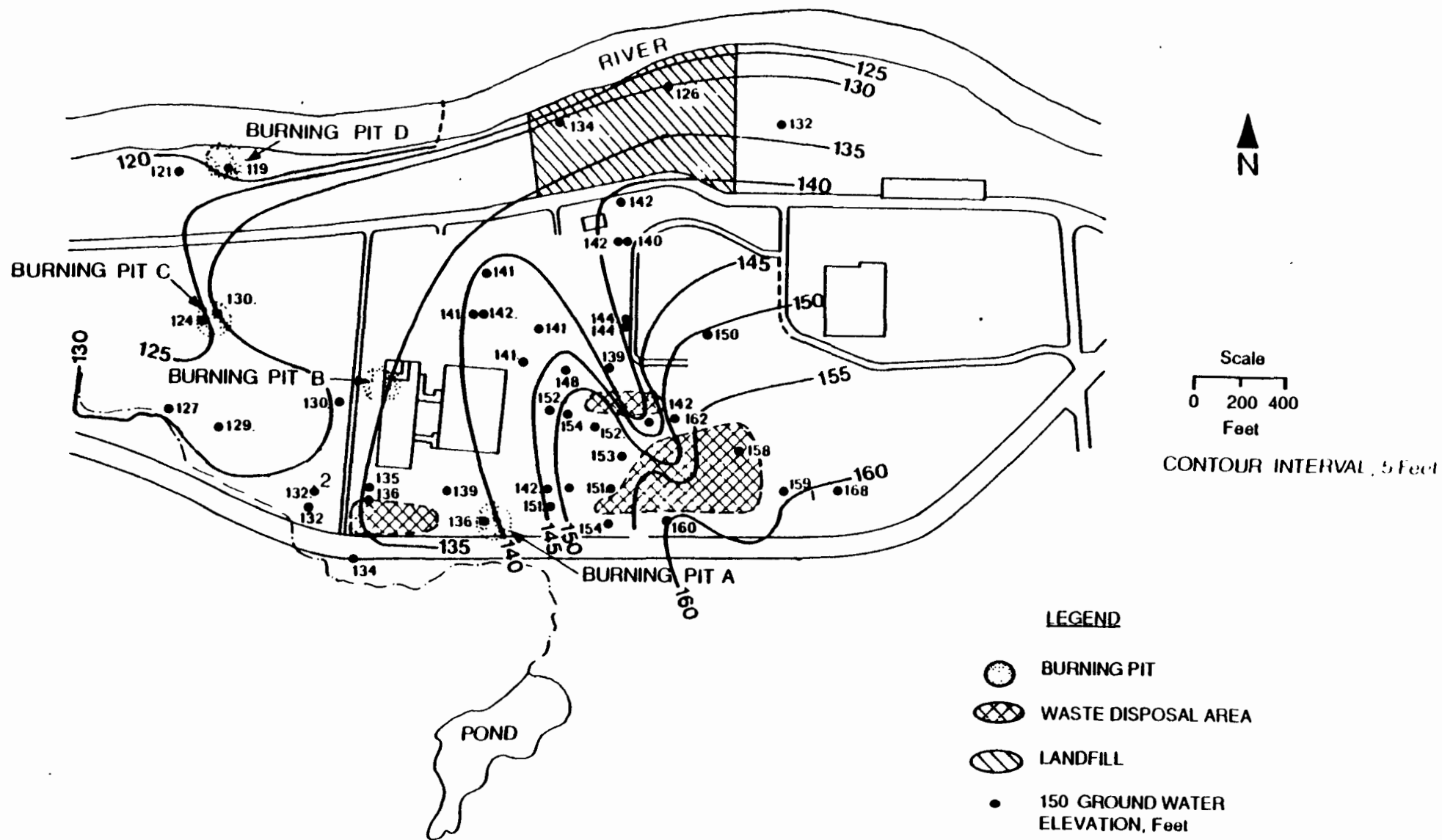


Figure 15-31. Ground-Water Elevations in November 1984

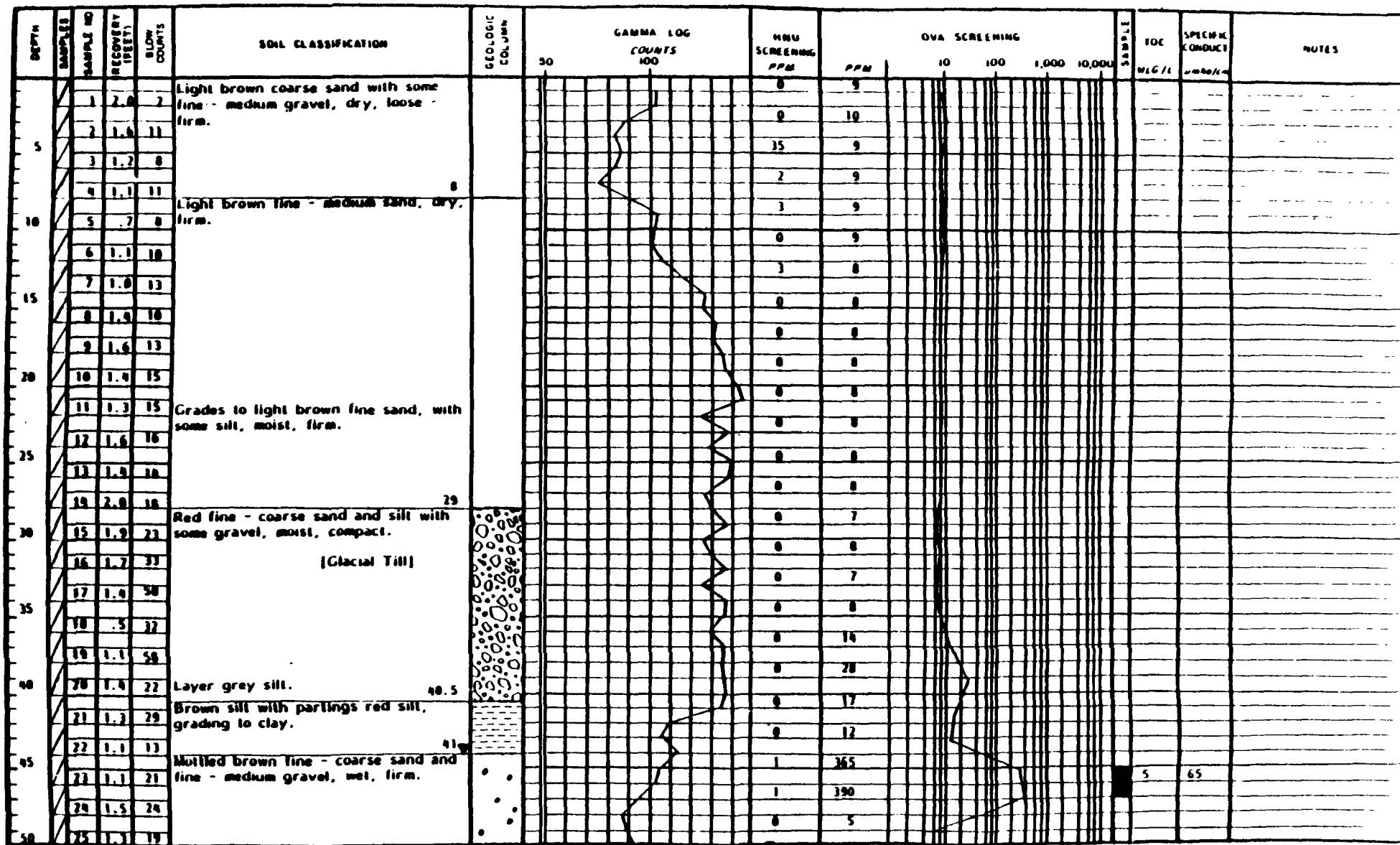
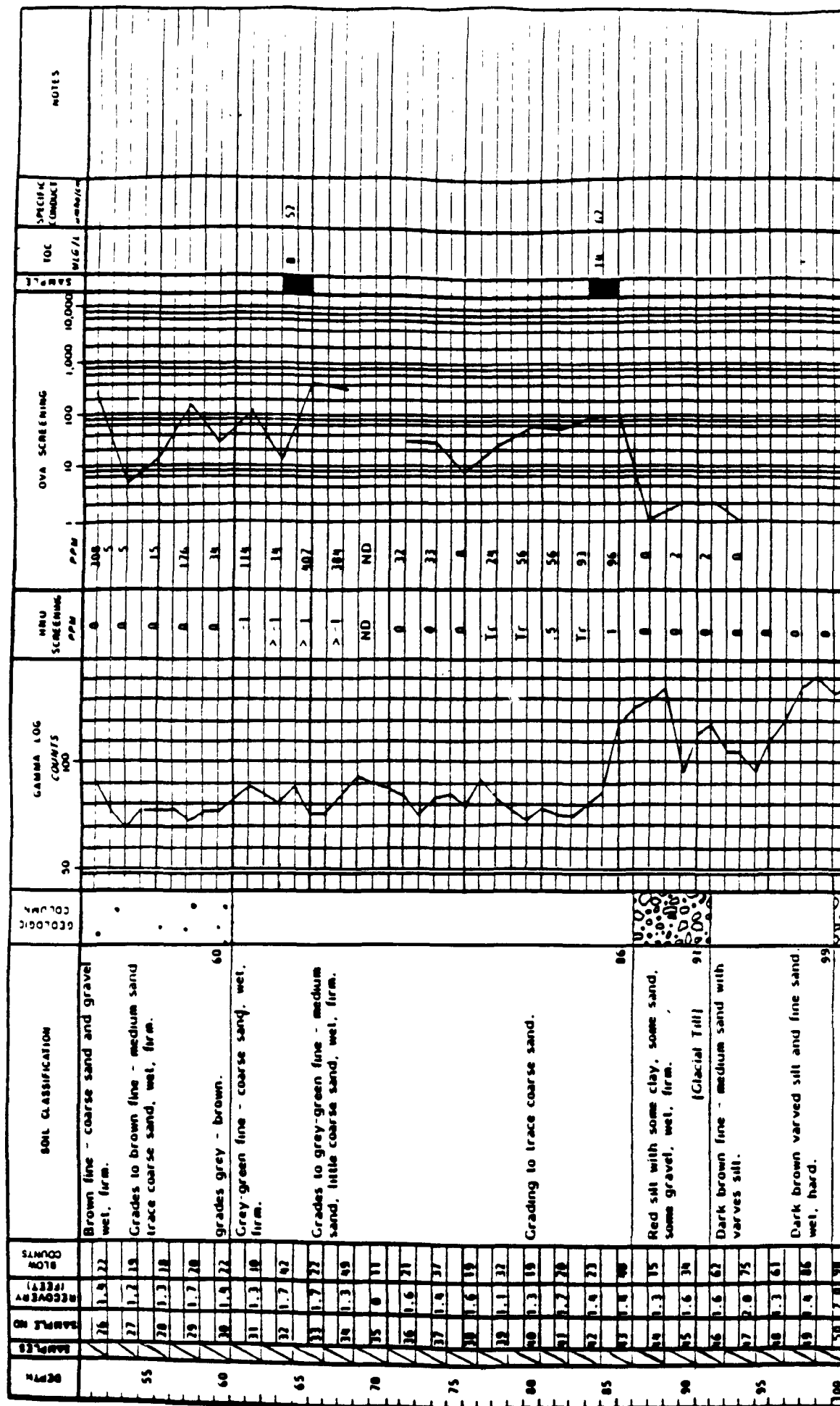


Figure 15-32. Example of Borehole Data Including HNU and OVA/GC Screening



**Figure 15-32. Example of Borehole Data Including HNU and OVA/GC Screening**  
(continued)

these results were used to select samples for detailed chemical analysis in the laboratory. As shown in Figure 15-32, samples in zones with OVA/GC readings of 365 ppm (45 feet deep), 407 ppm (65 feet deep), and 96 ppm (85 feet deep) were selected. In the laboratory, samples were first analyzed for total organic carbon (TOC). The ten samples with the highest TOC levels were then analyzed for purgeable organics using EPA Method 50-30 and extractable organics using EPA Method 82-50 (U.S. EPA, 1982 - Test Methods for Evaluating Solid Waste, SW 846).

The OVA/GC results were also used to select well screen intervals. Examination of the data in Figure 15-32 shows that the highest levels of volatile organics (by OVA/GC) were found at a depth of 65 feet. In addition, the gamma and geologic logs indicated that the permeable medium at that depth was coarse sand which would be a suitable location for the placement of a well screen. Thus, a 5-foot stainless steel screen was set over the depth interval of 62 to 67 feet.

### Case Discussion

This sampling program incorporated field techniques that detect the presence of volatile organics and allow on-site, rapid identification of likely contaminant "hot spots" for detailed laboratory analysis and to select depths for monitoring well screens.

## CASE STUDY 18: CONDUCTING A PHASED SITE INVESTIGATION

### Points Illustrated

- When ground-water contamination is known or suspected at a site, a set of initial borings is typically made to determine site hydrogeologic characteristics and to identify areas of soil and ground-water contamination (Phase I).
- These findings are then used to select well locations to fully delineate the extent of contamination (Phase II).

### Introduction

To identify the extent of ground-water contamination in an efficient manner, information is needed on the ground-water flow regime. Phase I investigations typically focus on determining site geologic characteristics and ground-water flow directions and velocities. Waste sources are also identified. The Phase I results are then used in planning the Phase II investigation to determine the extent of contamination and to refine estimated rates of contaminant migration.

### Facility and Site Description

Descriptions of the facility and site geologic characteristics were included in Case Studies 7, 8, 14 and 17.

### Sampling Program

The Phase I sampling program included geophysical surveys, water level monitoring, soil sampling, and ground-water quality sampling. Three seismic refraction lines were run to estimate the depth to the top of the deep till. The top of the till was found to occur at a depth of 70 to 120 feet over most of the site.

Available historical data indicated that the general ground-water flow direction was to the northwest across the site. The ground water was thought to discharge to the river. This information and historical drawings and maps of known

disposal areas were used to locate the Phase I borings (see Figure 15-29 in Case Study 17). One well (MW4) was located on the suspected upgradient side of the site. The other wells were located near waste sources to determine which sources appeared to be contributing contaminants to the ground water. For example, two wells (MW6 and 7) were immediately downgradient of solid waste disposal area #2. To determine the presence of vertical gradients, three two-well clusters were drilled--each with one well screened just below the water table and a second well screened considerably below that at the base of the till.

The results of the Phase I investigation indicated that all the wells contained solvents. Thus, investigations of the waste sources and contaminant plumes were continued in Phase II. The highest solvent concentrations were found in wells located near the liquid waste disposal area where downward vertical gradients were present. The contaminants had migrated down to depths of 75 feet in this portion of the site. The Phase I data confirmed the general northwest ground-water flow direction but showed a complex flow pattern near the buried stream channel. A second concern was whether observed lenses of fine-grained till under the site were producing localized saturated zones which could be contaminated.

Based on the Phase I results, a Phase II monitoring program was designed to determine the extent of contamination around the major disposal sites. Typically, two soil borings were made - one up- and one downgradient of the waste source. Because of the high solvent concentrations observed in the wells downgradient of the liquid disposal area, a more intensive field investigation of this area was included in Phase II. Instead of two borings per waste source at the liquid disposal area, 11 soil borings and five new monitoring wells were drilled. This represented one-third of the total effort for the entire 1,000 acre site. The total number of Phase II soil borings was 33 (Figure 15-33) and the total number of Phase II wells was 15 (Figure 15-34). The Phase II data indicated that most of the solvent contamination originated from the liquid disposal area and not from solid waste disposal area #1 which is upgradient of the liquid disposal area. The Phase II data did identify PCBs from solid waste disposal area #1 but not from any of the other sources. This was consistent with site records indicating that transformers had been disposed at this area.



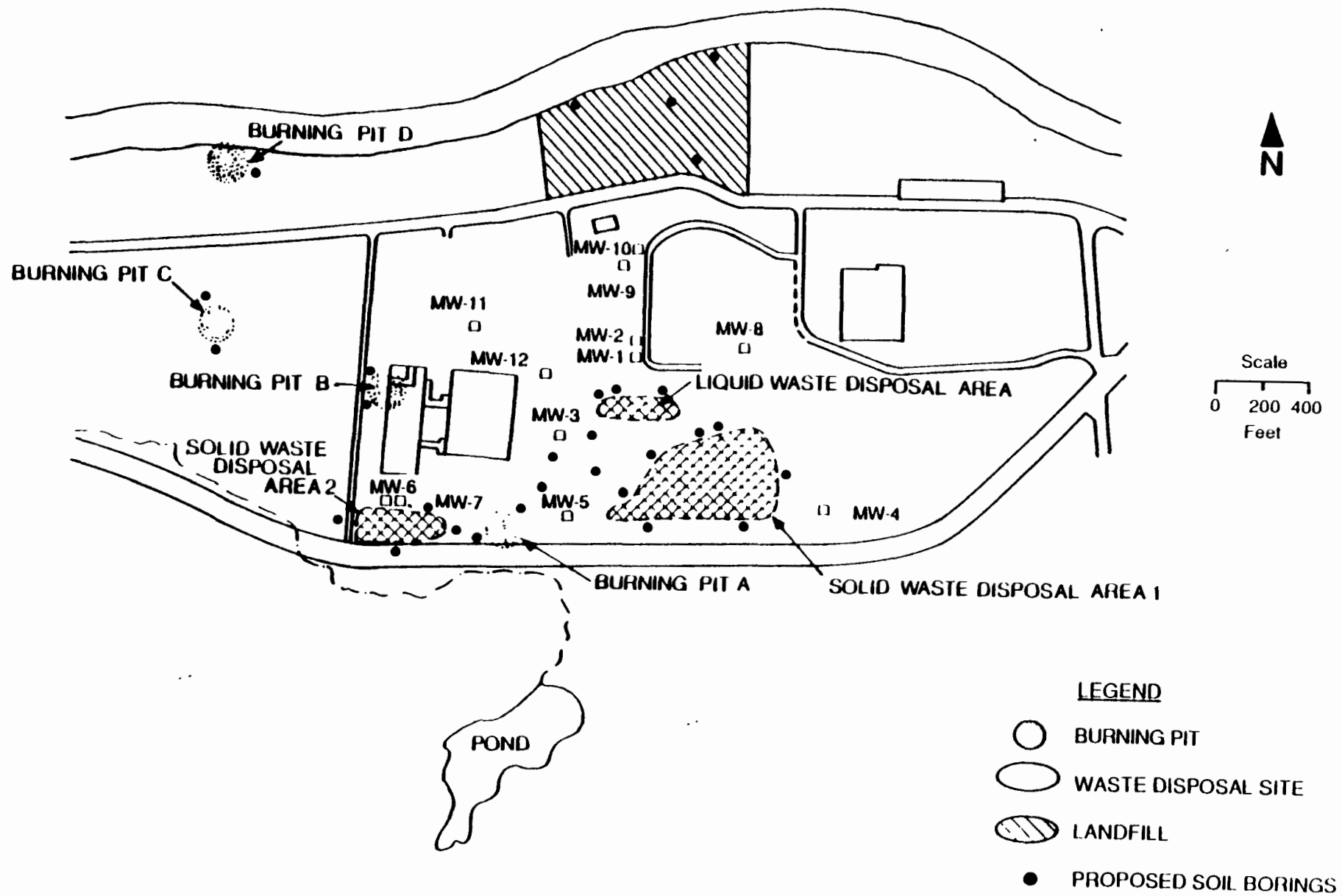


Figure 15-33. Proposed Phase II Soil Borings

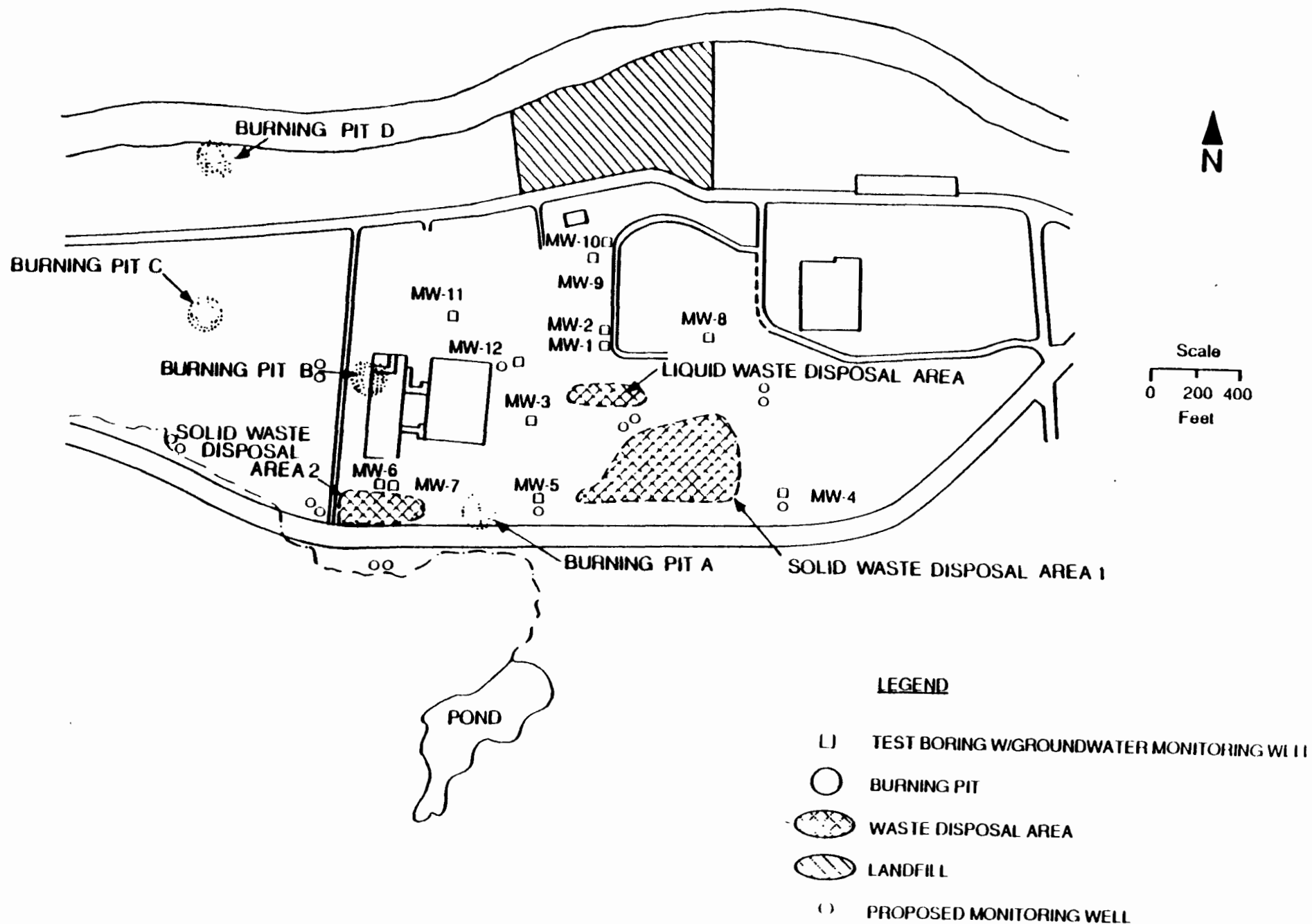


Figure 15-34. Proposed Phase II Monitoring Wells

## Case Discussion

Investigation of a large complex site is commonly conducted sequentially. Basic information is needed on site geologic characteristics and ground-water velocities and directions to appropriately locate wells for determining the extent of contamination. Thus, the initial installation of a limited number of exploratory borings and wells can provide the data needed to design a complete and effective investigation. Results from the latter investigation can then be used to determine the need for remedial action and to evaluate alternative remediation methods.

## CASE STUDY 19: MONITORING BASEMENT SEEPAGE

### Point Illustrated

- Basement monitoring can be used to estimate the extent of contaminant migration.

### Introduction

Leachate produced in a landfill can be transported downgradient in ground water by advection and dispersion. Shallow ground water may surface and seep into basements.

### Site Description

A channel, originally constructed as part of a hydroelectric power generation system, was used as a disposal site for a variety of chemical wastes from the 1920s through the 1950s. More than 21,000 tons of waste were dumped in and around the site before its closure in 1952. After closure, homes and a school were constructed on and around the site. In the 1960s, residents began complaining of odors and residues. During the 1970s, the local water table rose, and contaminated ground water seeped into nearby basements.

### Geologic and Hydrologic Setting

Figure 15-35 shows a cross-section of the site. The site has both a shallow and a deep aquifer. The shallow aquifer consists of approximately 5 feet of interbedded layers of silt and fine sands overlying beds of clay and glacial till. The deeper aquifer is a fractured dolomite bedrock overlying a relatively impermeable shale. Travel times from the shallow to the deeper aquifer are relatively long. Contamination has occurred in the shallow aquifer because of the "bathtub effect". The impermeable channel filled because of infiltration, and leachate spilled over the channel sides. The leachate contaminated the shallow ground water and was transported laterally in this system.

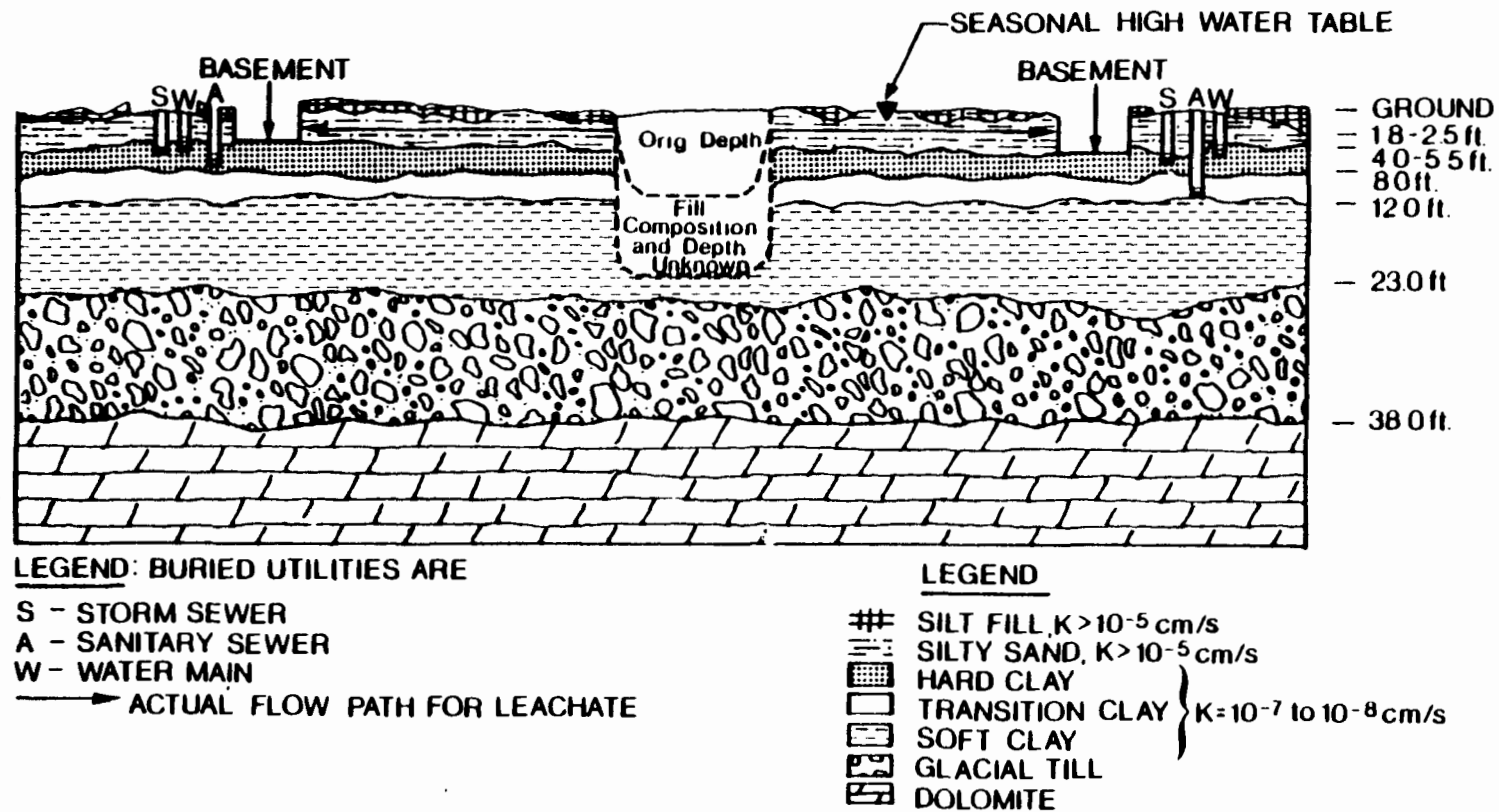


Figure 15-35. Geologic Cross-Section Beneath Site

## Sampling Program

The houses surrounding the channel were grouped into three sets (upgradient, downgradient, and on-site) based on preliminary data on the underlying strata and ground-water flow directions. Four houses from each group were selected for sampling for a total of 12 houses. Samples of water and sediments were collected from the sump pump wells in each basement. Water samples were collected when the sump pumps were running and 24 hours after pumping had ceased. Water and sediment samples were analyzed for purgeable and extractable organics. Benzene, carbon tetrachloride, chloroform, and trichloroethylene (TCE) were found in the water samples. Water samples taken while the sump pumps were running had higher concentrations of volatile organics. Sediment samples contained PCBs and dioxin, possibly due to cosolvation. Relatively immobile organics can become dissolved in another more mobile solvent. The mobile solvent containing traces of other organics can be advected along with the water. This process (cosolvation) is one facet of enhanced transport which has recently been proposed as a possible mechanism for the observed mobility of otherwise immobile organics. Samples of water and sediments from storm drains were also collected and analyzed to determine if discharges from the sumps to the storm drains were a significant source of organics in the storm runoff.

In addition to determining water quality, indoor and outdoor air quality was measured in the basements at each house. Tenax and polyurethane foam tubes were placed in air monitoring systems in each basement to measure 12-hour average concentrations of volatile organics (e.g., carbon tetrachloride, benzene, and TCE) and semi-volatile organics (e.g., pesticides). Volatile organics were present in the indoor air samples but semi-volatile organics were not detected. The highest volatile organic concentrations were observed when the sump pumps were operating.

## Case Discussion

At sites where hydrogeologic factors favor shallow lateral ground-water flow, initial site characterization may involve sampling of basements. Results from such an initial site characterization can provide information on contaminant migration

which can be used in the design and implementation of detailed soil and ground water monitoring programs.

The results of the sampling program described above led to the evacuation and destruction of a number of homes. A system of monitoring wells has been installed to replace the basement sump sampling sites. The shallow aquifer is being pumped and treated to arrest contaminant migration.

## CASE STUDY 20: USE OF PREDICTIVE MODELS TO SELECT LOCATIONS FOR GROUND-WATER MONITORING WELLS

### Point Illustrated

- Simple mathematical models can be used to estimate the longitudinal and transverse spread of a contaminant plume. Wells can then be located in areas expected to have elevated contaminant concentrations and in areas thought to be both up- and downgradient of the plume.

### Introduction

The use of mathematical models to estimate the migration of contaminants can be helpful for several reasons, including: 1) fewer wells may be needed to delineate a contaminant plume, and 2) wells can be rationally located in an attempt to determine the maximum concentrations in a plume, its furthest extent, and locations where concentrations should be at background levels.

### Facility Description

The site was an electronics manufacturing plant that had been in operation for 20 years. Four large diameter, rock-filled "dry wells" had been used to dispose of solvents and process wastes. These disposal units were between 35 and 60 feet deep. Depth to ground water was over 460 feet. Disposal Units 1 and 2 had received paint wastes and solvents, including trichloroethylene (TCE) and tetrachloroethylene, between 1964 and 1979. Disposal Units 3 and 4 had been used to dispose of plating solutions and spent acids between 1971 and 1977. These solutions contained copper, chromium, nickel, lead and tin. All the disposal units were closed in 1982. Exact quantities of wastes disposed are not known.

### Geologic and Hydrologic Setting

The site is located in a large alluvial basin in an arid region. The basin alluvium is over 1,000 feet thick and consists of an upper sand and gravel unit, a middle silty-clay unit, and a lower sand and gravel unit. Granitic bedrock underlies the unconsolidated formations. Prior to large withdrawals of ground water, the upper



unit had been saturated. At present, the silty-clay unit acts as an aquitard so that water beneath it is under confined conditions. The potentiometric surface is now 350 feet below the land surface. In addition to a drop in water level elevations, the ground-water flow direction has changed over the years from east to north in response to changing pumping regimes. Estimated horizontal flow velocities have varied from 10 to 40 feet/year.

### Site Investigation

In 1982, city water officials discovered TCE in water samples from wells within 3 miles of the site. On its own initiative, the site owner began a pre-remedial investigation, and then later a remedial investigation, to determine whether his site could be a source of the TCE. The pre-remedial investigation provides an example of how simple models can be used to determine well locations. The pre-remedial investigation included sampling nearby wells and drilling a single deep sampling well (over 500 feet deep).

Original plans called for locating the deep monitoring well between the waste disposal units in an attempt to determine whether solutes had contaminated the underlying ground water. However, site constraints, including an overhead power transmission line, underground power lines and major manufacturing buildings, necessitated that the monitoring well site be moved. The next step was to determine an appropriate location for this well. Because of the changing ground-water flow direction at this site, it was decided to use a simple mathematical model to predict the areal extent of contamination from the disposal units. The results would then be used in selecting a new location for the deep monitoring well. Data were collected to determine historical hydraulic gradients, pumping histories, and aquifer hydraulic characteristics (e.g., conductivity, porosity). Following data collection, a vector analysis model "the method of Mido" (1981) was used to predict plume evolution. The results showed that the major plume migration was to the north (Figure 15-36). Thus, the well was located north of the disposal units at a distance of 60 feet from Unit 4.

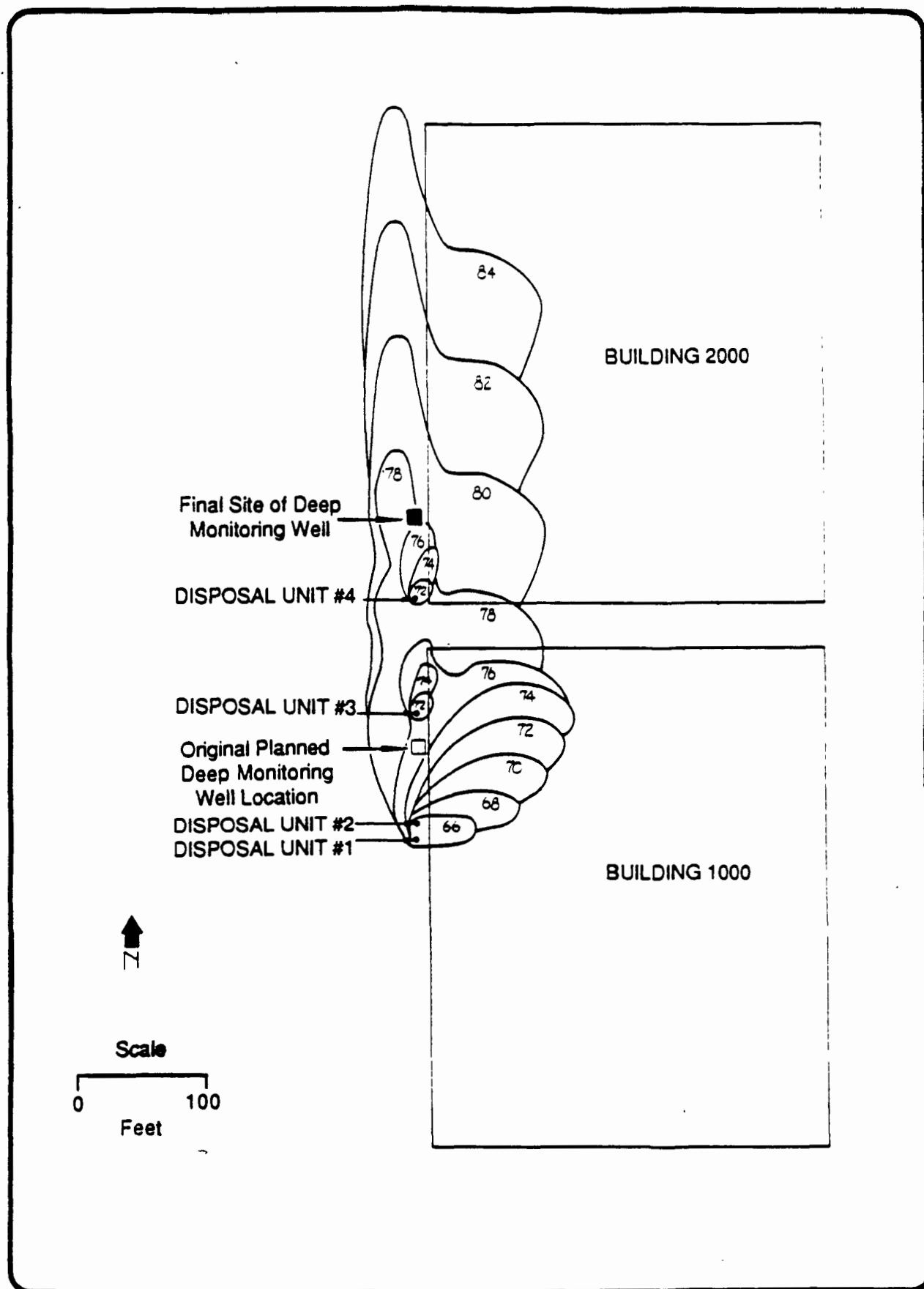


Figure 15-36. Estimated Areal Extent of Hypothetical Plumes from Four Wells

## Case Discussion

Use of a model to predict potential plume migration at this site provided a means of evaluating the long-term consequences of changing ground-water flow directions and velocities. Thus, the pre-remedial investigation deep monitoring well could be sited in the direction of net plume displacement, rather than at a location which might have had a low probability of intercepting contaminated ground water. A concentration below the detection limits from a well located beyond the expected plume boundaries would have been inconclusive (for example, see Figure 15-37). However, the deep monitoring well was located close to the disposal units and in the direction of plume migration. Additional wells are now being planned for the full-scale remedial investigation.

## Reference

Mido, K.W. 1981. An economical approach to determining extent of ground water contamination and formulating a contaminant removal plan. Ground Water, Vol. 19, No. 1, pp. 41-47.

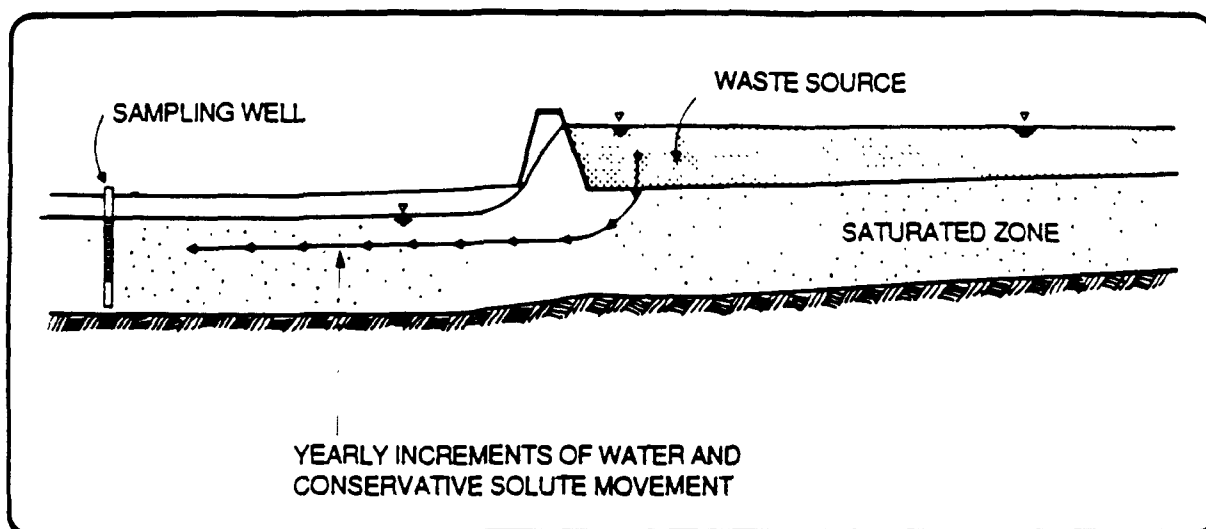


Figure 15-37. Consideration of Solute Migration Rates in Siting Sampling Wells.

If a monitoring well is sited farther downgradient than solutes could have traveled in the time since disposal, low concentrations in the well would certainly not prove that ground-water contamination had not or was not occurring. Prior to locating a well, average linear velocities should be estimated ( $v = Ki/\eta_e$  where  $v$  = average linear velocity for conservative solutes,  $K$  = hydraulic conductivity,  $i$  = ground-water gradient, and  $\eta_e$  = effective porosity). Using these estimates, and the age of the disposal unit,  $T$ , an approximate migration distance,  $D$ , can be computed ( $D = T/v$ ) for conservative solutes associated with the waste. For soil interactive solutes, migration distances will be less. Methods for estimating these distances are given by Mills *et al.* (1985).

## CASE STUDY 21: MONITORING AND CHARACTERIZING GROUND-WATER CONTAMINATION WHEN TWO LIQUID PHASES ARE PRESENT

### Point Illustrated

- Monitoring and characterizing ground-water contamination when two or more liquid phases are present requires knowledge of the physical and chemical properties of each phase.

### Introduction

Ground-water supplies are susceptible to contamination by immiscible organic liquids. Organic liquids such as PCB-contaminated transformer oils, petrochemical solvents, and motor fuels, because of their nature, often form a second liquid phase. This separate liquid, in either the vadose or saturated zone, represents a problem in multiphase flow. It is necessary to understand how these separate phases behave when designing monitoring and sampling programs for sites contaminated with such liquids. Techniques commonly used for single-phase flow systems may not be appropriate.

### Site Description

The facility is a transformer manufacturing plant which experienced a major discharge of polychlorinated biphenyls (PCBs) and trichlorinated benzenes (TCBs). The discharge resulted from a break in a buried pipeline, but surface spillage may have also occurred during production. The volume and duration of the subsurface discharge is not known; neither is the quantity released by above ground spillage.

### Geological and Hydrologic Setting

The site is comprised of 10 feet of fill over lacustrine clay which varies in thickness from 20 to 30 feet. Fractures with openings of approximately 0.1 cm have been observed in the clay. Below the clay lies a thin silt layer. Below that is a 40- to 60-foot-thick layer of glacial till composed of fine sand near the top, and gravel, sand, and silt below.

Perched water about 3 feet deep flows laterally in the fill. The permanent water table, located in the till, is partially confined. Potentiometric levels in this latter system are between 25 and 30 feet below the land surface.

### Sampling Program

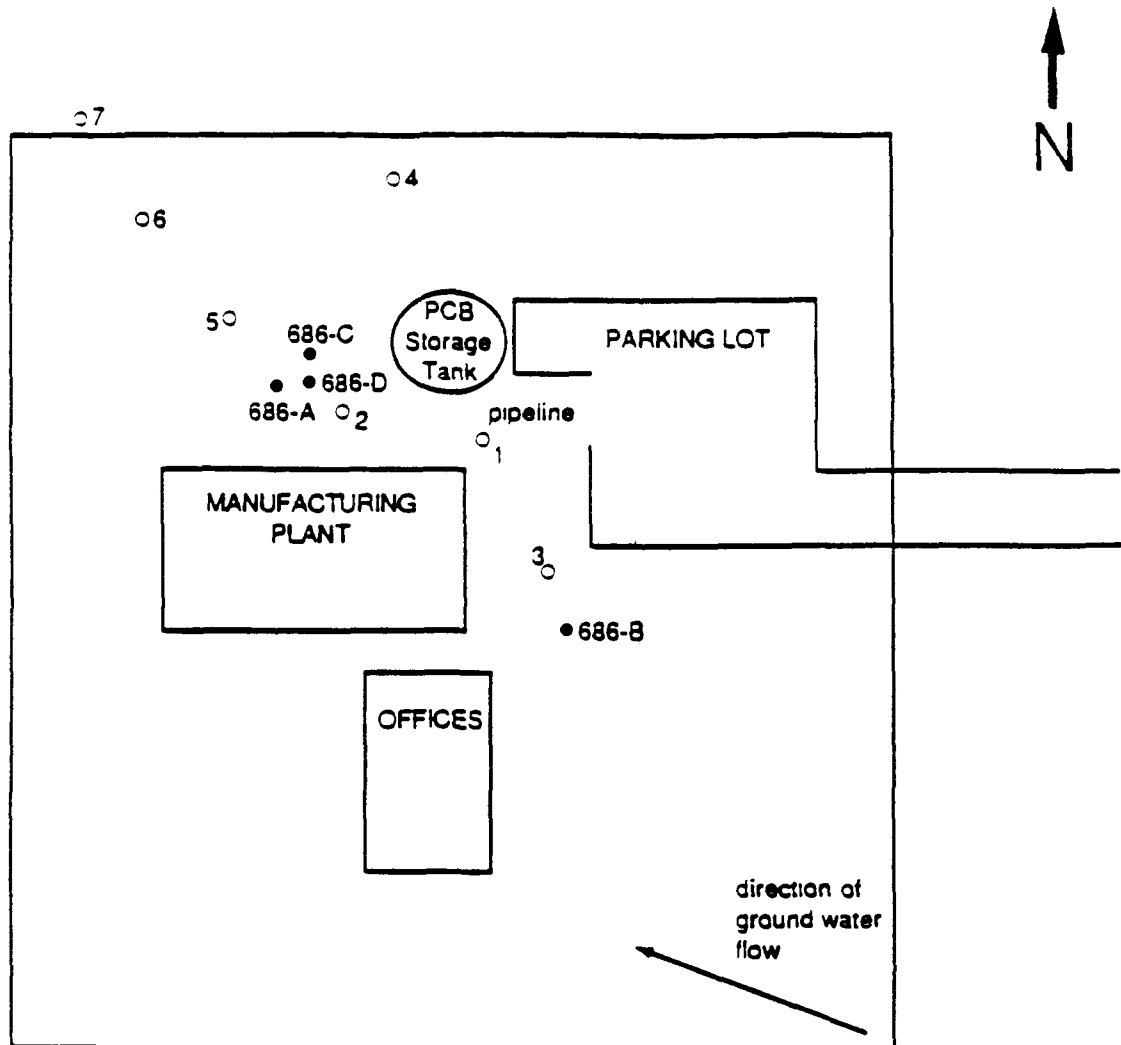
Over 1000 soil samples were taken as part of the site investigation. A mobile atmospheric pressure chemical ionization mass spectrophotometer (APCI/MS) was employed for rapid, on-site characterization of soil samples. This instrument can detect PCBs down to a minimum concentration of 100 mg/kg. About 20 percent of the PCB analyses were replicated by conventional gas chromatography.

Granular dry materials were sampled from an auger with care taken in cleaning sampling equipment to avoid cross-contamination. In taking samples from the clay, special effort was made to sample the surfaces of obvious fractures. This was done to maximize the chances of detection of PCBs in largely uncontaminated soil. Due to dilution, large bulk samples can prevent the detection of contaminant migration through fractures in low permeability soils.

Vertically, the soil sampling program showed PCBs to be distributed in a non-homogeneous pattern within the clay zone. Concentrations of PCBs greater than 500 mg/kg PCBs were detected. The lateral spreading of PCBs throughout the fill was much more extensive than the vertical movement. This could be due to the nature of the discharge/spillage, pressure from the broken pipe, or the fact that the fill is more permeable than the clay. The PCBs appear to have formed a layer along the fill/clay interface. Movement of PCBs more than 300 feet laterally from the original spill site has been confirmed.

Based on the soil sampling results, 12 well locations (Figure 15-38) were chosen to further characterize the site. Four boreholes were drilled into the till aquifer. One well, 686-B, was placed upgradient of the spill site with a screened interval between depths of 45 and 50 feet. The three downgradient wells in the till aquifer were screened over different intervals to increase the possibility of detecting a separate organic liquid layer. The screened intervals used were at depths 45 to 50 feet (well 686-A), 50 to 55 feet (well 686-C), and 55 to 60 feet (well 686-D). Eight

08



- deep well locations
- shallow well locations

Figure 15-38. Well Locations and Plant Configuration

shallow wells were also placed in the fill to monitor the perched water. The fill is approximately 10 feet deep and a layer of PCBs was suspected at the fill/clay interface. The depth of the perched water fluctuates between 7 and 8 feet. Six of the eight wells in the fill, 1, 3, 4, 6, 7, and 8, are screened from 7 to 10 feet. Samples from wells 1, 6, 4, and 7 showed PCB levels much higher than the solubility limits. The sampling results suggest that two separate liquid layers exist at these locations and that the liquids are being mixed during sampling. Wells 2 and 5 were screened from 5 to 8 feet to determine if a floating liquid layer was present. Again, samples having concentrations far in excess of solubility limits indicated the existence of a layer of organic liquid.

### Case Discussion

Ground-water systems contaminated with immiscible liquids require special attention. Well screen intervals should be placed to intercept flow along boundaries between soil layers of differing hydraulic conductivities and at water table surfaces. Sampling results must also be interpreted properly. Samples showing contaminant concentrations far in excess of solubility limits may indicate that two layers of different liquids are being pumped and mixed.

Finally, Figure 15-39 is offered as an illustration of the types of complexity which can be encountered with immiscible liquids having densities both greater than and less than water.



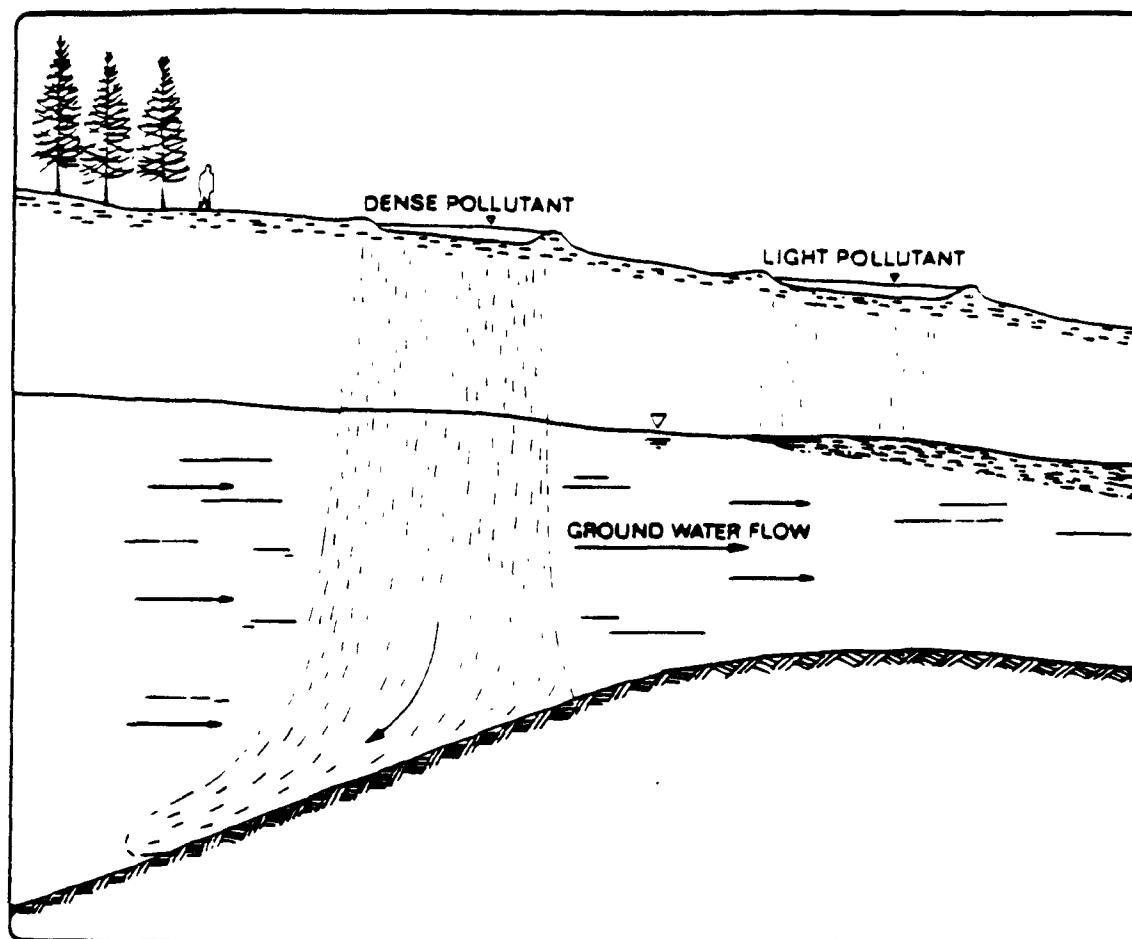


Figure 15-39. Behavior of Immiscible Liquids of Different Densities in a Complex Ground-Water Flow Regime

## CASE STUDY 22: METHODOLOGY FOR CONSTRUCTION OF VERTICAL FLOW NETS

### Point Illustrated

- Construction of a vertical ground-water flow net can be a valuable tool for evaluating ground-water (and contaminant) pathways and for determining additional actions that may be necessary to accurately delineate the ground-water flow regime at a facility.

### Introduction

Constructing a vertical flow net at a facility provides a systematic process for analyzing the accuracy of ground-water elevation and flow data, and can therefore foster a better understanding of the ground-water flow regime at the site.

### Facility Description and History

The site contains a large chemical manufacturing facility of approximately 300 acres located beside a major river in the northeastern United States. The site has been used for chemical manufacturing by different companies since 1904 and has a long history of on-site waste management. Several solid waste management units have been identified at the facility. This is the same facility as discussed in Case Studies 7, 8, 14, 17 and 18.

**Geologic and Hydrologic Setting:** At depths of 150 to 200 feet the site is underlain by bedrock identified as arkosic sandstone. Above this bedrock are glacial deposits consisting of a thick bed of hard till, overlain by lacustrine sediments and deltaic and outwash deposits. Discontinuous lenses of till were identified within the deltaic deposits. A trough cut into the thick-bedded till and trending approximately southeast to northwest has been identified. See Figure 15-40.

The river beside the facility flows westward and discharges into the main stem of a larger river approximately 4 miles west of the facility. A small tributary (brook) borders the facility to the southwest and west. Swamp-like areas are present near

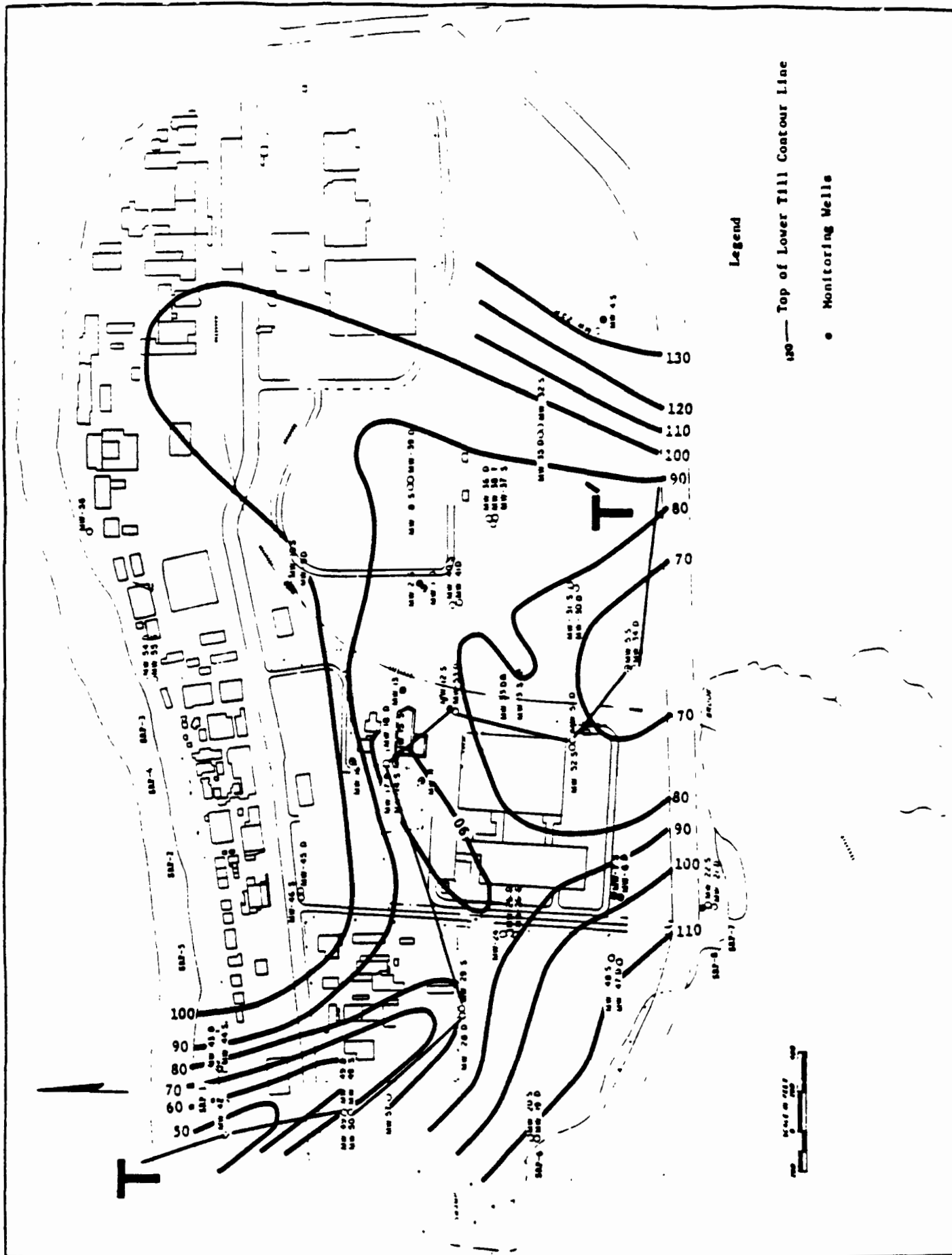


Figure 15-40. Top of Lowest Till Contour Map and Location of Vertical Flow Net

the tributary. It is suspected that the arkosic sandstone outcrops in the river adjacent to the facility. Whether this visible rock is a large glacial erratic or an outcrop of the arkosic sandstone bedrock is an issue identified during previous investigations and may be important in characterizing the ground-water flow regime at the facility.

### Program Design

The site was investigated in two phases. Phase I (1981-1984) included the installation and monitoring of wells MW-1 through MW-12, while Phase II (1984-1985) consisted of 34 soil borings, installation of wells MW-13 through MW-57, and monitoring and sampling of all wells. This two-phased approach allowed the use of the initial monitoring well data and soil boring data to determine the placement of the Phase II monitoring wells. Further discussion of this two-phased approach is provided in Case Studies 7 and 18.

### Data Analysis

Evaluation of the data was conducted based on information provided by the owner or operator, including the water-level elevation data presented in Table 15-13. Well locations and water-level elevations in the wells were mapped and compared to elevations of the midpoint of the well screens to show relative hydraulic head differences from well to well. Vertical gradients are a reflection of different head values at different elevations. For each well, the head can be determined at the elevation of the midpoint of the well screen by measuring the water-level elevation in the well. Different head values corresponding to different screen elevations were used to evaluate vertical gradients. During the plotting of this map, anomalous data were identified and marked for further investigation.

The geology of the site and the depositional processes forming the aquifer were studied to determine what sorts of hydrogeologic phenomena might be expected. Glacial outwash deposits exhibit trends in sediment size and sorting. Sediment size decreases and sorting increases from the marginal to the distal portions of the deltaic/lacustrine deposits.<sup>1</sup> It is expected that this tendency will be

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<sup>1</sup>Mary P. Anderson, "Geologic Facies Models: What Can They Tell Us About Heterogeneity," presented to the American Geophysical Union, Baltimore, May 18, 1987

TABLE 15-13

## GROUND-WATER ELEVATION SUMMARY TABLE PHASE II

Well Number	Ground Elevation (ft)	Well Depth (ft)	Midpoint of Well Screen Elevation <sup>1</sup>	Screen Length (ft)	Water Level Elevation 9/1/82
MW-1	162.80	76.50		3	
MW-2	162.50	22.50		3	
MW-3	174.20	31.00	145.7	3	150.54
MW-4	201.90	54.00	150.4	3	156.85
MW-5	186.30	47.50	141.3	3	149.95
MW-6	144.30	39.50	107.3	3	135.78
MW-7	144.60	19.50	127.6	3	135.94
MW-8	155.10	24.00	133.6	3	149.04
MW-9	160.50	61.00	135.0	3	141.53
MW-10	160.40	30.00	132.9	3	144.62
MW-11	154.70	27.00	130.2	3	140.57
MW-12	159.50	26.50	135.5	3	141.05
MW-13	162.20	29.00	139.2	10	141.22
MW-14	162.10	29.00	139.1	10	140.66
MW-15	162.00	29.00	139.1	10	140.67
MW-16	162.00	29.00	135.5	3	140.87
MW-17	162.00	71.00	104.5	25	140.52
MW-18	161.90	72.00	103.4	25	140.53
MW-19	137.10	24.00	116.6	5	127.83
MW-20	137.20	17.00	123.7	5	127.82
MW-21	141.40	26.50	118.4	5	135.39
MW-22	141.60	15.10	13.0	5	135.35
MW-23	204.30	225.50	-10.2	20	184.98
MW-24	143.90	70.00	76.4	5	136.47
MW-25	143.80	39.00	107.3	5	130.20
MW-26	143.80	24.00	123.2	5	130.17
MW-27*					
MW-28	142.70	46.00	100.2	5	127.86
MW-29	142.80	23.00	123.3	5	127.88
MW-30	172.00	85.50	90.0	5	152.70
MW-31	172.20	24.85	150.8	5	151.68
MW-32	203.10	61.00	145.6	5	154.78
MW-33	174.20	94.00	83.7	5	150.49

\*Not installed.

<sup>1</sup>Assumes screens are installed one foot above the bottom of the well.

TABLE 15-13 (continued)

Well Number	Ground Elevation (ft)	Well Depth (ft)	Midpoint of Well Screen Elevation <sup>1</sup>	Screen Length (ft)	Water Level Elevation 9/1/82
MW-34	186.20	75.80	113.9	5	149.72
MW-35	203.20	106.25	100.4	5	144.31
MW-36	189.40	101.20	91.7	5	143.22
MW-37	189.50	48.00	145.0	5	150.51
MW-38	189.30	135.30	57.5	5	145.04
MW-39	154.90	68.00	90.5	5	142.45
MW-40	173.80	47.50	129.8	5	146.59
MW-41	173.70	75.30	101.9	5	141.95
MW-42	134.20	64.00	73.7	5	117.62
MW-43	139.50	32.10	80.9	5	117.24
MW-44	139.50	28.00	115.0	5	119.62
MW-45	144.32	35.00	112.8	5	128.97
MW-46	144.15	25.00	122.6	5	126.48
MW-47	141.50	34.00	111.0	5	131.91
MW-48	141.60	17.00	128.1	5	131.74
MW-49	143.00	72.20	74.3	5	123.22
MW-50	143.00	30.20	116.3	5	123.85
MW-51	157.00	70.30	90.2	5	149.58
MW-52	157.00	34.00	126.5	5	139.48
MW-53	159.30	77.90	84.9	5	141.09
MW-54	145.80	52.00	97.3	5	120.18
MW-55	145.90	35.00	114.4	5	121.63
MW-56	133.60	20.30	116.8	5	119.84
MW-57	141.90				
Screen Reference Points					
SRP-1				114.41	
SRP-2				114.92	
SRP-3				116.05	
SRP-4				115.86	
SRP-5				NA	
SRP-6				128.81	
SRP-7				137.28	
SRP-8				134.11	

\*Not installed.

<sup>1</sup>Assume screens are installed one foot above the bottom of the well.

reflected in hydraulic conductivities throughout the outwash deposits at the facility. There is some suggestion of such a trend in the head data from the site.

The map of hydraulic head values and screen midpoint elevations were evaluated considering both the possible hydrogeologic phenomena expected for the geology of the area and the depositional processes creating the aquifer. Several working hypotheses were developed to explain the apparent ground-water flow patterns and the identified vertical gradients.

- Hypothesis 1: Vertical gradients can be explained by classifying areas where the vertical gradients were reflective of discharge and recharge areas. (See Figure 15-41.)
- Hypothesis 2: The top surface of the till forms a trough with a saddle. (See Figure 15-40.) The vertical gradients showing higher head with depth reflect the movement of water as it flows upward over the saddle.
- Hypothesis 3: The vertical gradient may correlate with locations of buildings and parking lots at the site. Recharge occurs primarily where the ground is not paved. The downward gradient near the river may be caused by runoff flowing downhill and recharging the ground water at the edge of the pavement.
- Hypothesis 4: Most of the ground-water flow is horizontal. The vertical gradients reflect phenomena whose scale is smaller than the resolution of available data, and an accurate interpretation cannot be made. Geologic systems exhibit heterogeneity on different scales, causing fluctuations in head on different scales. The small-scale fluctuations detected at the site are due to undefined causes and may represent:
  1. details of stratigraphy (such as till beds in parts of the outwash deposit),
  2. artificial recharge and discharge (such as leaky sewer pipes), or
  3. errors in the data.



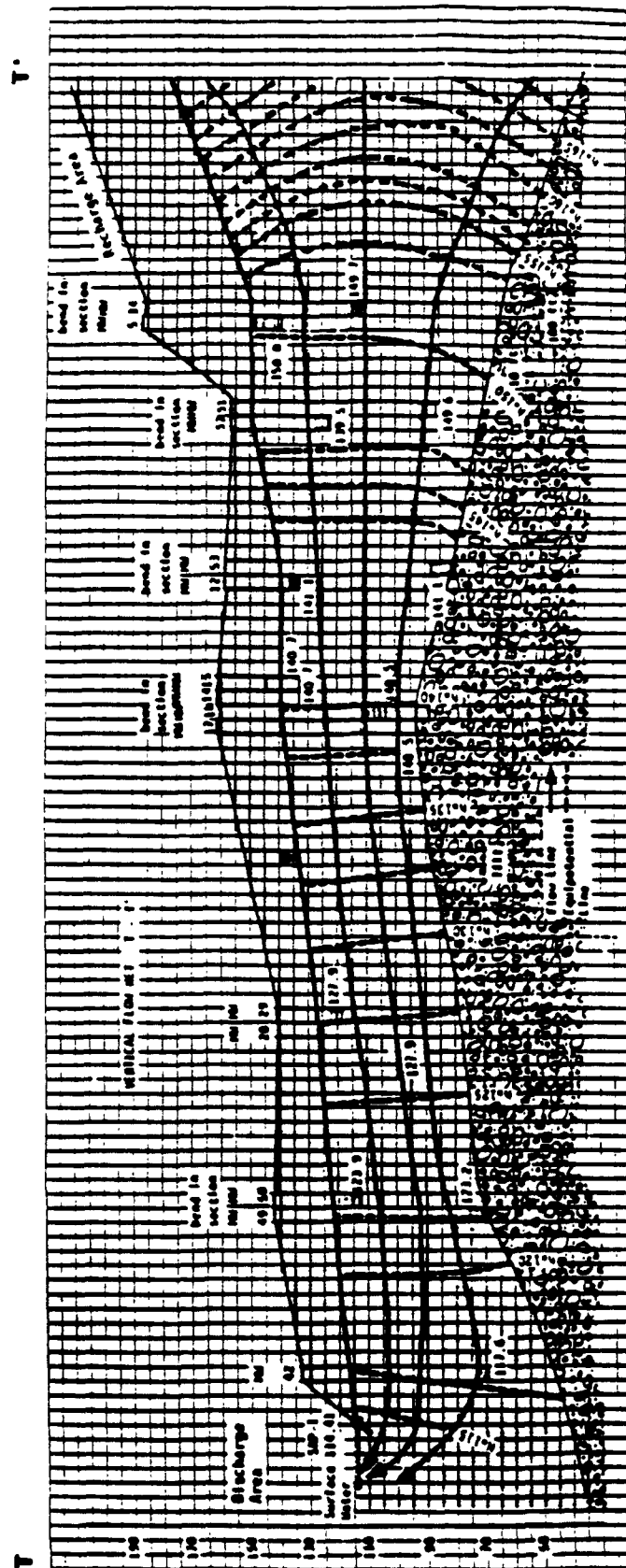


To characterize flow at the site and to support the design of corrective measures (if needed), a working (conceptual) model of flow at the site should be developed. This model, in this case a vertical flow net, can be used to identify data gaps and to prioritize gathering of the necessary additional information. Considering the hypotheses developed, an area for characterizing the vertical flow regime was selected. Determination of this area, where a geologic cross-section and flow net will be constructed, was based on:

- Assumptions and requirements necessary to construct flow nets, as identified in the Criteria for Identifying Areas of Vulnerable Hydrogeology, Appendix B: Ground-Water Flow Net/Flow Line Construction and Analysis (Vulnerable Hydrogeology, Appendix B). For example, ground-water flow should be roughly parallel to the direction of the cross-section and vertical flow net.
- Flow being representative of the hydrogeology of the facility.
- Flow representing the major paths of ground-water movement. For example, the aquifer is shaped like a trough and a major portion of the ground-water flow occurs in the middle of this trough; therefore, a cross-section and flow net should be constructed along the axis of the trough.

A geologic cross-section was constructed for the area of interest and is identified as T-T' in Figure 15-40. A flow net was then constructed following the methodology described in Vulnerable Hydrogeology, Appendix B; see Figure 15-42. Construction of a vertical flow net requires a graphical solution of Darcy's Law. Data that do not fit the solution become evident in Figure 15-42 as shown, for example, by the head value for MW 52.

Construction of a vertical flow net allowed for a systematic evaluation of the various hypotheses. Hypothesis 1, where vertical gradients are labeled recharge and discharge, is rejected because the gradients vary significantly in a very irregular pattern (compare well clusters MW 14-18 and MW 12 and 53); there is no apparent reason that natural recharge would vary so irregularly. Hypothesis 2 seemed reasonable initially but, after closer inspection, is rejected because upward



**Figure 15-42. Vertical Flow Net T-T'**

gradients are not consistently found near the saddle. Hypothesis 3 is feasible and deserves further study. Aerial photographs were examined to identify paved and unpaved areas, but the available ground-water data are insufficient for detailed correlation to these distinct areas. Additional data are needed to construct a more-detailed flow net to further evaluate this hypothesis. Hypothesis 4, which asserts that most of the flow is horizontal, addresses the area of the site where the major portion of ground-water flow occurs. Although it relies on undefined causes to explain fluctuations, it reflects the most logical explanation of the data.

## Results

During construction of the flow net and testing of the hypotheses several issues were identified. One of the most important gaps in the study to date is how localized flow at the site fits into the regional ground-water flow regime. Regional flow issues would need to be resolved prior to determining the extent and type of corrective measures, if necessary. The following regional flow issues were identified:

- Geologic information beyond the facility property boundary is necessary to explain the suspected bedrock in the middle of the river directly beside the site to characterize the regional ground-water flow (i.e., to determine the possibility for contamination of regional ground water). The difference in elevation of the top of the bedrock in the river and the top of the bedrock throughout the facility is approximately 120 feet. How can this be explained? Is the bedrock surface irregular or is this rock a glacially-transported boulder exposed in the river? How does this affect regional ground-water flow?
- Data consistently show a downward gradient (i.e., recharge conditions) near the river. This is difficult to explain because rivers in this region are not expected to be losing streams (Heath, 1984). The expected flow direction near a ground-water discharge area, in this case a gaining stream, is upward. Data points showing downward flow near the river are not included in flow net T-T'. (Further investigation of vertical gradients near the river is recommended). If this downward gradient near the river is confirmed, near-water-table contamination could move

downward and contaminate deeper ground water. If deeper, regional contamination must be addressed, corrective measures may be significantly more difficult and extensive.

Other issues deal with localized flow patterns that may affect design of corrective measures. Resolution of these issues will probably not change the overall scope of corrective measures, but would need to be considered in the detailed design.

These localized flow pattern issues are as follows:

- The hydraulic head in the brook is higher than the head in the closest wells in the aquifer, but the water slopes toward the stream. This is inconsistent. If ground water from the site is not discharging into this stream, fewer interceptor wells may be needed.
- Anisotropy must be taken into account in determining the region of flow captured by interceptor wells, drains, etc.
- Till identified as lenses in outwash deposits may actually be continuous with upgradient till, causing the aquifer to flow under confined conditions. Are the till beds isolated lenses or are they continuous? If the till beds in the outwash aquifer are continuous and isolate adjacent zones within the aquifer, they will have the potential of blocking flow to interceptor wells that may be included in the corrective measures plan.
- Vertical gradients of 0.25 and 0.002 in the same geologic unit are presented. Are these gradients accurate and how can they be explained? There could be artificial discharge (pumping) or recharge (possibly from a leaking sewer) near the wells showing a high vertical gradient. The areas labeled discharge areas show no signs of surface water or other surficial evidence of discharge. Artificial recharge and discharge may create areas of relatively constant head, such as where ground water contacts leaky sewers; these areas could limit the growth of cones of influence of any interceptor wells or drains. Also, any contaminated water that may be discharging from pipes should be identified and corrected.

## Case Discussion

Further investigation is necessary to resolve the above issues. Regional flow issues should be resolved first. This information would be used to better understand localized flow patterns which would affect the design of corrective measures. The following options for further investigation are suggested:

1. Study the regional geology and hydrogeology. Techniques that could be employed using existing data include review of geologic maps, analysis of well logs, and interpretation of existing surface geophysical data (e.g., gravity and magnetic surveys). Measurement of water level elevations in wells outside the site would also be useful.
2. Conduct a detailed study of the depositional environment of the glacial deposits on the site. This should provide a better understanding of flow patterns.
3. Collect a full-year series of head data at existing wells to differentiate transient from steady-state (e.g., artificial from natural) effects in the measured heads.
4. Conduct multiple-well pumping tests to determine the degree of connectivity of geologic formations using wells at different depths and locations. [Note: this should be done with careful attention to details of well construction so that it is understood exactly what is being measured.]
5. Collect detailed chemical data (including major ions and contaminants) at the existing wells and interpret them to aid in characterizing the flow regime.
6. Drill one or more wells into the bedrock near the river to determine the vertical component of ground-water flow at this location.

Options 1 through 5 above are recommended prior to drilling additional wells in the outwash deposits, unless more wells are needed to delineate the release.

Further single-well hydraulic conductivity tests in the glacial deposits are not recommended at this time. The large-scale flow in the outwash aquifer should be determined by the location and relative degree of continuity of the till versus the sand because the permeability contrasts between the till and sand is so much greater than the variability among the different sands. (See paper by Graham Fogg in *Water Resources Research*, 22, 679.) Single-well tests would be useful for determining localized hydraulic conductivities of the sand bodies, not their connectivity.

Gathering existing data and constructing an initial vertical flow net proved useful in identifying data gaps in defining ground-water flow, and identified problems due to differing interpretations of the existing data. Determining options for gathering additional data necessary to resolve these issues was based on a qualitative understanding of the ground-water flow regime gleaned from construction of the vertical flow net.

#### References

Fogg, Graham. *Water Resources Research*. 22, 679.

Heath. 1984. Ground Water Regions of the U.S. USGS Water Supply Paper No. 2242.

U.S. EPA. 1986. Criteria for Identifying Areas of Vulnerable Hydrogeology, Appendix B: Ground-Water Flow Net/Flow Line Construction and Analysis. Office of Solid Waste. Washington, D.C. 20460.

## CASE STUDY 23: PERFORMING A SUBSURFACE GAS INVESTIGATION

### Points Illustrated

- Design of a phased monitoring program to adequately characterize the extent and nature of a subsurface gas release.
- The use of ambient air and basement monitoring to supplement monitoring well data.
- The importance of subsurface characterization prior to design of a monitoring network.

### Introduction

Gases produced in a landfill will migrate via the path of least resistance. Subsurface, lateral migration of landfill gas can occur due to natural and man-made barriers to vertical gas migration, such as impermeable overlying soil layers, frozen soil, or surface water. Installation of a gas-monitoring well network, in conjunction with sampling in buildings in the area, can be used to determine the need for corrective measures.

### Facility Description

The unit in question is a landfill covering approximately 140 acres and bordered by a river on one side and a floodwall on the other. Beyond the floodwall lies a residential area (Figure 15-43). Several factors contribute to the subsurface gas migration problem at this landfill. The site reportedly received large quantities of organic wastes which, when decomposed in the absence of air, produce methane and carbon dioxide gases. The presence of "tight", low permeability soils at the ground surface (12 feet of clayey silt at the surface grading to coarse sand and gravel at a depth of 55 feet) in the residential area, combined with a rapidly rising water table below the landfill due to increased infiltration, restrict the vertical area available for gas migration and encourage lateral movement.

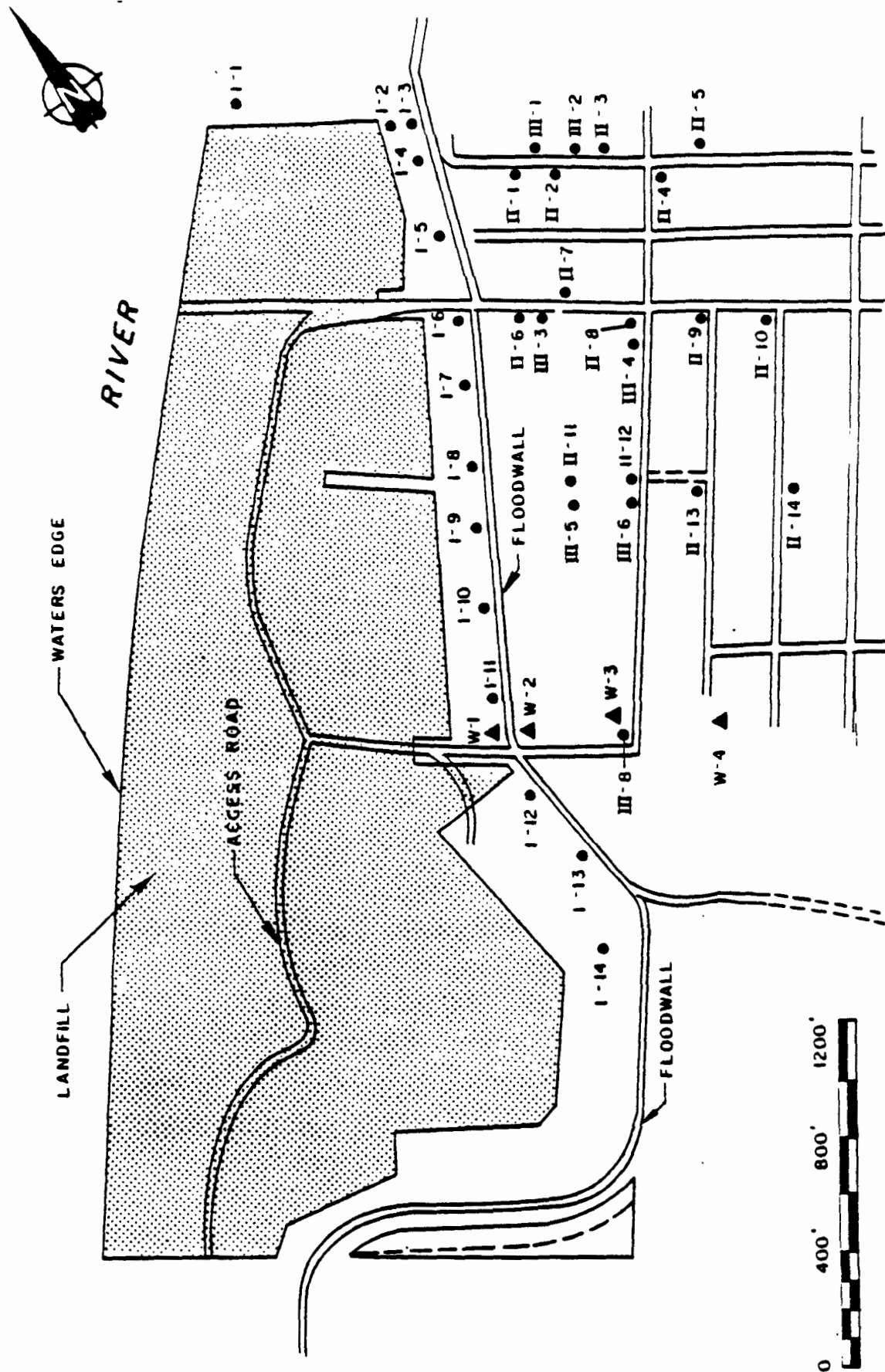


Figure 15-43. Site Plan



Investigation of the gas migration began when foul odors and explosive levels of methane (5 to 15 percent by volume in air) were discovered in the basement of a home approximately 200 feet from the landfill. Residents in the area were evacuated, a sampling network was installed, and monitoring was conducted.

### Sampling Program

The sampling was conducted in four phases, an initial screening phase and a more detailed three-phase sampling program. The monitoring network for the initial screening phase consisted of four wells (W1 through W4) aligned perpendicular to the long axis of the landfill, in the direction of (and extending beyond) the house where the gas was initially detected (Figure 15-43). The wells were drilled to an approximate depth of 30 feet below the land surface with the farthest well located about 1000 feet from the landfill boundary. These wells were sampled twice a day for a month. Samples were analyzed for methane and combustible hydrocarbons. The results of this initial monitoring showed average methane levels to be highest at the monitoring well closest to the landfill (30 percent by volume), and roughly grading to below the detection limit at the well farthest from the landfill.

Grab and composite ambient air samples were also taken at the landfill and around houses in the neighborhood where gas was detected during the initial monitoring phase. These samples were analyzed for methane and other combustible hydrocarbons. No gases were detected above normal background levels in any of these above ground samples.

The next phase of monitoring (Phase I of the detailed sampling) involved the installation of 14 new gas monitoring wells (I-1 through I-14 in Figure 15-43). Most of these were placed in a line 250 feet from and parallel to the longitudinal axis of the landfill. Seven of these wells were drilled to an average depth of 55 feet, at least 5 feet below the water table so that ground-water levels could be monitored. The other seven wells averaged 30 feet and did not intercept ground water. As shown in Figure 15-44, each well consists of three separate gas monitoring probes at evenly spaced depth intervals. Each probe was packed in gravel to allow gas to collect in its vicinity. Clay plugs were installed between each probe interval and

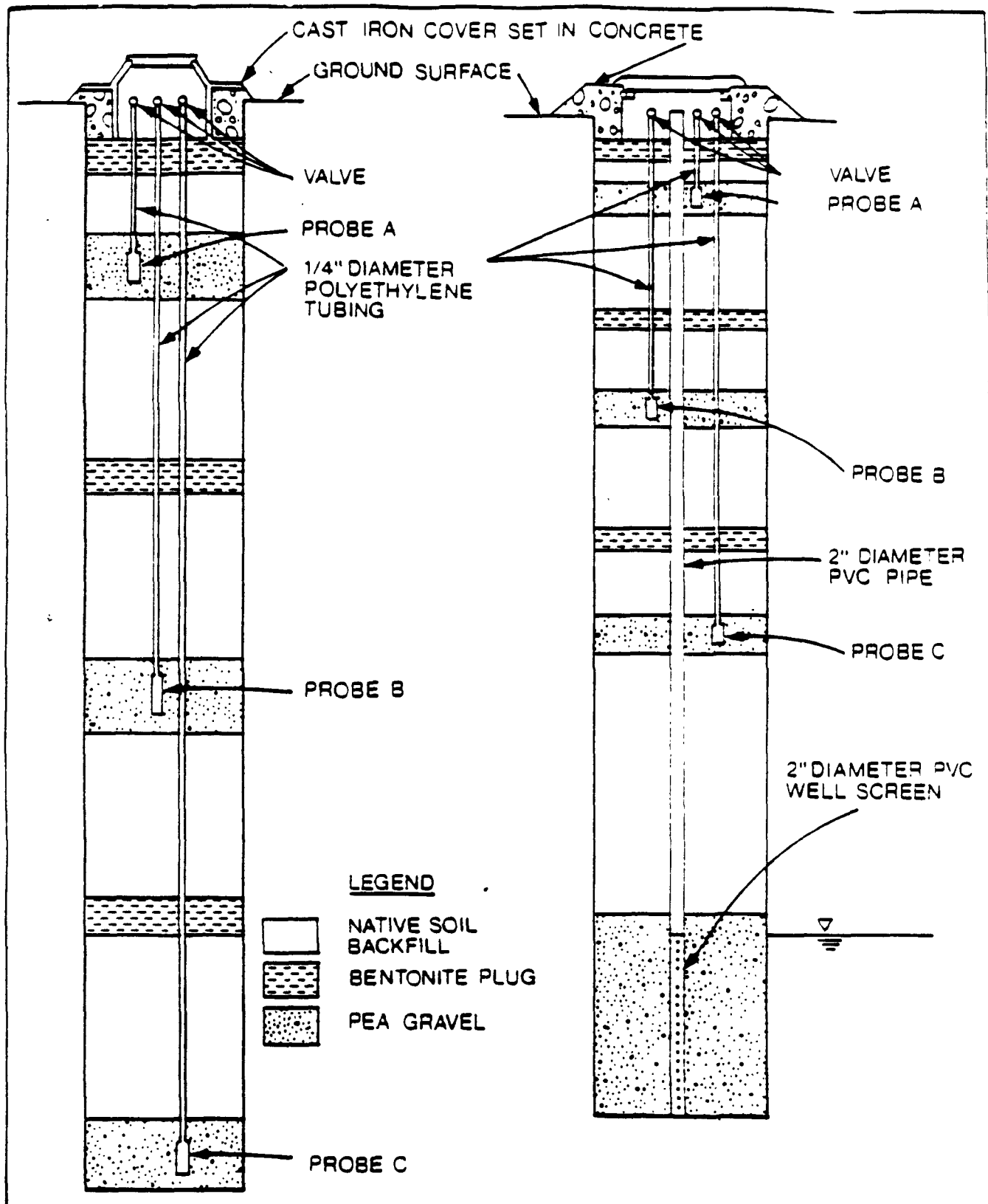


Figure 15-44. Gas Monitoring Well

between the top probe and the surface to minimize vertical movement of gas in the well. After two months of monitoring the well headspace twice monthly, concern over the high levels of methane that were being measured prompted an expansion of the monitoring well system.

The Phase II monitoring network involved another 14 wells (II-1 through II-14) installed to a depth of 6 feet along three radial lines from the landfill. These wells were monitored twice monthly with the Phase I wells. Methane was not detected at these wells because they were not deep enough to penetrate the clayey silt layer which in this area extended to a depth of 12 feet. Had adequate boring logs been compiled prior to the placement of these wells, the time and money involved in their installation and sampling could have been saved.

Detailed soil boring logs were compiled during the installation of the Phase III wells (III-1 through III-8 in Figure 15-43). These wells were drilled to ground water, averaging 55 feet in depth, were located in the vicinity of the Phase II wells, and were constructed in the same manner as the Phase I wells, with three gas probes placed in each well. The Phase III wells were located from 510 to 900 feet from the landfill. These wells were monitored twice a month for two months concurrently with the Phase I wells. Methane levels at all but two Phase III wells (which are located along the same radial line) exhibited explosive concentrations, ranging up to 67 percent by volume in air. These high concentrations of gas prompted another round of sampling of homes in the vicinity of wells exhibiting high methane concentrations.

Methane and combustible hydrocarbons were measured in basements, crawl spaces, and living areas of 28 homes adjacent to the landfill. All proved to be well below the lower explosive limit of methane.

Wells were then selected based upon proximity to houses exhibiting the highest levels of combustible gases, and sampled to determine gas composition and concentration. The proportion of constituents in the collected gas was similar in all samples analyzed, and concentrations decreased with increasing distance from the landfill.

Ambient air sampling for organic gases at the landfill and in the residential area was also performed at this time and showed low levels of several organic compounds. Air samples collected in houses near the landfill showed the presence of two of the gas components measured in the test wells (methane and ethane).

The gas migration hazard had been sufficiently characterized so that a plan for corrective measures could be developed. This involved the installation of 31 gas extraction wells which were located along a line between the landfill and the residential areas, and a blower system to "pump" the gas out of these extraction wells.

### Results

The monitoring program implemented for this case was, for the most part, effective in characterizing the extent and concentrations of subsurface gas contamination. The four initial monitoring wells verified that the landfill was the source of contamination. Phase I monitoring confirmed that the high levels of methane were present at all depths monitored and along the entire length of the landfill. The horizontal location of the Phase II wells, in lines radiating from the landfill, was appropriate, although the lack of subsurface characterization rendered them useless. Phase III sampling established the vertical and lateral extent of subsurface contamination into the residential area.

Throughout the study, ambient air sampling as well as monitoring of homes in the area of concern provided adequate safety control, as well as an additional indication of potential migration of landfill-generated gases.

### Case Discussion

Subsurface gas migration can occur when atmospheric ventilation of gases generated in a landfill is insufficient. The gas produced migrates along the paths of least resistance. Conditions restricting release to the atmosphere, such as saturated or tight surficial soils, may force the gas to move laterally over considerable distances.

This case was selected as an illustration of a phased approach to monitoring a subsurface gas release. The results of one phase of monitoring were incorporated into the design of the next phase throughout the study. Monitoring was performed at discrete vertical levels below the surface and at distances from the landfill that were adequate to confirm the extent of the contaminant plume.

The study also illustrates the importance of characterizing subsurface conditions prior to installing monitoring wells. Fourteen unusable wells were installed and then monitored for two months because of insufficient preliminary soil (stratigraphic) characterization.

The use of ambient and basement monitoring for gas to supplement monitoring well data is also noted in this case study. The location of new wells can be based in part on readings from these sources.

## **CASE STUDY 24:      USE OF A SUBSURFACE GAS MODEL IN ESTIMATING GAS MIGRATION AND DEVELOPING MONITORING PROGRAMS**

### **Point Illustrated**

- Predictive models can be used to estimate the extent of gas migration from a suspected subsurface source. This information can be used to estimate human exposure and to determine appropriate locations for monitoring wells and gas collection systems.

### **Introduction**

Methane is a common landfill gas and is often used as an indicator of landfill gas migration. The subsurface methane predictive model, described in Volume II, Appendix D of this document, will yield a methane concentration contour map and predict the distance that methane will migrate. The model consists of a series of charts developed by imposing a set of simplifying assumptions on a general methane migration computer model.

A methane migration distance prediction chart is used to find a preliminary migration distance based on the age of the site and the soil type. The remaining charts are used to find correction factors which are in turn used to adjust the migration distance. These factors are based upon site characteristics (e.g., depth of the waste).

### **Facility Description**

The unit is located on a 583-acre site in a suburb of a major metropolitan area. Figure 15-45 shows the site layout. The landfill itself occupies 290 acres. 140 acres of the landfill were used for the disposal of hazardous wastes. Both hazardous and nonhazardous wastes were disposed at the site from 1968 to 1984. Hazardous waste disposal ended in 1984. The disposal of sewage treatment sludges and municipal refuse continues. As seen in Figure 15-45, residential development has taken place with houses now bordering the facility to the south. A population of 30,000 to 40,000 people reside within a mile radius of the landfill center.

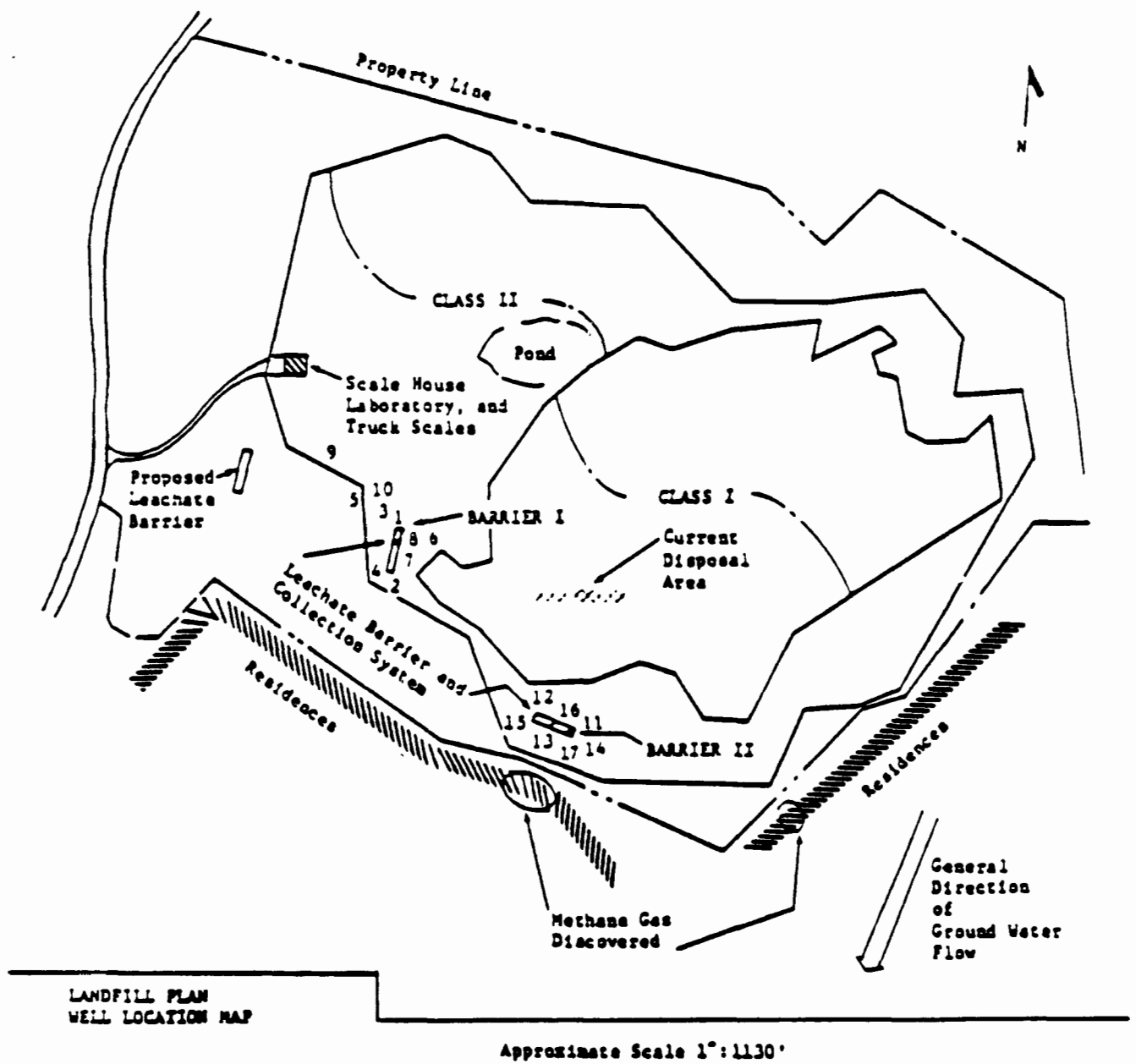


Figure 15-45. Facility Map

The unit is a V-shaped fill overlying sediment and bedrock. The rock type is a poorly consolidated, fractured sandy silt offering no lithologic barrier to gas migration. The shape of the water table has not been established. Also unknown are the possible effects of local, permeable formations such as sand lenses, faults, etc.

The warm climate at the site encourages rapid degradation of organic wastes and therefore rapid gas production. Site characteristics suggest that vertical gas migration is not hindered. However, the compaction of the fill cover by truck traffic combined with the rapid production of gas has forced lateral migration through the fractured sandy silt.

#### Applying the Subsurface Methane Predictive Model

The subsurface methane predictive model allows the development of a subsurface methane concentration contour map. The model predicts the distance methane will migrate from a unit based on its age, depth, soil type, and environmental factors. A contour map for two different methane concentrations, 5 and 1.25 percent, is predicted. The likelihood of human exposure can be estimated from the location of the contours with respect to on-site and off-site structures.

Application of the model involves three steps. The first step is the prediction of gas migration distances, based on the age of the landfill and the local soil type. The unit of interest is 18 years old and has sandy soils. Figure 15-46 shows the uncorrected methane migration distances for various soils over time. From Figure 15-46, the uncorrected migration distances for the subject site are 165 feet and 255 feet for 5 and 1.25 percent methane concentrations, respectively.

The second step in applying the model involves the application of a correction factor to the migration distances based on waste depth. The deeper the waste, the greater the opportunity for subsurface migration. Figure 15-47 is used to find the correction factors for depth. For the subject waste unit the depth is 25 feet, which corresponds to a correction factor of 1.0 for both concentrations.



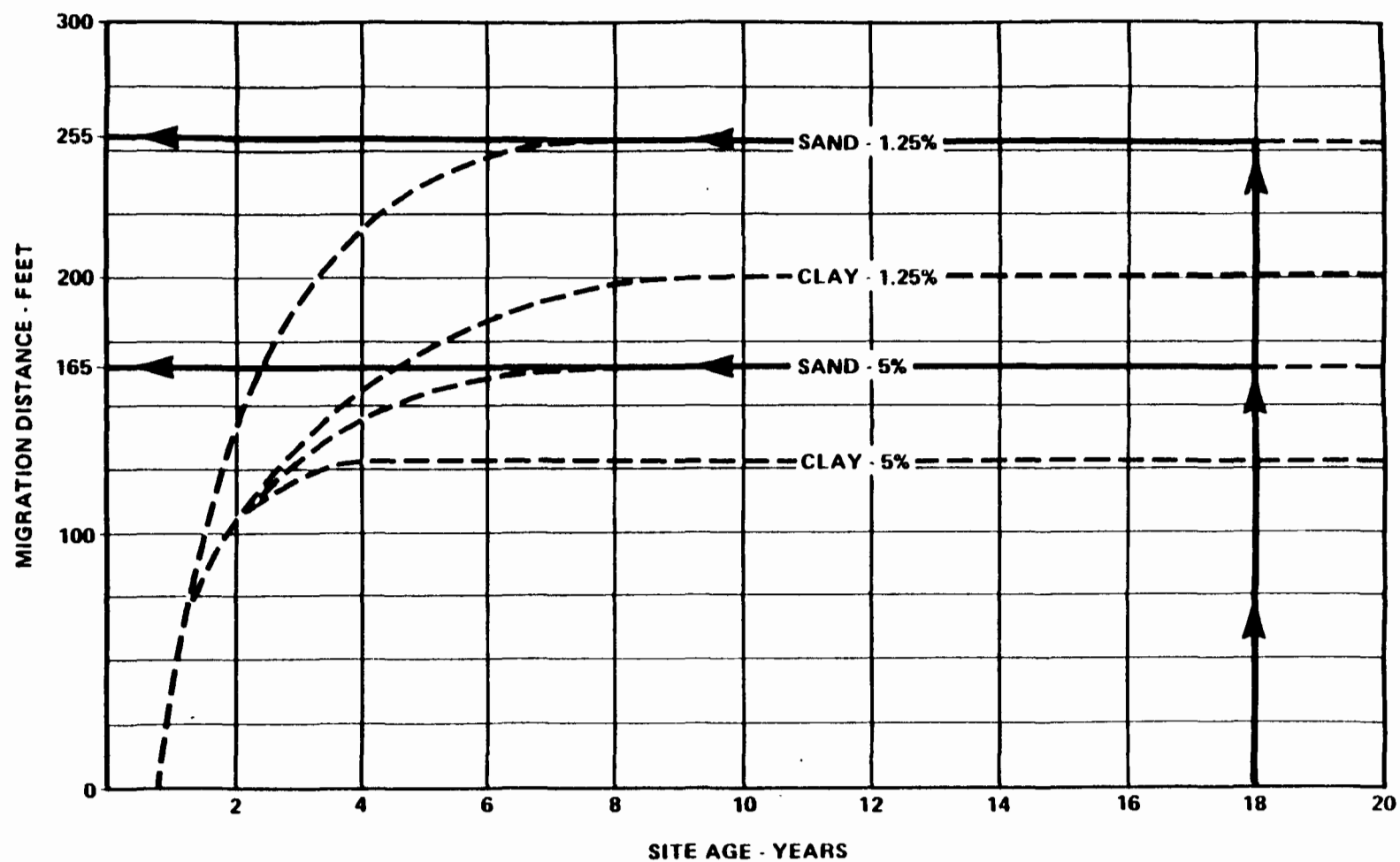


Figure 15-46. Uncorrected Migration Distances for 5 and 1.25% Methane Concentrations

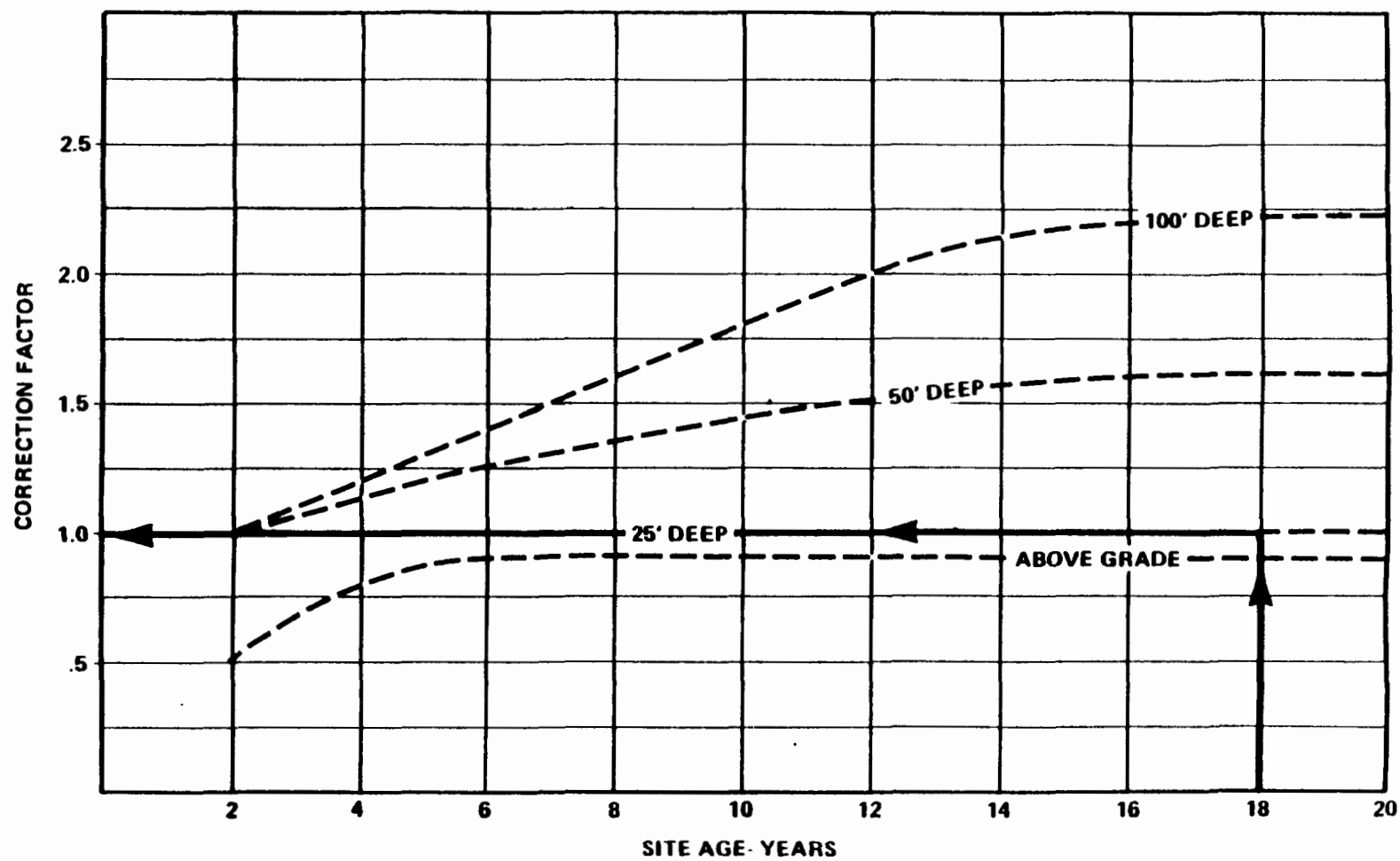


Figure 15-47. Correction Factors for Landfill Depth Below Grade

The final step in applying the model is the correction of migration distances based on surface venting conditions. The following equation is used to calculate the adjusted correction factor, ACF:

$$ACF = [(ICF-1)(\text{fraction of site which is impermeable})] + 1$$

The impervious correction factor, ICF, is obtained from Figure 15-48. In the above equation, ICF is adjusted to account for the fraction of time the solid is saturated or frozen and the fraction of the land area that is impermeable due to natural or man-made barriers. If corrections for both time and area are required, the fractions are additive. From Figure 15-48, the ICF for a unit 18 years old and 25 feet deep is 2.4. Site characteristics together with weather conditions indicate a value of 0.4 for the fraction of impermeable area. Substituting these values into the above equation yields an adjusted correction factor of:

$$ACF = [(2.4-1)(0.4)] + 1 = 1.56.$$

## Results

Table 15-14 summarizes the results from steps one through three of the model application. The predicted migration distances for methane are found by multiplying the uncorrected distance from step one by the correction factors from steps two and three. The predicted distances of travel for methane are 255 feet and 395 feet for 5 and 1.25 percent concentrations, respectively.

**TABLE 15-14**  
**MODEL RESULTS**

<u>Methane Concentration (percent)</u>	<u>Uncorrected Distance (ft)</u>	<u>Correction for Depth</u>	<u>Correction for Venting</u>	<u>Corrected Distance (ft)</u>
5	165	1.0	1.56	255
1.25	255	1.0	1.56	395

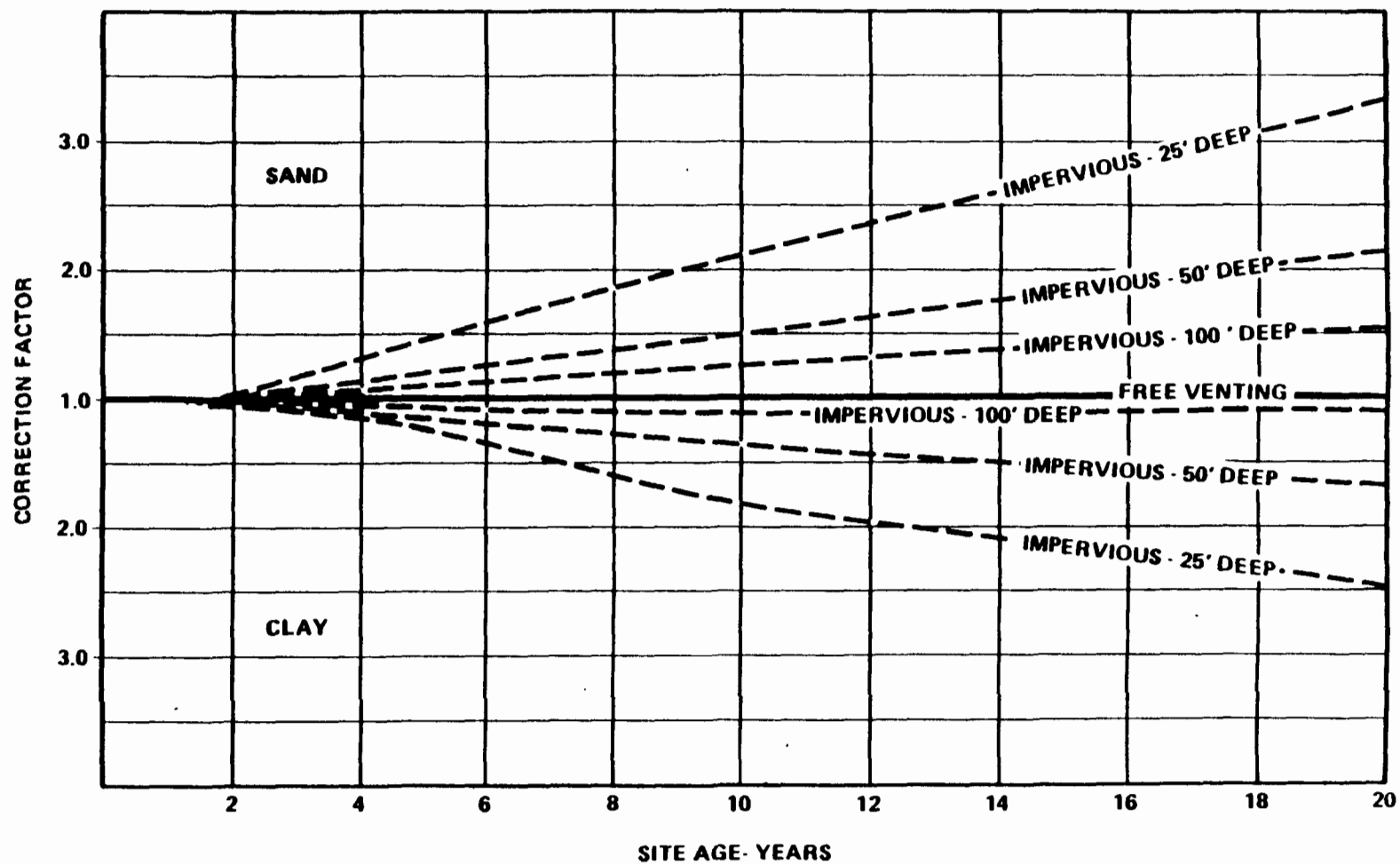


Figure 15-48. Impervious Correction Factors (ICF) for Soil Surface Venting Condition Around Landfill

## Case Discussion

Figure 15-49 is a methane concentration contour map developed from the predicted travel distances. The map indicates that the possibility of human exposure to landfill gas is high. Landfill gas is known to be present and well drilling operations at the landfill have caused minor explosions. The monitoring wells along the facility perimeter and testing in nearby homes indicate that gas has migrated off site. Both the 5 percent and 1.25 percent methane contours enclose homes evacuated because of gas accumulation. Measures have been taken to mitigate the immediate problems and the landfill operators have installed additional gas collection wells and extended the monitoring system.

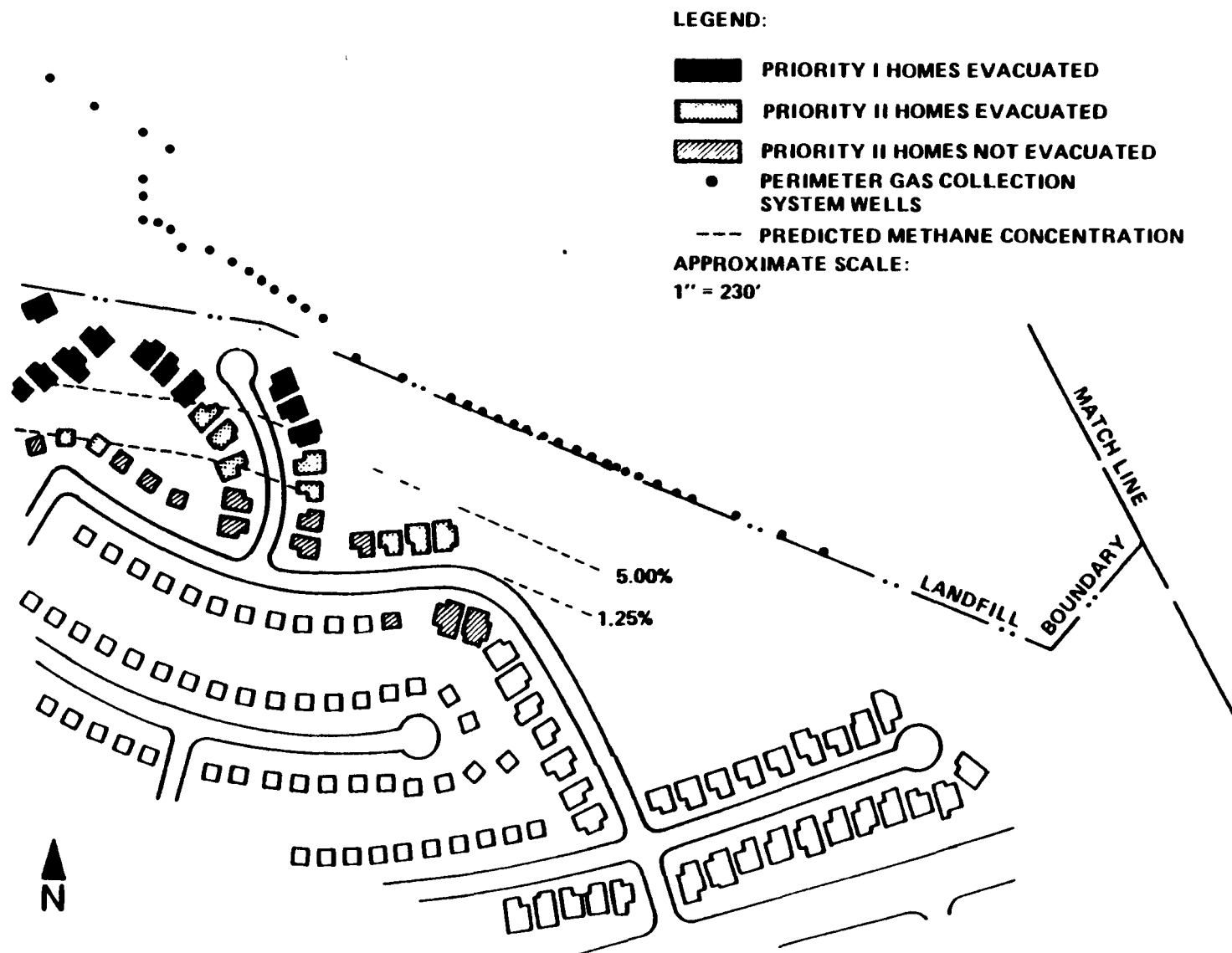


Figure 15-49. Landfill Perimeter Gas Collection System Wells

**CASE STUDY 25:      USE OF METEOROLOGICAL/EMISSION MONITORING DATA  
AND DISPERSION MODELING TO DETERMINE CONTAMINANT  
CONCENTRATIONS DOWNWIND OF A LAND DISPOSAL  
FACILITY**

**Point Illustrated**

- How to use meteorological/emission monitoring data and dispersion modeling to estimate contaminant concentrations.

**Introduction**

Concern over possible vinyl chloride transport into residential areas adjacent to a land disposal facility prompted initiation of this study. As a followup to a screening assessment (involving emission modeling) a survey and emission monitoring program with the application of an air dispersion model were used to assess potential health hazards.

**Facility Description**

The facility is a landfill which has been in operation since 1963. The facility occupies an area of 583 acres, of which 228 acres contain hazardous and municipal waste. The facility and surrounding terrain is hilly with elevations ranging from 600 to 1150 feet above mean sea level. Residential areas are located immediately adjacent to the south and southeast facility boundaries, as shown in Figure 15-50.

The facility previously received waste solutions from the synthesis of polyvinyl chloride which included the vinyl chloride monomer. Gas is generated by municipal waste decomposition and chemical waste volatilization. The primary air release from the particular unit is vinyl chloride. A gas collection system has not been installed for this unit.

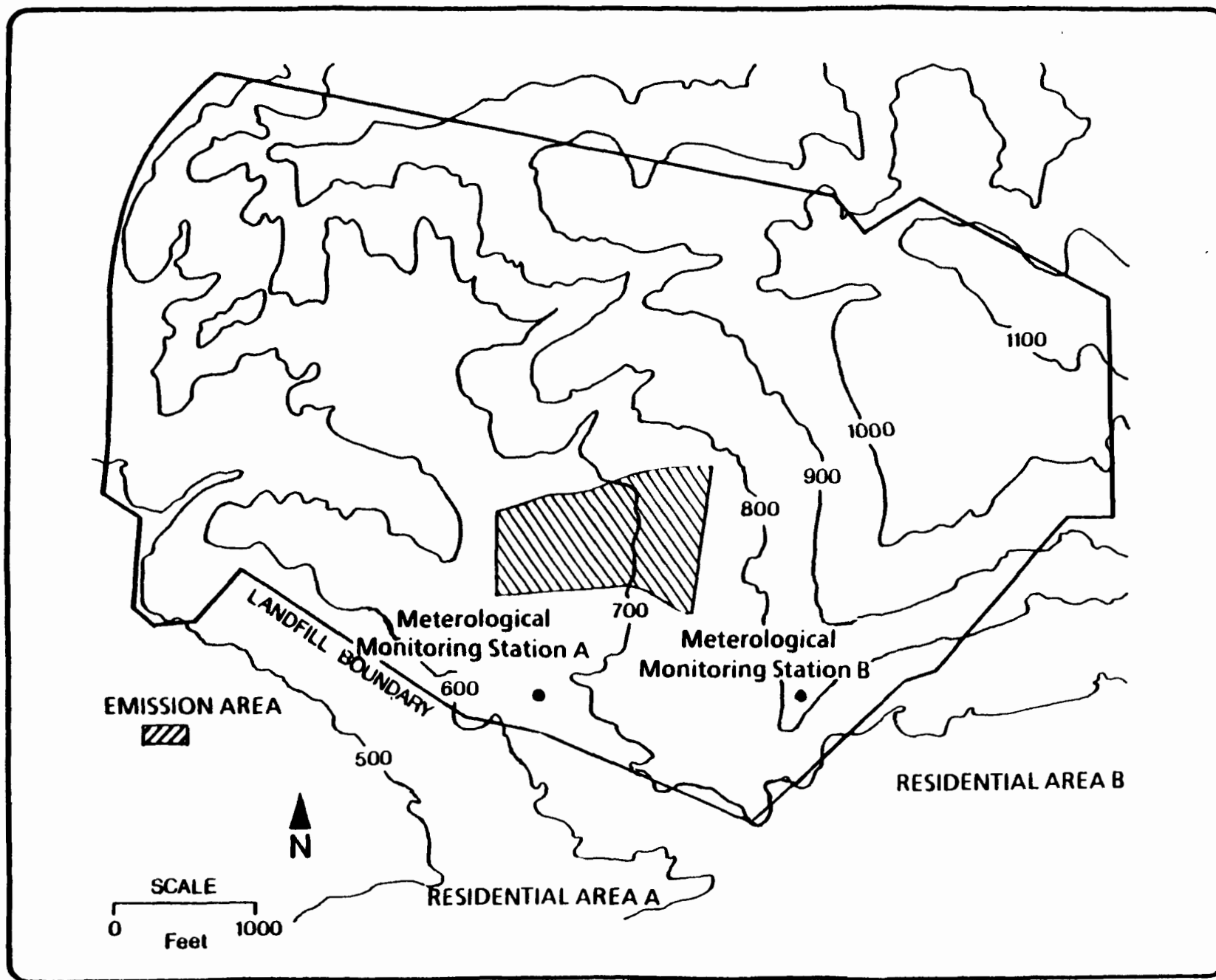


Figure 15-50. Site Map Showing Location of Meteorological Sites A and B  
(Adapted from Baker and Meeker, 1985)



### Program Design/Data Collection

A screening assessment (based on emission/dispersion modeling) was conducted to evaluate vinyl chloride emissions from the landfill. Evaluation of these results indicated that emission monitoring should be conducted to more accurately quantify the release. An isolation flux chamber was used to measure vinyl chloride emissions during a three-day period in August. This sampling period was selected based on the screening assessment results to represent worst case emission and dispersion conditions.

An on-site meteorological survey program was also conducted to characterize wind flows at this complex terrain site. Two meteorological stations were deployed to evaluate wind flows, as influenced by complex terrain, which may impact the two adjacent residential areas (see Figure 15-50.) A one-month data collection period during August was conducted to characterize on-site wind and stability patterns during worst-case, long-term emission/dispersion conditions. Although the facility is located in complex terrain, the diurnal wind pattern during the meteorological survey was very consistent from day to day. Therefore, the one-month meteorological monitoring period was adequate for this RFI application.

### Program Results/Data Analysis

The emission monitoring and meteorological monitoring data were used as input for dispersion modeling. The wind patterns were different for each of the on-site meteorological stations (see Table 15-15). Therefore, two sets of modeling runs were conducted (meteorological station A data were used to estimate concentrations at residential area A and meteorological station B data were used to estimate concentrations at residential area B).

The dispersion modeling results indicated that estimated concentrations at both residential areas were significantly below the RFI health criteria. Therefore, followup air release characterizations were not necessary and information was sufficient for RFI decision making.

**TABLE 15-15**

**SUMMARY OF ON-SITE METEOROLOGICAL SURVEY RESULTS**

	Station A	Station B
Prevailing daytime wind direction	S	SW
Prevailing nighttime wind direction	NNE	ENE

## Case Discussion

Emission sampling was appropriate for this application because of the uncertainties associated with emission rate modeling for landfills (including uncertainties in emission modeling inputs such as the waste composition and spatial distribution). The isolation flux chamber technique provided a basis for direct measurement of vinyl chloride emission rates for dispersion modeling input.

The conduct of an on-site meteorological monitoring survey provided the required wind and stability input for dispersion modeling. The use of multiple meteorological towers for this application was necessary to characterize wind flow patterns in complex terrain and to account for off-site exposure at two residential areas subject to different wind conditions. The combination of emission monitoring, meteorological monitoring and dispersion modeling provided an effective air release characterization strategy for this RFI application.

## References

Baker, L.W. and K.P. MacKay. 1985. Screening Models for Estimating Toxic Air Pollution Near a Hazardous Waste Landfill. Journal of Air Pollution Control Association, 35:11.

## CASE STUDY 26: USE OF METEOROLOGICAL DATA TO DESIGN AN AIR MONITORING NETWORK

### Points Illustrated

- How to design an air monitoring program
- How to conduct an upwind/downwind monitoring program when multiple sources are involved.

### Introduction

A screening assessment (based on emission/dispersion modeling) commensurate with RFI guidance was conducted to characterize hazardous air constituents being released from a wood treatment facility. Evaluation of these screening results indicated that it was necessary to conduct a monitoring program to more accurately quantify air emissions from units at the facility. Meteorological data were first collected to determine the wind patterns in the area. The wind direction data with the locations of the potential emission sources were then used to select upwind/downwind air sampling locations.

### Facility Description

The site is a 12-acre wood treatment facility located in a flat inland area of the southeast. Creosote and pentachlorophenol are used as wood preservatives; heavy metal salts have been used in the past. Creosote and pentachlorophenol are currently disposed in an aerated surface impoundment. Past waste disposal practices included treatment and disposal of the metal salts in a surface impoundment, and disposal of contaminated wood shavings in waste piles. The constituents of concern in the facility's waste stream include phenols, cresols, and polycyclic aromatic hydrocarbons (PAH) in the creosote; dibenzodioxins and dibenzofurans as contaminants in pentachlorophenol; and particulate heavy metals. The potential emission sources (Figure 15-51) include the container storage facility for creosote and pentachlorophenol, the wood treatment and product storage areas, the aerated surface impoundment for the creosote and pentachlorophenol wastes, and the contaminated soil area which previously contained both the surface

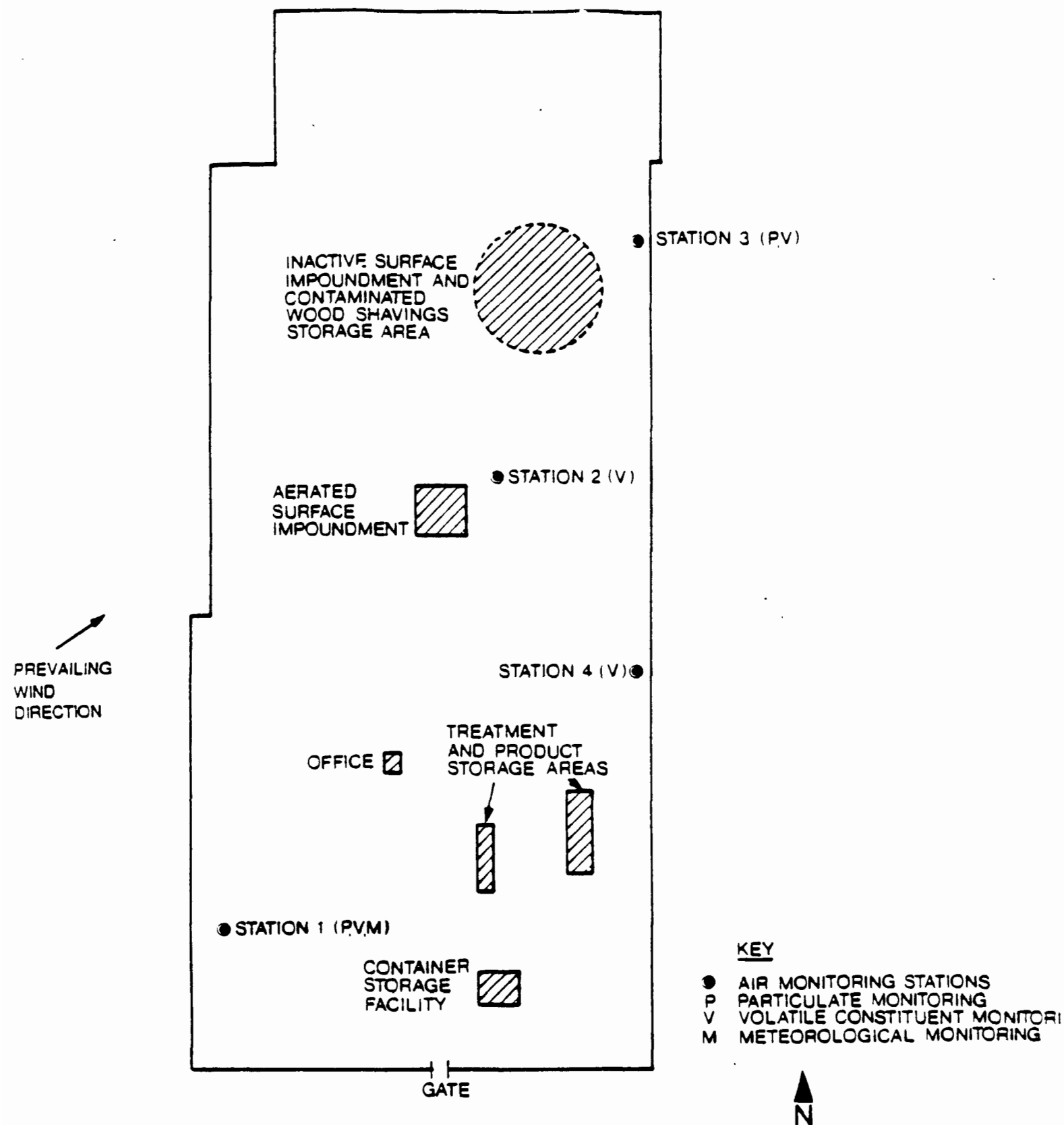


Figure 15-51. Site Plan and Locations of Air Monitoring Stations

impoundment for treating the metal salts and the wood shavings storage area. Seepage from these waste management units has resulted in documented ground-water and surface water contamination.

The area surrounding the facility has experienced substantial development over the years. A shopping center is now adjacent to the eastern site perimeter. This development has significantly increased the number of potential receptors of air releases of hazardous constituents.

#### Program Design/Data Collection

##### Preliminary Screening Survey--

A limited-on-site air screening survey was first conducted to document air releases of potentially hazardous constituents, to prioritize air emission sources, and to verify screening assessment modeling results and the need to conduct a monitoring program. Total hydrocarbon (THC) levels were measured with a portable THC analyzer downwind of the aerated surface impoundment, wood treatment area, and product storage area. Measurements were also made upwind of all units to provide background concentrations. Because THC levels detected downwind were significantly higher than background levels, a comprehensive monitoring program to characterize releases to the air was designed and implemented.

##### Waste Characterization--

To develop an adequate monitoring program, the composition of wastes handled in each waste management unit was first determined to identify which constituents were likely to be present in the air releases. Existing water quality data indicated contamination of ground water with cresols, phenol, and PAHs and of surface water with phenols, benzene, chlorobenzene, and ethylbenzene. A field sampling program was developed to characterize further the facility's waste stream. Wastewater samples were collected from the aerated surface impoundment and soil samples were collected from the heavy metal salt waste treatment/disposal area. Analytical data from this sampling effort confirmed the presence of the constituents previously identified. Additional constituents detected included toluene and xylenes in surface impoundment wastes, and arsenic, copper, chromium, and zinc in the treatment/disposal area.

Based on their individual emission potentials and potentials for presenting health and environmental hazards, the following constituents were selected for measurement in the air monitoring program:

Volatile/semi-volatile constituents: toluene, benzene, total phenols, penta-chlorophenol, PAHs, cresols

Particulate constituents: arsenic, copper, chromium, zinc.

#### Meteorological Data Collection--

Meteorological information is critical for designing an air monitoring program because stations must be located both upwind and downwind of the contaminant sources. Therefore, a one-month meteorological monitoring survey was conducted at this flat terrain site. The survey was conducted under conditions considered to be representative of the summer months during which air samples would be collected. Summer represented worst-case conditions of light steady winds and warm temperatures. The collected meteorological data showed that the local wind direction was from the southeast. No well-defined secondary wind flows were identified.

#### Initial Monitoring--

Alternative methods were considered for monitoring emissions from the aerated surface impoundment and contaminated storage area. Direct emission measurements (such as use of isolation flux chambers) would not be practical for aerated ponds or for monitoring particulate emissions from area sources. Therefore, an air monitoring program with samplers located in proximity to the other units of concern was selected for this application.

The on-site meteorological survey data were used with the EPA atmospheric dispersion model, ISC (Industrial Source Complex Model), to estimate worst-case air emission concentrations and to help determine the locations for the air sampling stations. The ISC model was used because it is capable of simulating conditions of point and non-point source air emissions. Using the established southeast wind direction, maximum downwind concentrations were predicted for different

meteorological conditions (e.g., wind speed). Upwind background stations and downwind monitoring stations were selected based on the predicted dispersion pathways. Because the releases from the individual waste management areas overlapped, the model also provided a means for separating the incremental contamination due to each source.

Figure 15-51 shows the locations of the selected sampling stations. Station 1 is the upwind background station. Here background volatile concentrations, particulate concentrations, and meteorological conditions were monitored. Stations 2 and 4 were located to identify volatile emissions from the aerated surface impoundment and wood treatment/product storage areas, respectively. Station 3 was located downwind of the inactive surface impoundment/wood shavings disposal area. This station was sited to document releases from these waste management units and to document worst-case concentrations of volatiles and particulates at the facility property boundary. For this application the locations of Stations 2, 3 and 4 were adequate to characterize air concentrations at both the unit boundary as well as the facility property boundary (due to the proximity of these two boundaries in the area downwind, based on the prevailing wind direction, of the units of concern). A trailer-mounted air monitoring station was used to supplement the permanent stations and to account for any variability in wind direction.

#### **Sample Collection--**

The air quality monitoring was conducted over a three-month period during the summer. Meteorological variables were measured continuously on site throughout the study. Air samples were taken over a 24-hour period approximately every six days. The sampling dates were flexible to insure that worst-case conditions were documented.

Volatile and semi-volatile constituents were sampled by drawing ambient air through a sampling cartridge containing sorbent media. A modified high volume sampler consisting of a glass fiber filter with a polyurethane foam backup sorbent (EPA Method TO4) was used to sample for total phenols, pentachlorophenol, and PAHs. Benzene and toluene were collected on Tenax sampling cartridges (EPA



Method TO1) and cresol was collected on silica gel cartridges (NIOSH Method 2001). Particulates were collected on filter cassettes using high-volume samplers.

In addition to the constituents previously discussed, Appendix VIII metals were analyzed on the first few sets of samples. These analyses were conducted to identify air releases of constituents other than those known to be present. The results indicated that no additional constituents were present in significant concentrations, so the additional analyses were dropped for the remainder of the study.

### Program Results/Data Analysis

Standard sampling/analytical methods were available for all the target monitoring constituents. Analytical detection limits were below specific health and environmental criteria for all constituents except cresol. The high analytical detection limit for cresol which exceeded reference health criteria complicated data analysis. This difficulty was handled by the routine collection and analysis of waste water samples during the air monitoring program. These data were used to estimate cresol levels in the air by comparing its emission potential to the other air monitoring constituents which have relatively low detection levels.

Analytical results obtained during this sampling program established that fugitive air emissions significantly exceeded reference health criteria. Source control measures were implemented to reduce emission concentrations below health criteria levels. Subsequent air monitoring was conducted at the same stations used previously on a weekly basis immediately after implementation of the remedial measures, and on a quarterly basis thereafter.

### Case Discussion

This case illustrates a sequence of tasks which were taken to design an air monitoring program at a site with multiple air emission sources. An initial field survey was conducted to identify local prevailing wind patterns and to identify potential downwind receptors of fugitive air emissions. The meteorological survey results were used to design an effective monitoring network. Monitoring station locations were selected to obtain background conditions and to document air releases downwind of each emission source. Also, the monitoring strategy included

use of a portable sampling station to provide flexibility in sampling locations to account for variation in wind direction. Spatial variability in air concentration was assessed with the aid of an air dispersion model to assist in data interpretation.

Air emissions data showed an air release of hazardous constituents significantly above health criteria levels. Remedial measures were implemented, and periodic subsequent monitoring was conducted to insure compliance with the health criteria.

#### References

Methods T01 and T04, Compendium of Methods for Determination of Toxic Organic Compounds in Ambient Air, 1984, EPA-600/4-84-041.

Method 2001, NIOSH Manual of Analytical Methods, 1984, National Institute of Occupational Safety and Health.

## CASE STUDY 27: DESIGN OF A SURFACE WATER MONITORING PROGRAM

### Point Illustrated

- When designing a surface water monitoring program, site-specific sediment and suspended solids information should be considered.

### Introduction

Designing a surface water monitoring program to determine the extent of contamination involves identifying the potential waste sources, the contaminants likely to be present in each waste stream, and the flow paths by which the contaminants could reach surface waters. The fate of the contaminants once they reach the surface water must also be considered when selecting sampling stations and parameters to be measured. The example described here illustrates the design of a monitoring program for a river system.

### Facility Description

A facility which processed zinc, copper and precious metals from ores operated along a river for five years. The plant was closed after being cited for repeated fish kills which were reportedly due to failures of a tailings pond dike. At present, the site is covered with tailings containing high concentrations of copper, zinc, cadmium, arsenic and lead. There is no longer a tailings pond.

### Site Setting

The site is located on coarse colluvium (hill-slope deposits of weathered bedrock) and fine-grained alluvium. These deposits are typically 50 feet thick. Metamorphic rock (phyllite) underlies the unconsolidated materials. Ground water moves laterally in the gravel formations from the steep valley walls towards the river.

The site is about 400 feet from the river. Two drainage ditches cross the lower portion of the site and merge prior to leaving the site. The ditch carries the

combined flow and discharges directly into the river (Figure 15-52). No other tributaries enter the river within two miles of this location.

### Sampling Program

A surface water monitoring program was designed as part of the Phase I remedial investigation to determine the extent of contamination in the river. Existing data from a reconnaissance visit had shown high concentrations of metals in the drainage ditch sediments (e.g., 5,170 mg/kg Cu and 11,500 mg/kg Zn). Ground water data from the plant's well showed concentrations of Cu (7 µg/l) and Zn (54 µg/l). The contribution of metals to the river by ground-water discharge at the site was considered to be relatively small.

Based on a review of the plant history and the available water quality and sediment data, a monitoring program was designed. The potential pathways by which metals could reach the river appeared to be direct discharge from the drainage ditch, seepage of contaminated ground water, and storm water runoff. Plant records indicated that typical flows in the drainage ditch at its confluence with the river varied from 1 to 3 cubic feet per second (cfs) in the spring. During extreme flood conditions, the flow in the ditch exceeded 20 cfs. In the summer, flows in the drainage ditches at all locations were less than 0.5 cfs. Resuspension of contaminated sediments in the ditches during storm runoff appeared to be the most likely pathway for metals to reach the river. The specific metals of concern were identified as As, Cd, Cu, Pb and Zn based on the processes used at the plant and the composition of the ores which contained some arsenopyrites (As, Cu), galena (Pb), and sphalerite (Zn, Cd).

The available soil and water quality data from the reconnaissance visit were reviewed to determine the likely fate of the metals. Soils in the area were circumneutral (pH = 6.5) and contained about 0.5 percent organic matter by weight. Thus the metals, particularly Pb, would be expected to adsorb onto the soil particles. In the on-site tailings piles, the pH of core samples ranged between 3.3 and 4.9. Low soil pH values had been measured in sediments in the drainage ditch just downgradient of the tailings pile. The pH of the river during the reconnaissance was 6.9. The suspended solids concentration was 10 mg/l.

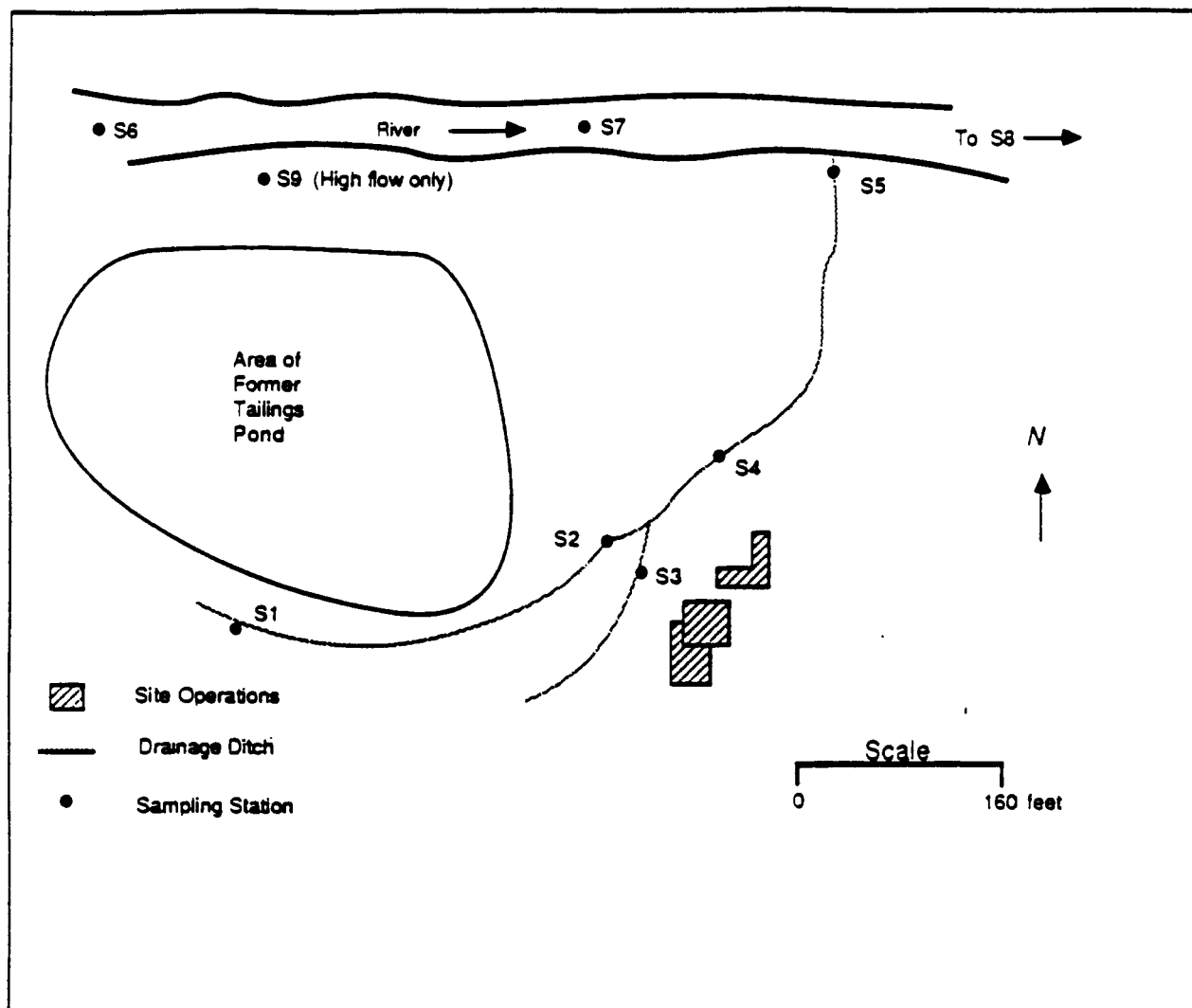


Figure 15-52. Sampling Station Locations for Surface Water Monitoring

Estimates of the distribution of metals between the dissolved and adsorbed phases for a range of partition coefficients ( $K_p$ ) are shown in Table 15-16. For example, if  $K_p = 10^4$  and the suspended solids concentration was 10 mg/l, 90 percent of the metal present would be in the dissolved phase. This information indicated that even though a metal (e.g., lead), was known to sorb strongly, a significant amount could be transported in the dissolved phase. Thus, both water and suspended solids should be analyzed for metals. The complete list of parameters selected for measurement in the Phase I investigation and the rationale for their selection are outlined in Table 15-17.

The sampling stations were selected to determine river quality up- and downstream of the site and to determine whether particulates with sorbed metals were deposited on the river banks or streambed. The sampling stations and the rationale for their selection are listed in Table 15-18. The station locations are shown in Figure 15-52. Because floods were considered to be one cause of contamination incidents, samples were to be collected under both high and low flow conditions.

Selected results of the surface water quality sampling program for spring conditions are given below:

Station	Dissolved Copper Concentration, $\mu\text{g}/\text{l}$
S5 (mouth of ditch)	1110
S7 (upstream)	2.7
S8 (downstream)	4.0

TABLE 15-16

**RELATIONSHIP OF DISSOLVED AND SORBED PHASE POLLUTANT  
CONCENTRATIONS TO PARTITION COEFFICIENT AND SEDIMENT  
CONCENTRATION**

$K_p$	SS (ppm)	$C_w/C_T^a$	If $C_T = 100$ ppb		
			$C_w =$	$X =$	$C_s =$
100	1	1.0	100.	100.	0.0
	10	1.0	100.	100.	0.0
	100	1.0	100.	100.	0.0
	1000	1.0	100.	100.	0.0
	10,000	1.0	99.	99.	1.0
10 <sup>1</sup>	1	1.0	100.	$1 \times 10^3$	0.0
	10	1.0	100.	$1 \times 10^3$	0.0
	100	1.0	99.9	999.	0.1
	1000	1.0	99.0	990.	1.0
	10,000	0.9	90.9	909.	9.1
10 <sup>2</sup>	1	1.0	100.	$1 \times 10^4$	0.0
	10	1.0	99.9	$1 \times 10^4$	0.1
	100	1.0	99.0	$9.9 \times 10^3$	1.0
	1000	0.9	90.9	$9.1 \times 10^3$	9.1
	10000	0.5	50.	$5 \times 10^3$	50.
10 <sup>3</sup>	1	1.0	99.9	$1 \times 10^5$	0.1
	10	1.0	99.0	$9.9 \times 10^4$	1.0
	100	0.9	90.9	$9.1 \times 10^4$	9.1
	1000	0.5	50.	$5 \times 10^4$	50.
	10000	0.1	9.1	$9 \times 10^3$	90.9
10 <sup>4</sup>	1	1.0	99.0	$9.9 \times 10^5$	1.0
	10	0.9	90.9	$9.1 \times 10^5$	9.1
	100	0.5	50.	$5 \times 10^5$	50.
	1000	0.1	9.1	$9.1 \times 10^4$	90.9
	10,000	0.0	1.0	$9.9 \times 10^3$	99.0

After Mills *et al.*, 1985.

<sup>a</sup>The fraction dissolved ( $C_w/C_T$ ) is calculated as follows:

$$\frac{C_w}{C_T} = \frac{1}{1 + K_p \times 5 \times 10^{-6}}$$

here  $K_p$  = partition coefficient,  $\ell/\text{kg}$

SS = suspended solids concentration,  $\text{mg}/\ell$

**TABLE 15-17**  
**PARAMETERS SELECTED FOR SURFACE WATER MONITORING PROGRAM**

Parameters	Rationale
Metals - As, Cd, Cu, Pb, Zn	Determine extent of contamination
pH	Predict sorption behavior, metal solubility, and speciation
Dissolved Oxygen, Sulfide, Fe(II), Fe(III)	Determine redox conditions which influence behavior of metals, particularly the leaching of tailings
Alkalinity	A measure of how well buffered a water is; allows consideration of the likelihood of pH change
Total Dissolved Solids	Used as a water quality indicator and for QA/QC checks
Major Cations ( $\text{Ca}^{2+}$ , $\text{Mg}^{2+}$ , $\text{Na}^{+}$ , $\text{K}^{+}$ , $\text{NH}_4^{+}$ ) Major Anions ( $\text{Cl}^{-}$ , $\text{SO}_4^{2-}$ , $\text{NO}_3^{-}$ )	May identify other waste sources; can influence fate of trace metals
Suspended Solids	Predict the fraction of metal in water which is sorbed
Streamflow	Compute mass balances and assist in identifying sources of observed contamination



**TABLE 15-18****SELECTED SURFACE WATER MONITORING STATIONS AND RATIONALE**

Station	Media	Rationale
Drainage ditch west of site (S1)	Water and sediments	Determine whether off-site drainage is significant source of contamination
Drainage ditches on site (S2 and S3)	Water and sediments	Identify on-site sources
Downstream of confluence of 2 ditches (S4)	Water and sediments	Provide information for checking mass balances from the two drainage ditches
Mouth of drainage ditch (S5)	Water, suspended sediment, bedload	Determine upstream water quality
River (S6, S7, and S9)	Water, suspended sediment, bedload	Determine upstream water quality
River (S8)	Water, suspended sediment, bedload	Determine quality downstream of site and provide data for mass balance

A mass balance was computed to determine how much of the apparent decrease from the ditch (S5) to the downstream river sampling point (S8) was due to dilution and how much could be attributed to other processes (e.g., sorption, precipitation). The concentration in the river considering dilution alone was predicted using the following mass balance equation:

$$C_R = \frac{C_U Q_U + C_W Q_W}{Q_U + Q_W}$$

where

$C_R$  = downstream concentration of pollutant in river following mixing with ditch waters (S8),  $\mu\text{g/l}$

$C_W$  = concentration in ditch water (S5),  $\mu\text{g/l}$

$C_U$  = concentration in river above ditch (S7),  $\mu\text{g/l}$

$Q_W$  = discharge rate of ditch,  $\text{ft}^3/\text{sec}$

$Q_U$  = flow rate of river above ditch,  $\text{ft}^3/\text{sec}$ .

At the time of sampling, the flow in the ditch at station S5 was 1 cfs and the river flow at station S7 was 155 cfs. Using the above equation, the predicted river concentration for Cu was approximately 10  $\mu\text{g/l}$ . (The observed concentration was 4  $\mu\text{g/l}$ .) The observed decrease in concentration was primarily due to dilution, although other attenuation processes (e.g., sorption) were probably occurring. The expected sorbed concentration was estimated as follows:

$$X = K_p C$$

where

$X$  = sorbed concentration,  $\mu\text{g/kg}$

$K_p$  = partition coefficient,  $\text{l/kg}$

$C$  = concentration of dissolved phase,  $\mu\text{g/l}$ .

Here, the sorbed concentration of Cu was estimated as  $8 \times 10^5 \mu\text{g/kg}$  (800 mg/kg).

## Case Discussion

This case illustrates the use of site-specific data and the use of information on the environmental fate of contaminants in the design of a surface water monitoring program. Site data are needed to locate waste sources and to determine the likely flow paths by which contaminants reach rivers. An understanding of the general behavior of the contaminants of interest and of the factors which influence their fate is helpful in determining where samples should be collected and what parameters, particularly master variables, should be measured. Collecting data on such parameters (e.g., pH, suspended solids) ensures that the necessary information is available to interpret the data.

## CASE STUDY 28: USE OF BIOASSAYS AND BIOACCUMULATION TO ASSESS POTENTIAL BIOLOGICAL EFFECTS OF HAZARDOUS WASTE ON AQUATIC ECOSYSTEMS

### Point Illustrated

- Measurements of toxicity (i.e., bioassays) and bioaccumulation can be used to assess the nature and extent of potential biological impacts in off-site areas.

### Introduction

A study was conducted to determine whether leachate discharged into surface waters had adversely affected biota in a stream adjacent to a waste site and in a nearby lake. The components of the study included chemical analyses of the leachate, surface waters, sediments, and tissue samples; toxicity testing of the surface waters; and surveys of the structure and composition of the biological communities. Tissue analyses are important for determining contaminant bioaccumulation and assessing potential human exposure through consumption of aquatic organisms. Toxicity testing is important for determining potential lethal and sublethal effects of contaminant exposure on aquatic biota. Although ecological analysis of community structure and composition is also an important component of biomonitoring, it will not be discussed here since the focus is on the relationships between the leachate source, the distributions of contaminants near the waste site, and the toxic effects and bioaccumulation of the contaminants in the tissues of local fauna.

### Site Description

The 5-acre facility is an industrial waste processing site which accepts wastes from nearby plastic manufacturing and electroplating industries. Liquid wastes are dewatered on site prior to removal to an off-site disposal area. The principal wastes processed at the facility include several organic compounds and metals.

The site contains a wastewater impoundment with numerous seeps and drainage channels that transport leachate into an adjacent river (Figure 15-53). The river flows from northeast to southwest, and is joined by a tributary stream before

entering a nearby lake. The RFA indicated an oily sheen associated with a strong chemical odor on the surface of the stream below the treatment pond, and further reported numerous violations of the NPDES permit. Subsequent analyses of samples taken from the drainage channels and seeps flowing into the river showed high concentrations of organic and trace metal contaminants, principally bis(2-ethylhexyl) phthalate, ethylbenzene, phenol, copper, cadmium, and zinc.

### Sampling Program

Six stations were sampled to assess possible toxicity and bioaccumulation of released substances (Figure 15-53). Station 6, located upstream of the release, was selected as a reference location for the stream. Station 17 was selected as a reference location for the lake because it is distant from the river mouth and because prevailing winds from the northwest direct the river discharge along the southeast shore of the lake away from the station. Stations 7, 15, and 18 were selected to determine the extent of toxic impacts on river and lake biota.

Water, sediments, and tissues of bottom-dwelling fishes (brown bullhead catfish, Ictalurus nebulosus) were collected at each station. Concentrations of bis(2-ethylhexyl) phthalate, ethylbenzene, phenol, copper, cadmium, and zinc were measured in each matrix. Analyses were conducted according to U.S. EPA guidelines for sediments, water, and tissues. Water quality variables (dissolved oxygen, temperature profiles, and alkalinity), total organic carbon in sediments, and lipid content of tissues were also measured.

Three independent bioassays were conducted on each water sample. The test species and endpoints used in the bioassays were those recommended in the U.S. EPA protocol for bioassessment of hazardous waste sites (Tetra Tech, 1983). Growth inhibition in the alga Selenastrum capricornutum, and mortality in the crustacean Daphnia magna were determined using U.S. EPA (1985) short-term methods for chronic toxicity testing. Inhibition of enzyme-mediated luminescence in the bacterium Photobacterium phosphoreum (i.e., the Microtox procedure) was measured according to the methods established by Bulich et al. (1981).

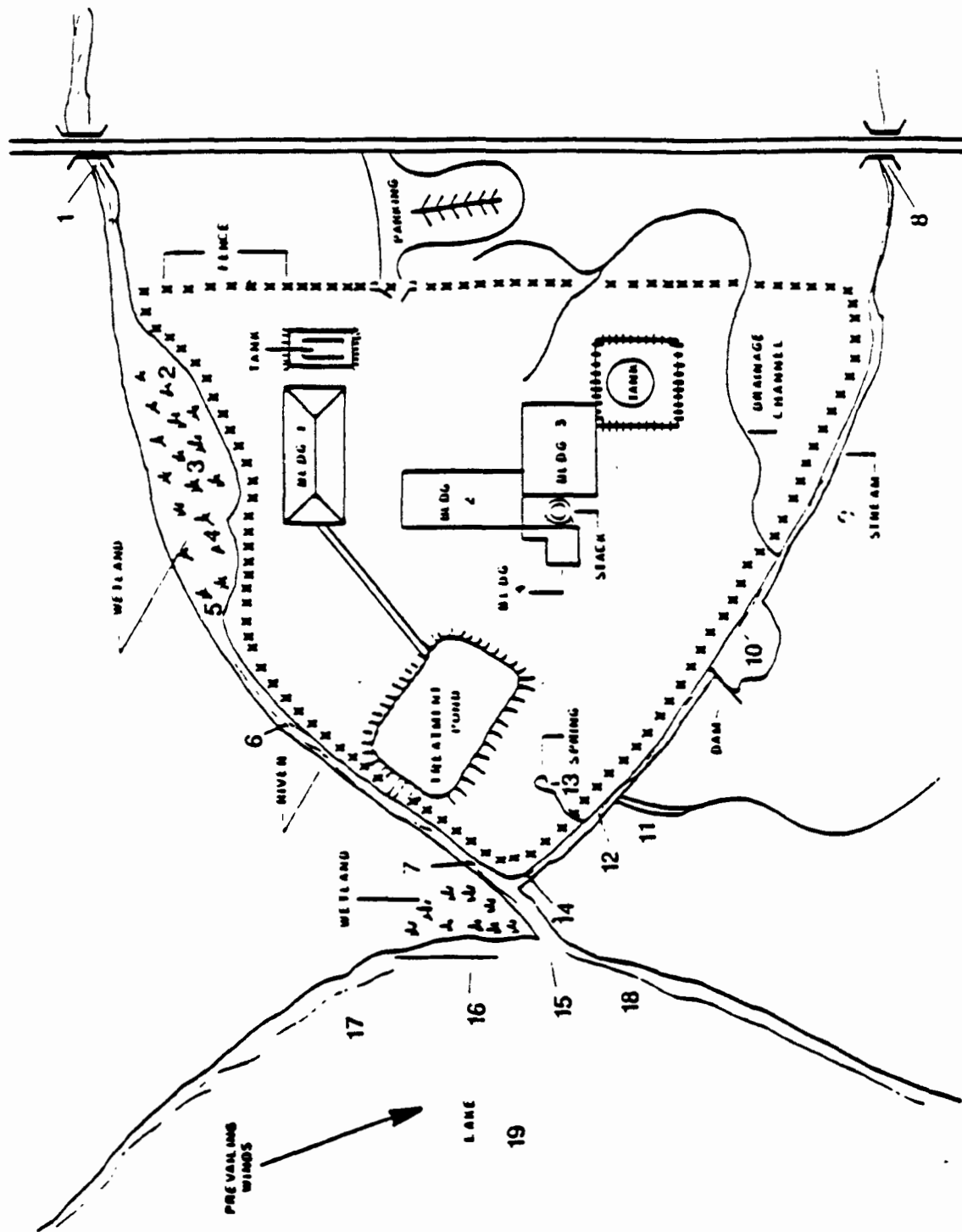


Figure 15-53. Site Plan and Water Sampling Locations

## Results

Results of the survey indicated that concentrations of organic contaminants in the surface waters were generally less than U.S. EPA water quality criteria, but that concentrations of inorganic contaminants generally exceeded water quality criteria at Stations 7, 15, and 18 (Table 15-19). In comparison with the reference stations, significant sediment contamination was evident at Stations 7, 15, and 18 for the three trace metals (Table 15-20). Tissue concentrations of organic substances exceeded detection limits for bis(2-ethylhexyl) phthalate at Stations 7 and 15, and for ethylbenzene at Station 7 (Table 15-21). However, trace metal concentrations in tissues were highly elevated at Stations 7 and 15, but only slightly elevated at Station 18.

The bioassay data showed a considerable range in sensitivity, with the algal bioassay being the most sensitive (Table 15-22). Consequently, the bioassay results were normalized to the least toxic of the reference stations (i.e., Station 6) to compensate for the wide range of sensitivity among the test species (Table 15-23). Overall, the bioassay results showed a high degree of agreement with contaminant concentrations in water and sediments (Figure 15-54, Table 15-19 and 15-20). Stations 7 and 15 showed highly toxic results, and Station 18 indicated moderate toxicity. Only the algal bioassay indicated significant, but low, toxicity at Station 17 (the lake reference station).

In summary, the results indicated that the organic contaminants were less of a problem than the trace metals in terms of bioaccumulation and potential toxicity. Most of the observed toxicity was attributed to trace metal contamination, which is consistent with the elevated concentrations of trace metals measured in the water, sediments, and tissues.

## Case Discussion

This case study provides an example of a biomonitoring program designed to characterize the relationship between a contaminant source, contaminant concentrations in sediments and water, bioaccumulation in tissues, and receiving-water toxicity. It should be recognized that in many instances, the relationship

TABLE 15-19

**MEAN CONCENTRATIONS ( $\mu\text{g/l}$ ) OF ORGANIC SUBSTANCES AND TRACE METALS  
IN LEACHATE AND SURFACE WATERS<sup>a</sup>**

Chemical Class	Chemical	Station						Water Quality Criteria <sup>o</sup>	
		Seep L1	River 6	River 7	Lake 15	Lake 18	Lake 17	Acute	Chronic
Base Neutral	Bis (2-ethylhexyl) phthalate	600	2	11	10	1	2	940	3
Volatile	Ethylbenzene	100	1	1	<1	1	2	32,000	NA <sup>c</sup>
Acid Extractable	Phenol	1500	<1	18.37	<1	<1	<1	10,200	2560
Metals	Copper	4300	<1	489	56	26	2	18	12
	Zinc	35,000	17	4290	1100	37	35	320	47
	Cadmium	4800	<1	146	49	<1	<1	3.9	1.1

<sup>a</sup>River and lake alkalinity = 100 mg CaCO<sub>3</sub>/L

<sup>b</sup>Trace metal criteria adjusted for alkalinity

<sup>c</sup>Not available for this substance



TABLE 15-20

**MEAN SEDIMENT CONCENTRATIONS ( $\mu\text{g/kg}$  DRY WT) OF ORGANIC  
SUBSTANCES AND TRACE METALS**

Chemical Class	Chemical	Station					
		Seep L1	River 6	River 7	Lake 15	Lake 18	Lake 17
Base Neutral	Bis (2-ethylhexyl) phthalate	NA <sup>a</sup>	216	1188	1080	108	216
Volatile	Ethylbenzene	NA	10	34	20	14	8
Acid Extractable	Phenol	NA	<30	<30	<30	<30	<30
Metals	Copper	NA	3	1663	190	88	7
	Zinc	NA	11	28,314	7260	24	23
	Cadmium	NA	<0.1	19	6	<0.1	<0.1

<sup>a</sup>Not applicable (NA).

TABLE 15-21

**MEAN LIVER TISSUE CONCENTRATIONS ( $\mu\text{g/kg}$  WET WT) OF ORGANIC  
SUBSTANCES AND TRACE METALS**

Chemical Class	Chemical	Station					
		Seep L1	River 6	River 7	Lake 15	Lake 18	Lake 17
Base Neutral	Bis (2-ethylhexyl) phthalate	NA <sup>a</sup>	<25	95	86	<25	<25
Volatile	Ethylbenzene	NA	<5	9	<5	<5	<5
Acid Extractable	Phenol	NA	<30	<30	<30	<30	<30
Metals	Copper	NA	118	1600	750	237	180
	Zinc	NA	983	28,400	8500	2139	1420
	Cadmium	NA	115	1600	639	190	125

<sup>a</sup>Not applicable (NA).

TABLE 15-22

MEAN LC<sub>50</sub> AND EC<sub>50</sub> VALUES (PERCENT DILUTION) FOR SURFACE-WATER BIOASSAYS<sup>a</sup>

Bioassay	Endpoint	Station					
		Seep L1	River 6	River 7	Lake 15	Lake 18	Lake 17
Algae	Growth inhibition (EC <sub>50</sub> %) <sup>a</sup>	NA <sup>b</sup>	> 100 <sup>c</sup>	0.4	10.0	24.9	75.0
Daphnia	Mortality (LC <sub>50</sub> %) <sup>d</sup>	NA	> 100	3.3	18.5	100.0	90.0
Microtox	Decreased luminescence (EC <sub>50</sub> %) <sup>a</sup>	NA	> 100	5.6	15.0	43.4	> 100

<sup>a</sup>Percent dilution required corresponding to a 50 percent response<sup>b</sup>Not applicable (NA) because leachate toxicity was not tested<sup>c</sup>Response of > 100 indicates that samples were not toxic at all dilutions tested<sup>d</sup>Percent dilution corresponding to 50 percent mortality

**TABLE 15-23**  
**RELATIVE TOXICITY OF SURFACE-WATER SAMPLES<sup>a</sup>**

Bioassay	Endpoint	Station					
		Seep L1	River 6	River 7	Lake 15	Lake 18	Lake 17
Algae	Growth inhibition (EC <sub>50</sub> %)	NA <sup>a</sup>	0.0	99.6	90.0	75.1	25.0
Daphnia	Mortality (LC <sub>50</sub> %)	NA	0.0	96.7	81.5	0.0	10.0
Microtox	Decreased luminescence (EC <sub>50</sub> %) <sup>a</sup>	NA	0.0	94.4	85.0	56.6	0.0

<sup>a</sup>Relative toxicity = 100 x [(Reference Station - Impacted Station)/Reference Station]

<sup>a</sup>Not applicable (NA) because leachate toxicity was not tested

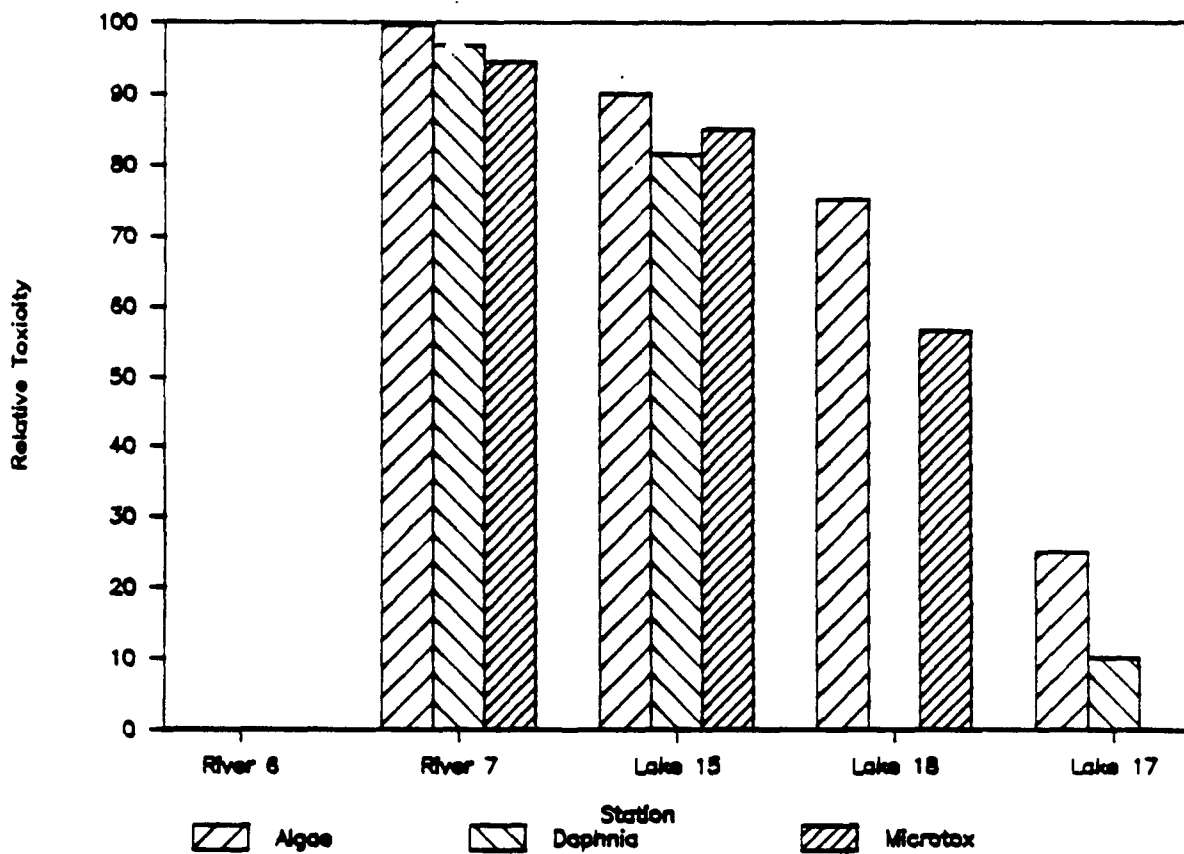
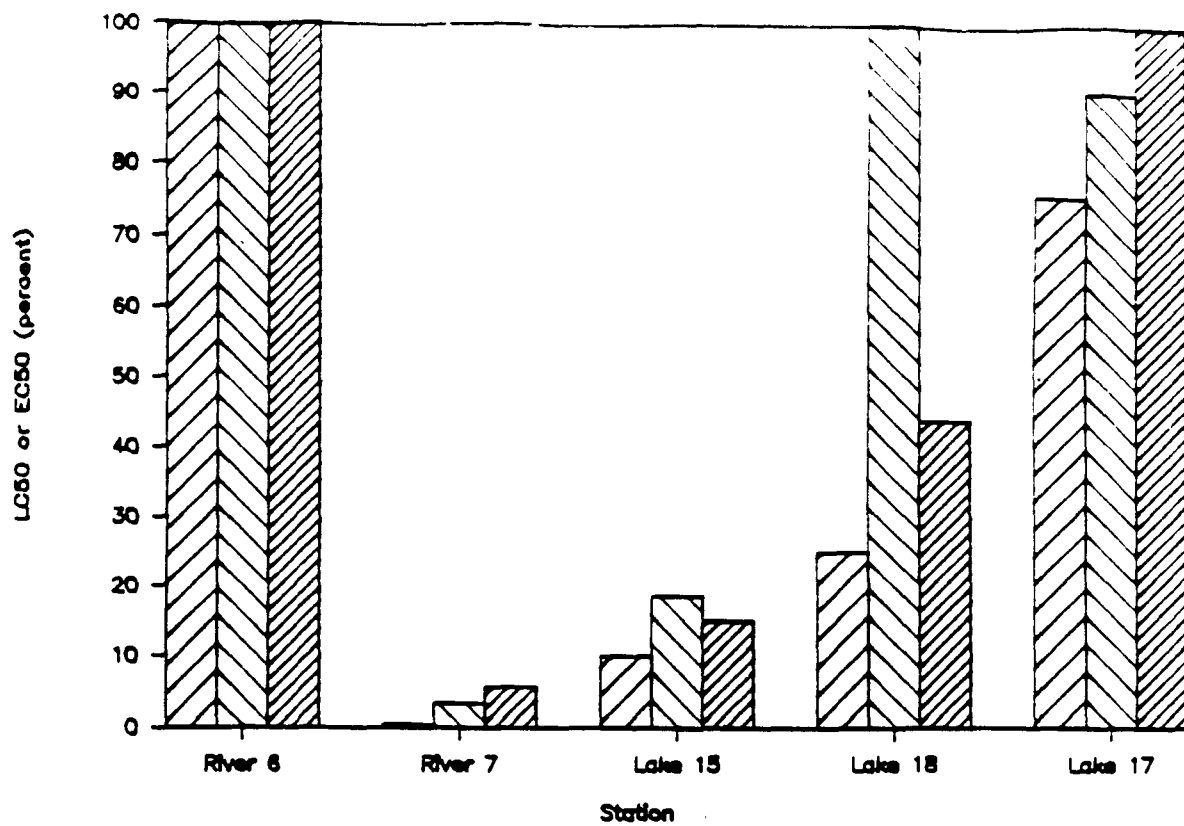


Figure 15-54. Bioassay Responses to Surface Water Samples

between contaminant concentrations in the water and toxicity will not be as clear-cut as described in this example. Consideration of the chemical composition in leachate samples, mass balance calculations, and transport and fate mechanisms may indicate that sediments are the primary repository of contaminants. In such instances, sediment bioassays rather than receiving-water bioassays may be better suited for characterization of potential toxic effects on local fauna.

### References

Bulich, A.A., M.W. Greene, and D.L. Isenberg. 1981. Reliability of the bacterial luminescence assay for determination of the toxicity of pure compounds and complex effluent. pp. 338-347. In: Aquatic toxicology and hazard assessment: Proceedings of the fourth annual symposium. ASTM STP 737. D.R. Branson and K.L. Dickson (eds). American Society for Testing and Materials, Philadelphia, PA.

Tetra Tech. 1983. Protocol for bioassessment of hazardous waste sites. EPA- 600/2-83-054. Lafayette, CA. 42 pp. + appendices.

U.S. Environmental Protection Agency. 1985. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms. EPA/600/4-85/014. U.S. EPA, Environmental Monitoring and Support Laboratory, Cincinnati, OH. 162 pp.

## **CASE STUDY 29: SAMPLING OF SEDIMENTS ASSOCIATED WITH SURFACE RUNOFF**

### **Point Illustrated**

- Contaminated sediments associated with surface runoff pathways (rivulets or channels) are indicative of the migration of chemicals via overland flow.

### **Introduction**

This facility is a secondary lead smelting plant which began operation in 1976. The plant reclaims lead from materials such as waste automotive batteries, byproducts of lead weight manufacture, and wastewater sludges. Lead grid plates from salvaged batteries are temporarily stored on site in an open pile prior to being re-melted. It is therefore appropriate to conduct some form of runoff sampling to monitor migration of contaminants from the site via this route.

### **Facility Description**

The facility covers approximately 2,000 ft<sup>2</sup> and is situated in an area primarily used for farming. A creek flows adjacent to the plant and drains into a major river 6 miles west of the site. Population is sparse with the nearest town 4 miles to the south. In the past, there have been four on-site impoundments in operation and two landfills. In addition, blast furnace slag, lead grid plates, and rubber chips from the recycled batteries have been stored in two on-site waste piles.

### **Sediment Sampling**

Four sediment samples (020, 022, 025, and 027) were collected from surface runoff pathways and a creek which receives runoff from the site. Figure 15-55 shows the locations of the runoff pathways relative to the facility and the four sampling points. Additional sediment samples were collected from the creek at various points upstream and downstream of known overland leachate seeps and surface water runoff routes. The program design enabled comparison between

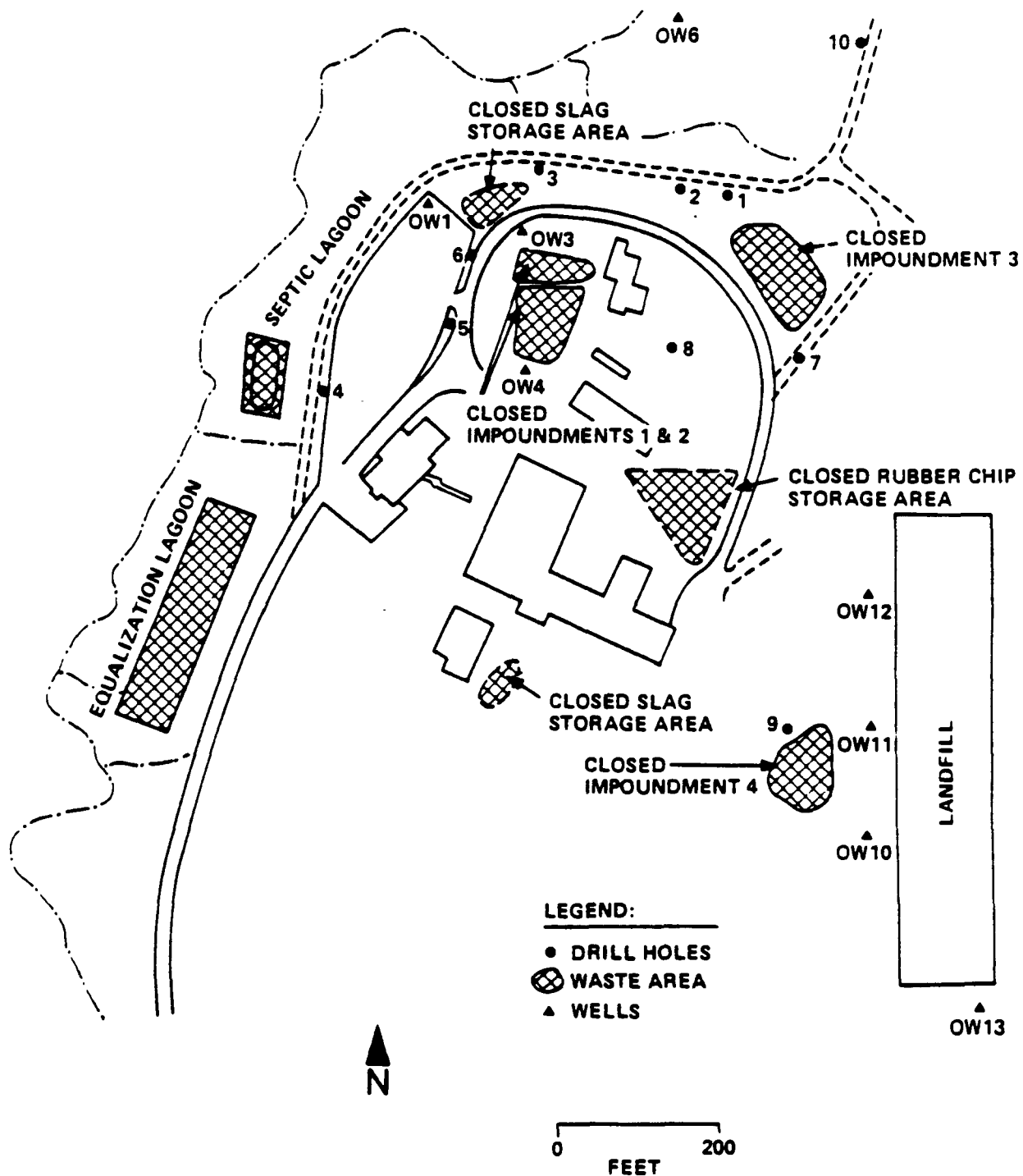


Figure 15-55. Surface Water and Sediment Sample Locations



concentrations at different sections of the creek and background locations in relation to the runoff pathways.

### Results

Table 15-24 presents the concentrations of lead and arsenic measured on the four surface runoff pathways and at location 029, which represents an upstream background concentration (Figure 15-55). It is clear that highly elevated levels of lead were detected in all four of the runoff pathway samples. The highest concentration of lead, 1,900 ppm, was detected in the western-most portion of the site. Runoff pathway sediment at the northern end of the facility, adjacent to the slag storage area, recorded 1,600 ppm of lead. Concentrations of this order represent a substantial source of sediment contamination.

**TABLE 15-24**  
**ARSENIC AND LEAD CONCENTRATIONS (PPM) IN RUNOFF**  
**SEDIMENT SAMPLES**

<u>Contaminant</u>	<u>Sampling Location</u>				<u>Background</u>
	<u># 020</u>	<u># 022</u>	<u># 025</u>	<u># 027</u>	<u># 029</u>
Arsenic	11.0	9.6	2.0	8.9	<0.1
Lead	1300	1900	1600	1700	11.0

### Case Discussion

This case illustrates the importance of monitoring surface runoff pathways, because they can represent a major route of contaminant migration from a site, particularly for contaminants likely to be sorbed on or exist as fine particles. This type of monitoring is especially useful for units capable of generating overland flows. Such monitoring can establish the need for corrective measures (e.g., surface runoff/runoff controls and/or some form of waste leachate collection system).

## CASE STUDY 30: SAMPLING PROGRAM DESIGN FOR CHARACTERIZATION OF A WASTEWATER HOLDING IMPOUNDMENT

### Points Illustrated

- Sampling programs should consider three-dimensional variation in contaminant distribution in an impoundment.
- Sampling programs should encompass active areas near inflows and outflows, and potentially stagnant areas in the corner of an impoundment.

### Introduction

This study was conducted to assess whether an active liquid waste impoundment could be assumed to be of homogenous composition for the purpose of determining air emissions. This case shows the design of an appropriate sampling grid to establish the three-dimensional composition of the impoundment.

### Facility Description

The unit being investigated in this study is a wastewater impoundment at a chemical manufacturing plant. The plant primarily produces nitrated aromatics and aromatic amines. Raw materials include benzene, toluene, nitric acid, and sulphuric acid. Wastewater from the chemical processing is discharged into the impoundment prior to being treated for release into a nearby water body. The impoundment has an approximate surface area of 3,750 m<sup>2</sup> and a depth of 3 m.

### Sampling Program

For the most part, sampling involved the collection of grab samples using an extended reach man-lift-vehicle. The program was designed to collect samples at different locations and depths in the impoundment.

## Sampling Locations and Procedures--

**Sampling Grid** - The wastewater impoundment was divided into 15 segments of equal area. Within this grid, eight sampling locations were selected which included all pertinent areas of the impoundment, such as active portions near the inflows and outflows, potential stagnant areas in the corners, and offshore points near the center line of the impoundment.

It was decided to take samples from four depths in the liquid layer and one from the bottom sediments at each of the eight locations. Figure 15-56 shows the impoundment schematic and sampling locations.

**Liquid Sampling** - A total of 32 liquid grab samples were taken. These were analyzed for the following parameters: all identifiable volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) using gas chromatograph/mass spectroscopy; and selected VOCs and SVOCs by gas chromatography using a flame ionization detector.

**Sediment/Sludge Sampling** - The bottom layer was sampled using a Ponar grab sampler. The same analyses were performed on the eight sediment/sludge samples as on the liquid samples.

**Meteorological Monitoring** - The ambient meteorological conditions were monitored throughout the sampling period, including wind speed, wind direction, and air temperature. A video camera was also used to record the movement of surface scum on the impoundment.

Table 15-25 summarizes the sampling locations and analyses, including locations where QC data were collected.

## **Results**

From the sampling program, it was discovered that approximately 99 percent of the organic compounds (by weight) were contained in the bottom sludge layer.

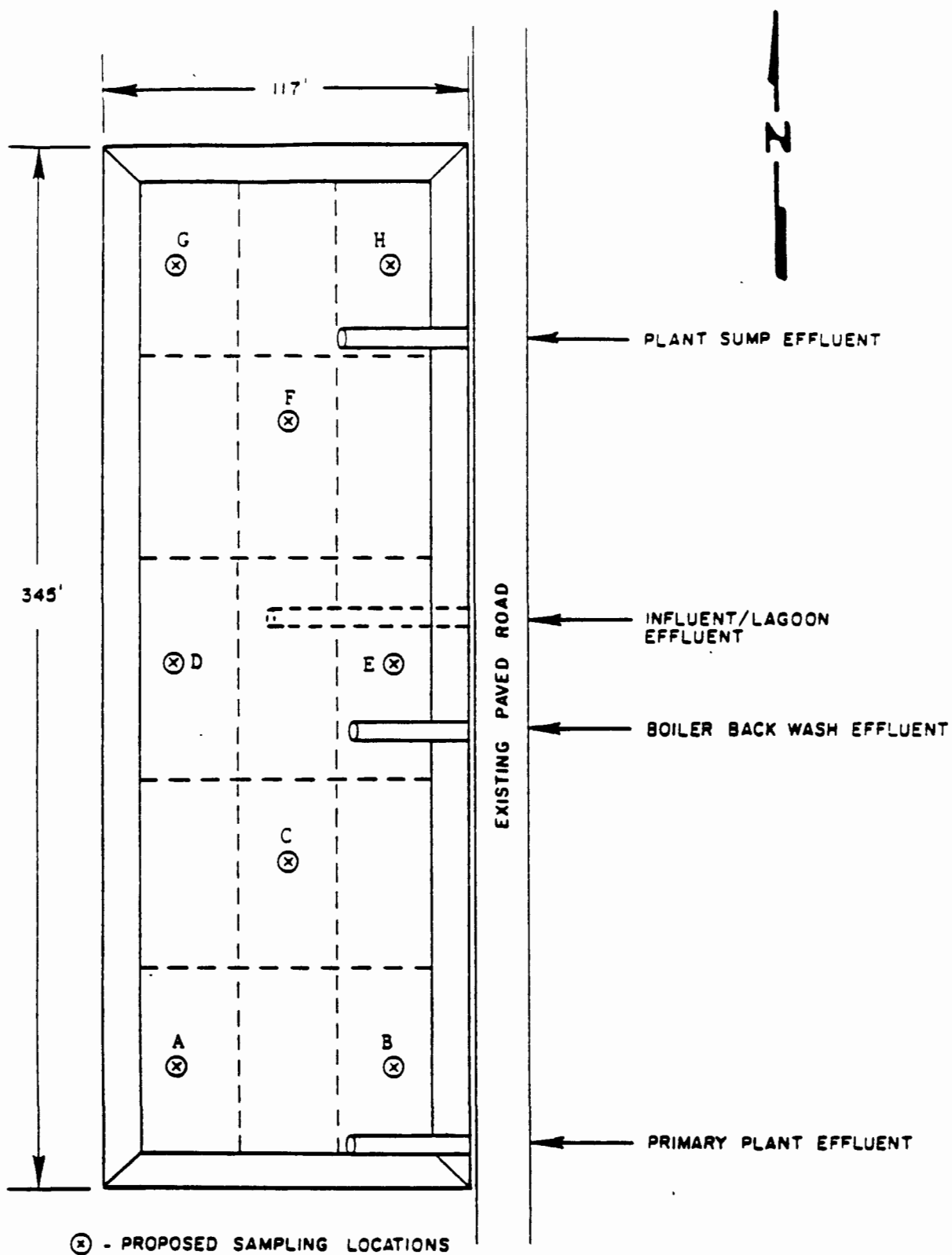


Figure 15-56. Schematic of Wastewater Holding Impoundment Showing Sampling Locations

TABLE 15-25

**SUMMARY OF SAMPLING AND ANALYSIS PROGRAM FOR  
WASTEWATER IMPOUNDMENT**

Location	Depth (Feet)	Sample Analyses						
		GC/FID VOA	GC/MS VOA	TOC	POC	Onsite Parameters <sup>a</sup>	GC/FID SVOC	GC/MS SVOC
A-1	0-1	X	X	X	X	X	X	X
A-2	2	X				X	X	
A-3	4	X				X	X	
A-4	6	X				X	X	
A-5	Bottom Sediment	X	X	X		X	X	X
B-1	0-1	X	X	X	X	X	X	X
B-2	2	X				X	X	
B-3	4	X				X	X	
B-4	6	X				X	X	
B-5	Bottom Sediment	X	X	X		X	X	X
C-1	0-1	X	X	X	X	X	X	X
C-2	2	X				X	X	
C-3	4	X				X	X	
C-4	Bottom Sediment	X	X	X		X	X	X
D-1	0-1	X	X	X	X	X	X	X
D-2	2	X				X	X	
D-3	4	X				X	X	
D-4	6	X				X	X	
D-5	Bottom Sediment	X	X	X		X	X	X

<sup>a</sup> Includes pH, turbidity, specific conductance, and dissolved oxygen measurements.

X Indicates locations where QC samples were collected.

TABLE 15-25 (continued)

Location	Depth (Feet)	Sample Analyses						
		GC/FID VOA	GC/MS VOA	TOC	POC	Onsite Parameters <sup>a</sup>	GC/FID SVOC	GC/MS SVOC
E-1	0-1	X	X	X	X	X	X	X
E-2	2	X				X	X	
E-3	4	X				X	X	
E-4	6	X				X	X	
E-5	Bottom Sediment	X	X	X		X	X	X
F-1	0-1	X	X	X	X	X	X	X
F-2	2	X				X	X	
F-3	4	X				X	X	
F-4	6	X				X	X	
F-5	Bottom Sediment	X	X	X		X	X	X
G-1	0-1	X	X	X	X	X	X	X
G-2	2	X				X	X	
G-3	4	X				X	X	
G-4	6	X				X	X	
G-5	Bottom Sediment	X	X	X		X	X	X
H-1	0-1	X	X	X	X	X	X	X
H-2	2	X				X	X	
H-3	4	X				X	X	
H-4	6	X				X	X	
H-5	Bottom Sediment	X	X	X		X	X	X

<sup>a</sup> Includes pH, turbidity, specific conductance, and dissolved oxygen measurements.

X Indicates locations where QC samples were collected.

Vertical and horizontal variation in the composition of the lagoon was apparent. The degree of horizontal variation was relatively small, but sample point "A" showed considerably higher concentrations of 2,4-dinitrophenol than the other locations. This could have resulted from a recent discharge from the outflow at the southern end of the impoundment. Vertical variation in composition showed a general trend of increasing concentration with depth, but certain chemicals tended to have higher concentrations at mid-depth in the impoundment.

### Case Discussion

This case provides an example of a sampling program at an areal source designed to yield accurate information for characterizing air emissions from the unit. The study illustrated the importance of characterizing the organic composition of the lagoon in three dimensions and considering variations resulting from inflow and outflow areas.

It should be mentioned that this study did not consider variation in the chemical composition of the impoundment with time. To obtain this information, it would be necessary to conduct subsequent sampling programs at different times. From this study, it is apparent that chemical composition varies both horizontally and vertically, and is likely to change depending on inflows and outflows of wastes. This sampling program is therefore limited to effectively characterizing composition at a single point in time.

## CASE STUDY 31: USE OF DISPERSION ZONE CONCEPTS IN THE DESIGN OF A SURFACE WATER MONITORING PROGRAM

### Point Illustrated

- Estimation of the dispersion zone of contaminants downstream of a release point can be used to help design a surface water monitoring program.

### Introduction

When a contaminant is initially released to a body of water, the concentration of the contaminant will vary spatially until fully dispersed. In streams, the contaminant will disperse with the surrounding ambient water as the water moves downstream and will eventually become fully dispersed within the stream. Downstream of this point, the contaminant concentration will remain constant throughout the stream cross-section, assuming that streamflow is constant and that the contaminant is conservative (e.g., nondegradable). The area in which a contaminant's concentration will vary until fully dispersed, referred to here as the dispersion zone, should be considered when determining the number and location of sampling stations downstream of the release point.

### Facility Description

A facility that processed zinc, copper and precious metals from ores operated along a stream for five years. The plant was closed after being cited for repeated fish kills, reportedly due to failures of a tailings pond dike. At present, the site is covered with tailings containing high concentrations of copper, zinc, cadmium, arsenic, and lead. There is no longer a tailings pond. This is the same facility described in Case Study 27.

### Site Setting

The site is located on coarse colluvium (hill-slope deposits of weathered bedrock) and fine-grained alluvium. These deposits are typically 50 feet thick. Metamorphic rock (phyllite) underlies the unconsolidated materials. Ground water



moves laterally in the gravel formations from the steep valley walls toward the stream.

The site is located about 400 feet from the stream. Two drainage ditches cross the lower portion of the site and merge prior to leaving the site. The ditch carries the combined flow and discharges directly into the stream (Figure 15-57). No other tributaries enter the stream within 2 miles of this location. Downstream of the release point, stream width and depth remain fairly constant at 45 and 3 feet, respectively. Mean stream velocity is 0.5 feet per second and channel slope is 0.0005 feet per foot.

### Sampling Program

A surface water monitoring program was designed as part of a Phase I investigation to determine the extent of contamination in the stream. Existing data from previous sampling had shown high concentrations of metals in the drainage ditch sediments (e.g., 5,170 mg/kg Cu and 11,500 mg/kg Zn). Ground-water data from the plant's well showed concentrations of Cu (7  $\mu\text{g/l}$ ) and Zn (54  $\mu\text{g/l}$ ). The contribution of metals to the stream by ground-water discharge was considered to be relatively minor.

Based on a review of the plant history and the available water quality and sediment data, a monitoring program was designed. The potential pathways by which metals could reach the stream appeared to be direct discharge from the drainage ditch, discharge of contaminated ground water, and storm water runoff over the general facility area. Plant records indicated that typical flows in the drainage ditch at its confluence with the stream varied from 1 to 3 cubic feet per second (cfs) in the spring. During extreme flood conditions, the flow in the ditch exceeded 20 cfs. In the summer, flows in the drainage ditches at all locations were less than 0.5 cfs. Resuspension of contaminated sediments in the ditches during storm runoff appeared to be the most likely pathway for metals to reach the stream. The specific metals of concern were identified as As, Cd, Cu, Pb and Zn, based on the processes used at the plant and the composition of the ores which contained some arsenopyrites (with As, Cu), galena (Pb), and sphalerite (with Zn, Cd).

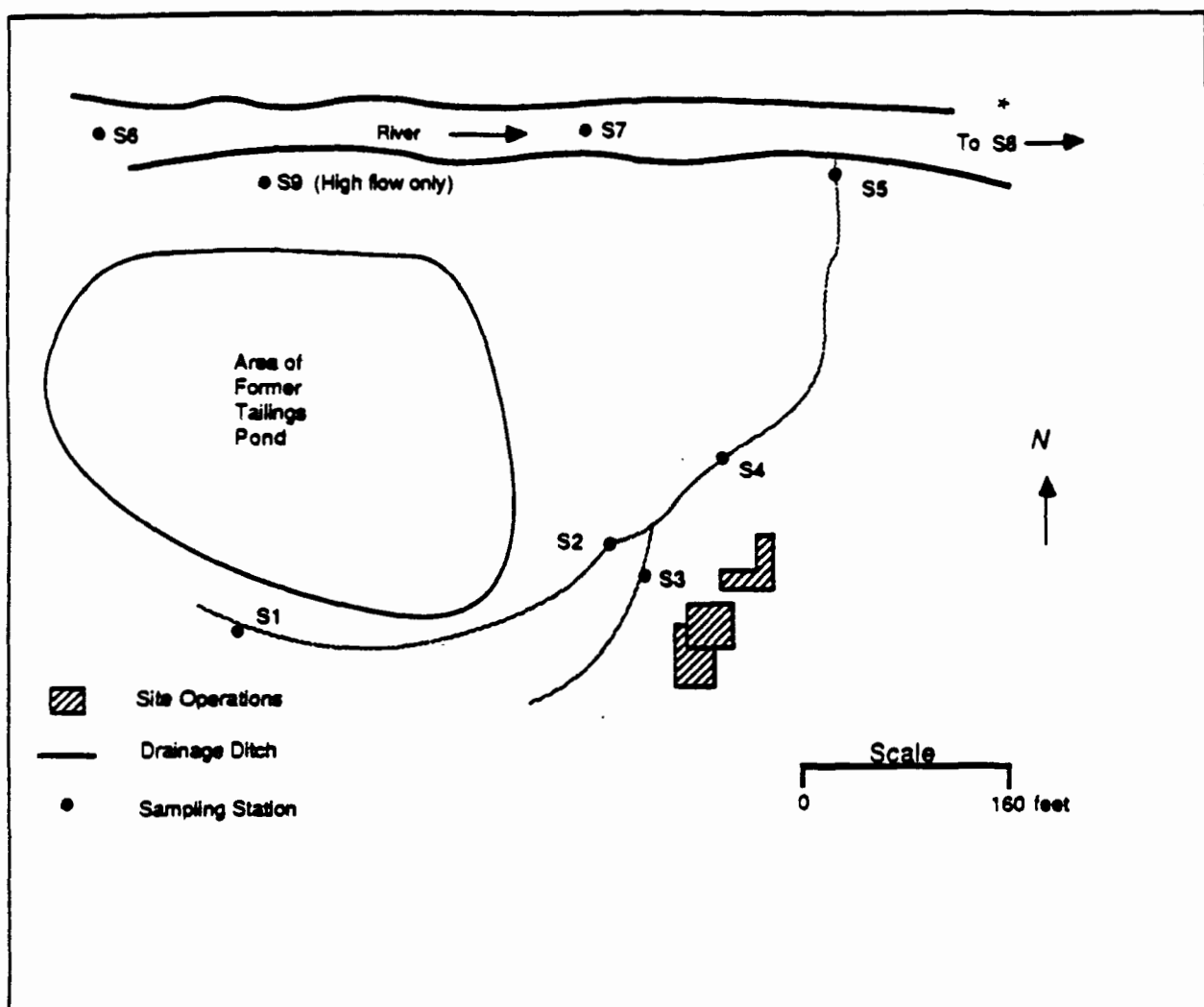


Figure 15-57. Sampling Station Locations for Surface Water Monitoring

- \* Located approximately 1030 feet downstream of the confluence of the ditch with the stream.

The available soil and water quality data from previous sampling were reviewed to help determine the likely fate of the metals. The pH of soils in the area is about 6.5 and they contain about 0.5 percent organic matter by weight. Under such conditions, the metals, particularly Pb, would be expected to adsorb onto the soil particles. In the on-site tailings piles, the pH of core samples ranged between 3.3 and 4.9. Low soil pH values had been measured in sediments in the drainage ditch just downgradient of the tailings pile. The pH of the stream during the previous sampling was 6.9. The suspended solids concentration was 10 mg/l.

Estimates of the distribution of metals between the dissolved and adsorbed phases for a range of partition coefficients ( $K_p$ ) are shown in Table 15-26. For example, if  $K_p = 10^4$  and the suspended solids concentration was 10 mg/l, 90 percent (0.9) of the metal present would be in the dissolved phase. This information indicated that even though a metal (e.g., lead) was known to strongly sorb, a significant amount could still be transported in the dissolved phase. Thus, both water and suspended solids should be analyzed for metals. The complete list of parameters selected for measurement in the Phase I investigation and the rationale for their selection are outlined in Table 15-27.

The sampling stations were selected to determine stream water quality up- and downstream of the site and to determine whether particulates with sorbed metals were deposited on the stream banks or streambed. The sampling stations and the rationale for their selection are listed in Table 15-28. The station locations are shown in Figure 15-57. Because floods were considered a cause of contamination incidents, samples were to be collected under both high and low flow conditions.

The location of the downstream station (S8) was determined after estimating the stream length that may be required for complete dispersion of the contaminants. The following equation was used for this estimation:

$$DZ = \frac{0.4 w^2 u}{0.6 d \sqrt{g d s}}$$

TABLE 15-26

**RELATIONSHIP OF DISSOLVED AND SORBED PHASE CONTAMINANT  
CONCENTRATIONS TO PARTITION COEFFICIENT AND SEDIMENT  
CONCENTRATION**

$K_p$	SS	$C_w/C_T^a$
10 <sup>0</sup>	1	1.0
	10	1.0
	100	1.0
	1000	1.0
	10,000	1.0
10 <sup>1</sup>	1	1.0
	10	1.0
	100	1.0
	1000	1.0
	10,000	0.9
10 <sup>2</sup>	1	1.0
	10	1.0
	100	1.0
	1000	0.9
	10,000	0.5
10 <sup>3</sup>	1	1.0
	10	1.0
	100	0.9
	1000	0.5
	10,000	0.1
10 <sup>4</sup>	1	1.0
	10	0.9
	100	0.5
	1000	0.1
	10,000	0.0

After Mills *et al.*, 1985.

<sup>a</sup>The fraction dissolved ( $C_w/C_T$ ) is calculated as follows:

$$\frac{C_w}{C_T} = \frac{1}{1 + K_p \times 5 \times 10^{-6}}$$

where  $K_p$  = partition coefficient,  $\ell/\text{kg}$   
 $SS$  = suspended solids concentration,  $\text{mg}/\ell$   
 $C_w$  = Dissolved concentration  
 $C_T$  = Total concentration

TABLE 15-27

## PARAMETERS SELECTED FOR SURFACE WATER MONITORING PROGRAM

Parameters	Rationale
Metals - As, Cd, Cu, Pb, Zn	Determine extent of contamination
pH	Predict sorption behavior, metal solubility, and speciation
Dissolved Oxygen, Sulfide, Fe(II), Fe(III)	Determine redox conditions which influence behavior of metals, particularly the leaching of tailings
Alkalinity	A measure of how well buffered a water is, allows consideration of the likelihood of pH change
Total Dissolved Solids	Used as a water quality indicator and for QA/QC checks
Major Cations ( $\text{Ca}^{+2}$ , $\text{Mg}^{+2}$ , $\text{Na}^{+}$ , $\text{K}^{+}$ , $\text{NH}_4^{+}$ ) and Major Anions ( $\text{Cl}^{-}$ , $\text{SO}_4^{-2}$ , $\text{NO}_3^{-}$ )	May identify other waste sources, can influence fate of trace metals
Suspended Solids	Predict the fraction of metal in water which is sorbed
Streamflow	Compute mass balances and assist in identifying sources of observed contamination

**TABLE 15-28****SELECTED SURFACE WATER MONITORING STATIONS AND SELECTION RATIONALE**

Station	Media	Rationale
Drainage ditch west of site (S1)	Water and sediments	Determine whether off-site drainage is significant source of contamination
Drainage ditches on site (S2 and S3)	Water and sediments	Identify on-site sources
Downstream of confluence of two ditches (S4)	Water and sediments	Provide information for checking mass balances from the two drainage ditches
Mouth of drainage ditch (S5)	Water, suspended sediment, bedload	Determine quality of direct discharge to stream
Stream (S6, S7 and S9)	Water, suspended sediment, bedload	Determine upstream water quality
Stream (S8)	Water, suspended sediment, bedload	Determine quality downstream of site following complete dispersion and provide data for mass balance

where:

- DZ = dispersion zone length, ft
- w = width of the water body, ft (45 ft)
- u = stream velocity, ft/sec (0.5 ft/sec)
- d = stream depth, ft (3 ft)
- s = slope (gradient) of stream channel, ft/ft (0.0005)
- g = acceleration due to gravity (32 ft/sec<sup>2</sup>).

Using the above equation, the estimated stream length required for complete contaminant dispersion is 1030 feet. This can serve as an approximate distance downstream of the release point at which a sampling station should be located.

#### Case Discussion

This case illustrates the use of contaminant dispersion zones in the design of a surface water monitoring program. In this example, the data indicate that approximately 1030 feet of flow within the described stream channel is required before a contaminant will become fully dispersed. A downstream station should therefore be located at or below this dispersion zone to fully characterize the extent of the release. An adequate number of sampling stations should also be located upstream of this point.