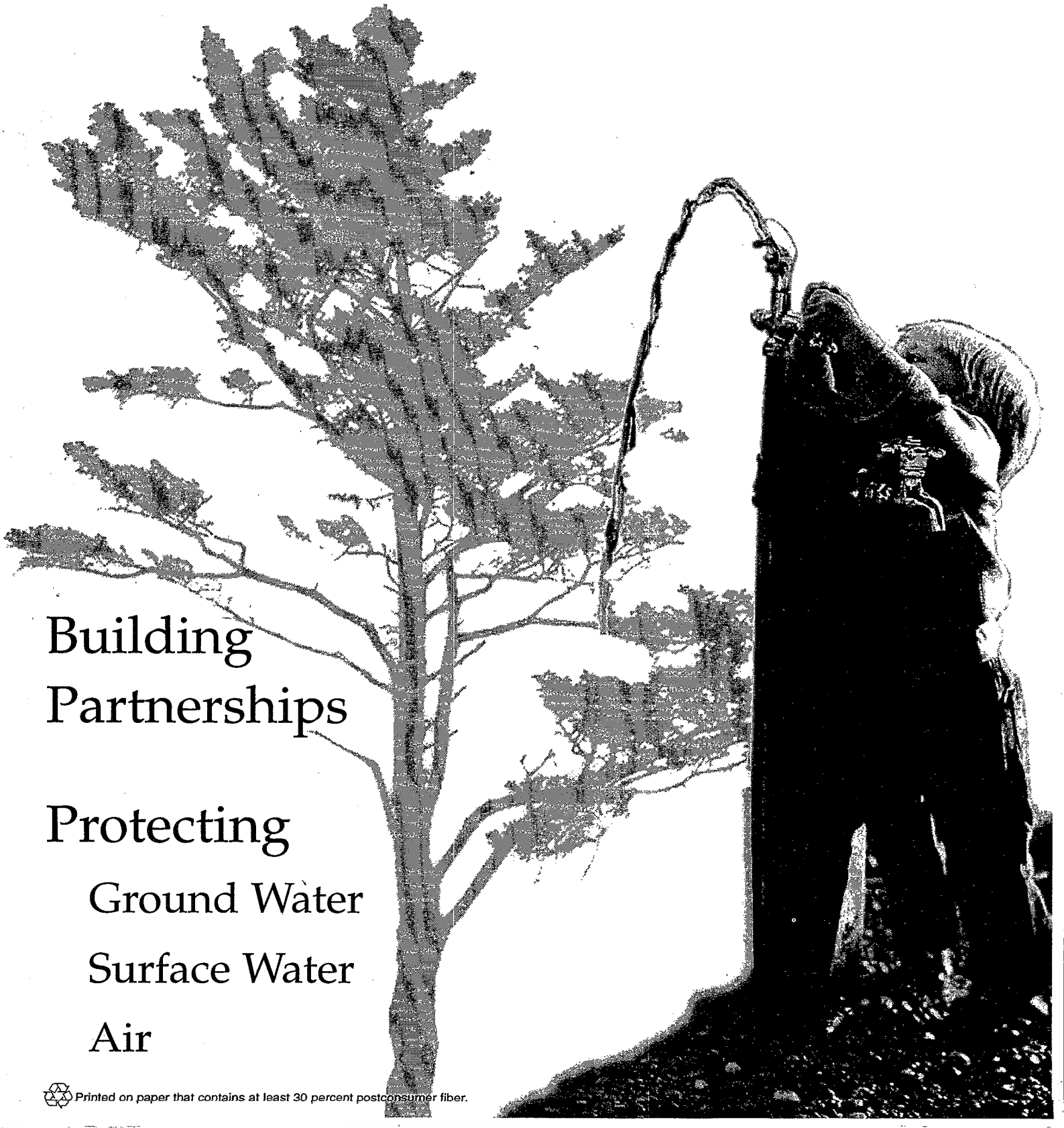
United States Environmental Protection Agency
Solid Waste and Emergency Response (5305W)
EPA530-R-99-001
May 1999
www.epa.gov/osw

EPA

Guide for Industrial Waste Management



Building Partnerships

Protecting

Ground Water

Surface Water

Air

Printed on paper that contains at least 30 percent postconsumer fiber.

Guide
for
Industrial Waste Management

U.S. Environmental Protection Agency
Office of Solid Waste
401 M Street SW (5305W)
Washington, DC 20460

Disclaimer

All aspects of this guidance are in draft form, subject to comment, and not intended to be used in current waste management decision-making. The draft guidance and modeling tools have been developed only to address issues within the scope of the guidance. The guidance is not a guideline or regulation under the Resource Conservation and Recovery Act, nor can this draft guidance be relied upon to create any rights enforceable by any party in litigation with the United States. EPA retains the right to modify the final guidance from time to time.

Acknowledgements

The following members of the Industrial Waste Focus Group and the Industrial Waste Steering Committee are gratefully acknowledged for all of their time and assistance in the development of this draft guidance document.

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This guidance document, CD-ROM, and the ground-water and air modeling tools were developed with assistance from Eastern Research Group (Birute Vanatta and Marty Marchaterre, Project Officers), Science Applications International Corporation (Chris Long and Bob Stewart, Project Officers), HydroGeologic, Inc. (Sam Figuli, Project Officer), and Research Triangle Institute (Anne Cook Lutes , Project Officer and Terrence K. Pierson, Program Director).

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Glossary

EPA's Guide for Industrial Waste Management Introduction

This voluntary guide is designed to assist facility managers, state and tribal environmental managers, and the public to evaluate and choose protective practices for managing industrial waste in new landfills, waste piles, surface impoundments, and land application units. This guide identifies the components of a sound waste management system and why each is important. It also includes ground-water and air models, as well as other tools to help tailor waste management practices to a particular facility.

This guidance reflects four underlying principles:

- **Protect human health and the environment.** This is the focal point. The guidance is multi-media, emphasizing surface water, ground water, and air protection, with a comprehensive framework of technologies and practices that make up a sound waste management system.
- **Tailor management practices to risks.** There is enormous diversity in the nature of industrial wastes and the environmental settings where they are managed. The guidance provides conservative national management recommendations and user-friendly modeling tools to make location-specific adjustments It also identifies complex analytic tools to conduct comprehensive site-specific analyses.
- **Affirm state and tribal leadership.** States, tribes, and some local governments have primary responsibility for adopting and implementing programs to ensure proper management of industrial waste. It is important to note that individual states or tribes may have more stringent or extensive regulatory requirements based on local or regional conditions or policy considerations. This guide complements, but does not supersede those regulatory programs. It can help you make decisions on meeting requirements and filling potential gaps. Facility managers and the public, consult with appropriate regulatory agencies throughout the process to understand their requirements and how they want you to use this guide.
- **Foster a partnership.** The public, facility managers and regulatory agencies share a common interest in preserving quality neighborhoods, protecting the environment and public health, and enhancing the economic well-being of the community. This guide provides a common technical framework to facilitate discussion. Stay involved and work together to achieve meaningful environmental results.

I. Setting the context

About 7.6 billion tons of industrial solid waste are generated and managed on-site at industrial facilities each year. Almost 97 percent is wastewater managed in surface impoundments; the remainder is managed in landfills, waste piles, and land application units. Most of these wastewaters are treated and ultimately discharged into surface waters under Clean Water Act permits issued by EPA or state governments (National Pollutant Discharge Elimination System or NPDES permits). These wastes come from the broad spectrum of American industries. This guidance is not designed to address municipal wastes or wastes defined as hazardous under federal or state laws.

EPA and 12 state representatives selected from the membership of the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) began development of this guidance in 1996 with the formation of a State/EPA Steering Committee. We set out with three goals: first to define a baseline of management practices that protect human health and the environment; second, to complement existing state and tribal regulatory programs; and third to produce an effective and user-friendly guide that all stakeholders will rely on. The Steering Committee is co-chaired by one EPA and one state member. At the same time, we had the benefit of a Focus Group of industry and public interest stakeholders chartered under the Federal Advisory Committee Act to consult with us throughout development of the guidance. The Steering Committee and Stakeholders' Focus Group members are listed in the front of this document.

The draft guide you have in hand reflects a remarkably productive consultative process. Focus Group members provided extensive comment and commitment of their time throughout. Their thoughtful input helped us to make this a more comprehensive and effective product, although the final decisions are those of the Steering Committee. Right now, our work is half completed. The Steering Committee will reconvene to consider the feedback we receive during the comment period and continue to seek advice from the Stakeholders' Focus Group as we develop the final guidance.

II. Scope

This guidance is useful for a broad array of industrial process wastes, especially those that are managed at the industrial facilities where they are generated. However, we did not consider certain extractive wastes, such as from mining or oil and gas production, and recommendations may not be suitable for these wastes without further tailoring. Furthermore, any facilities that receive municipal solid waste are subject to municipal landfill criteria at 40 CFR Part 258 and to separate state or tribal municipal landfill regulations and are not addressed by this guidance.

The guidance focuses on the design of new units. Liner design and siting concerns are clearly directed at new units. However, other management recommendations, such as for groundwater monitoring, corrective action, operating practices, and closure and post closure care, may be helpful in making management decisions for currently operating units as well.

III. Using the guidance

There are a few key steps to follow:

- **Understand and comply with all existing Federal, state or tribal regulations, permits and operating agreements that apply to a waste management unit.** The guidance is designed to complement them, never to take their place.
- **Thoroughly characterize constituents and concentrations in the waste.** Waste characterization is the foundation for choosing and implementing tailored, protective management practices. To assess potential ground-water risks, the guidance provides drinking water maximum contaminant levels (MCLs), when they exist, and health-based reference levels for 191 constituents. To assess potential air risks, the guidance provides inhalation health-based reference levels for 95 volatile and semi-volatile constituents.
- **Take advantage of pollution prevention opportunities.** Pollution prevention, recycling and, to some extent, treatment, can minimize reliance on waste disposal, reduce disposal costs and reduce future costs and liabilities for closure and post closure care and potential corrective action. Pollution prevention can also conserve raw materials.
- **Build a partnership between all stakeholders who have an interest in waste management decisions.** Keep stakeholders informed and involved on an ongoing basis.
- **Tailor management practices to the wastes and the environmental setting of the unit.** The guide covers all the components of a sound waste management system. It recommends best management practices and the key factors to take into account in siting, operation, design, monitoring, corrective action, closure and post closure care. The guidance also directs you to a wide variety of useful tools and resources, and includes a number of these tools as appendices. In particular, the guidance recommends risk-based approaches to choose liner systems and waste application rates for ground-water protection and to evaluate the need for air controls.

Here is an example of how the risk-based evaluation would work for choosing a liner system design. For ground-water protection, the approach is three-tiered, relying on modeling fate and transport of constituents through subsurface soils to ground water. Successive tiers in the analysis incorporate more site-specific data to tailor protective management practices to your particular circumstances.

Tier 1 - National Evaluation: Once you know the concentrations of constituents in the waste, generic "look-up tables" give you recommendations on appropriate liner design. If the waste going into a unit contains several constituents, choose the most protective liner design indicated for any of the constituents.

Tier 2 - Location Adjusted Evaluation: You can use location-specific data for up to seven of the most sensitive waste and site-specific variables to assess whether a particular liner design will be protective. The CD ROM version of the guidance provides a ground-water model for Tier 1 and 2 analyses.

Tier 3 - Comprehensive Site Assessment: This tier relies on a comprehensive analysis of specific waste and site characteristics to assess whether a particular liner design will be protective. The guidance identifies a number of models for this detailed analysis.

IV. Next Steps

We have provided the draft guidance in a printed version, on a CD ROM and it is accessible through the Internet at **<www.epa.gov/osw>**. Now, EPA and the state participants from ASTSWMO welcome your comments on all aspects of this draft: the substantive recommendations, the risk-based modeling tools, practicality and user friendliness. The accompanying *Federal Register* notice and some chapters of the guidance frame a number of key questions and issues to help you get started. The public comment period will extend for six months from the date of the *Federal Register* notice. Based on your comments, we will make revisions and release the final guidance.

EPA and state representatives participating in this effort believe that the recommendations in the final version of this guide can help to improve management of industrial waste at facilities across the country. EPA and ASTSWMO will widely disseminate the final version of the guide and explain the rationale behind the recommendations to regulators, industries and the public to foster understanding and encourage stakeholders to integrate final recommendations in future industrial planning throughout the country.

V. Final Thoughts

This guidance is designed for users with different levels of knowledge and experience. Because many of the recommendations here address complex and highly technical practices and engineered systems, users are urged to seek out technical experts and resources to assist in detailed planning, design and implementation.

Facility managers, regulatory agency staff, and the public all have a different role in ensuring protective waste management and, therefore, this guidance can help all of you.

- **Facility managers:** The guide can help you make the decisions necessary to ensure environmentally responsible unit siting, design, and operation in partnership with state and tribal regulators and the public.
- **State and tribal regulators:** The guide provides a handy implementation reference that complements your program and can help you address any gaps.
- **The public:** The guide can help you be an informed and knowledgeable partner in addressing industrial waste management issues in your community.

Part I
Getting Started

Chapter 1
Building Partnerships

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Building Partnerships

Build a partnership through an active involvement program designed to build trust and credibility between a company that generates and manages waste, the community within which the company lives and works, and the state agency that regulates the industry.

Residents located near waste management units want to understand the management activities taking place in their neighborhoods. They want to know that waste is being managed safely, without danger to public health or the environment. Create opportunities for dialogue between industries, states, and concerned citizens before decisions are made. Partnership efforts also need to be ongoing in order to be successful.

I. Benefits of Building Partnerships

Building partnerships in the decision-making process provides a number of benefits:

- Enhanced understanding of waste management activities at an industrial facility;
- Enhanced understanding of industry, state, and community concerns;
- Greater support of industry and state policies;
- Reduced delays and costs associated with opposition and litigation; and
- A positive image and relationship.

II. Principles of Building Partnerships

Regardless of the size or type of an industry waste unit, industries, states, and local communities can all follow similar principles of building partnerships. These principles are based on various state public involvement guidance documents, various EPA publications, and state requirements for waste facilities. These principles embody sound business practices and common sense, and may go beyond state requirements that call for public participation during the issuance of a permit. This guidance document recommends principles that can be adopted throughout the operating life of facilities, not just during the permitting process. Following these principles

This chapter will help address the following questions:

- What are the benefits of building partnerships?
- What building partnership methods have been successful?
- What is involved in preparing a meeting?

will help all involved consider the full range of activities possible to give partners an active voice in the decision-making process, and in so doing, will result in a positive working relationship.

A. Develop a Partnership Involvement Plan

The key to effective involvement, like any activity, is good planning. Developing a plan for how and when to involve all parties in the decision-making process will help to make involvement activities run smoothly and achieve the best results. Developing an involvement plan also helps identify concerns and determine which involvement activities best address those concerns.

The first step in developing an involvement plan is to work with the state agency to understand what involvement requirements exist. (State contacts are provided in Appendix I.) Existing state requirements dealing with involvement plans must be followed.

After this step, it will be important to assess how much interest facility activities will generate in the community. Several criteria influence the amount of public interest, including implications for public health and welfare, current relationships between the facility and community members, and the community's political and economic climate. Even if facilities have not generated much public interest in the past, involving the public is a good idea. Interest in a facility can increase suddenly when changes to existing activities are proposed or when residents' attitudes and a community's political or economic climate change over time.

To gauge public interest in a facility and to identify the community's major concerns, industries can conduct interviews with community members. They can first talk with representatives from major community groups, such as civic groups, religious organizations, and business associations. If interest in the facility seems high, industries can consider conducting a more comprehensive set of community interviews. Other individuals to interview may include the facility's immediate neighbors, representatives from other agencies and environmental organizations, and any individuals in the community who have expressed interest in the facility.

Using the information gathered during the interviews, industries can develop a list of the major community concerns regarding the facility. They can then begin to engage in involvement activities necessary to address those concerns. These activities form the basis of a partnership involvement plan.

B. Inform the State and Public About New Facilities or Significant Changes in Facility Operating Plans

A facility's decision to change its operations provides a valuable opportunity for involvement. Notifying the state and public of new facilities and proposed changes gives them the opportunity to identify applicable state requirements and comment on matters that apply to them.

What are examples of effective methods for notifying the public?

Table 1 presents examples of effective methods for public notification and associated advantages and disadvantages. The method used at a particular site, and within a particular community, will depend on the type of information or issues that need to be communicated and addressed. Public notices usually provide the name and address of the facility owner and operator and a brief description of the change being considered. After a public notice is issued, industries can develop informative fact sheets to explain proposed changes in more detail. Fact sheets and public notices can include the name and telephone number of a contact person who is available within the industry to answer questions.

Table 1
Effective Methods for Public Notification

Methods	Features	Advantages	Disadvantages
Briefings	Personal visit or phone call to key officials or group leaders to announce a decision, provide background information, or answer questions.	Provides background information. Determines reactions before an issue "goes public." Alerts key people to issues that may affect them.	Requires time.
Mailing of key technical reports or environmental documents	Mailing technical studies or environmental reports to other agencies, leaders of organized groups, or other interested parties.	Provides full and detailed information to people who are most interested. Often increases the credibility of studies because they are fully visible.	Costs money to print and mail. Some people might not read the reports.
News conferences	Brief presentation to reporters, followed by a question-and-answer period, often accompanied by handouts of presenter's comments.	Stimulates media interest in a story. Direct quotes often appear in television and radio. Might draw attention to an announcement or generate interest in public meetings.	Reporters will only come if the announcement or presentation is newsworthy. Cannot control how the story is presented, although some direct quotes are likely.
Newsletters	Brief description of what is going on, usually issued at key intervals for all people who have shown interest.	Provides more information than can be presented through the media to those who are most interested. Often used to provide information prior to public meetings or key decision points. Helps to maintain visibility during extended technical studies.	Requires staff time. Costs money to prepare, print and mail. Stories must be objective and credible, or people will react to the newsletters as if they were propaganda.
Newspaper inserts	Much like a newsletter, but distributed as an insert in a newspaper.	Reaches the entire community with important information. Is one of the few mechanisms for reaching everyone in the community through which you can tell the story your way.	Requires staff time to prepare the insert, and distribution costs money. Must be prepared to newspaper's layout specification.
Paid advertisements	Advertising space purchased in newspapers or on the radio or television.	Effective for announcing meetings or key decisions or as background material for future media stories.	Advertising space can be costly. Radio and television may entail expensive production costs to prepare the ad.
News releases	A short announcement or news story issued to the media to get interest in media coverage of the story.	Might stimulate interest from the media. Useful for announcing meetings-or omajor decisions or as background material for future media stories.	Might be ignored or not read. Cannot control how the information is used.

Table 1
Effective Methods for Public Notification (cont.)

Methods	Features	Advantages	Disadvantages
Presentations to civic and technical groups	Deliver presentations, enhanced with slides or overheads, to key community groups.	Stimulates communication with key community groups. Can also provide in-depth responses.	Few disadvantages except some groups can be hostile.
Press kits	A packet of information distributed to reporters.	Stimulates media interest in the story. Provides background information that reporters can use for future stories.	Few disadvantages except cannot control how the infor- is used and might not be read.
Advisory groups and task forces	A group of representatives of key interested parties is established. May be a policy, technical, or citizen advisory group.	Promotes communication between key constituents. Anticipates public reaction to publications or decisions. Provides a forum for reaching consensus.	Potential for controversy exists if "advisory" recommendations are not followed. Requires substantial commitment of staff time to provide support to committees.
Focus groups	Small discussion groups established to give "typical" reactions of the public. Conducted by a professional facilitator. Several sessions may be conducted with different groups.	Provides in-depth reaction to ideas or decisions. Good for predicting emotional reactions.	Gets reactions, but no knowledge of how many people share those reactions. Might be perceived as an effort to manipulate the public.
Telephone line	Widely advertised phone number that handles questions or provides centralized source of information.	Gives people a sense that they know whom to call. Provides a one-step service of information. Can handle two-way communication.	Is only as effective as the person answering the telephone. Can be expensive.
Meetings	Less formal meetings for people to present positions, ask questions, and so forth.	Highly legitimate form for the public to be heard on issues. Can be struc tured to permit small group interaction—anyone can speak.	Unless a small group discussion format is used, it permits only limited dialogue. Can get exaggerated positions or grandstanding. Requires staff time to prepare for meetings.

U.S. EPA 1990. *Sites for Our Solid Waste: A Guidebook for Effective Public Involvement.*

What is involved in preparing a meeting with industry, community, and state representatives?

Meetings can be an effective means of giving and receiving comments and addressing concerns. To publicize a meeting, the date, time, and location of the meeting should be placed in a local newspaper and/or advertised on the radio. To help ensure a successful dialogue, meetings should be at times convenient for members of the community, such as early in the evenings during the week, or on weekends. An interpreter may need to be obtained (hire or seek a volunteer) if the local community includes residents whose primary language is not English.

Prior to a meeting, an industry should develop a waste management plan for the facility or come to the meeting prepared to describe how the industrial waste from the facility will be managed. A waste management plan provides a starting point for public comment and input. Keep data presentations simple and provide information relevant

to the audience. Public speakers should be able to respond to general questions, as well as technical questions. Also, industry should review and be familiar with the concerns of groups or citizens who have previously expressed an interest in the facility. In addition, it is important to anticipate questions and plan how best to respond to these questions at a meeting.

State representatives should also be prepared to answer questions that are anticipated at the meeting. State representatives should be prepared to answer questions on specific regulatory or compliance issues, as well as to address how the industry has been working in cooperation with the state agency.

Questions often asked at a meeting include:

- What are the risks to me associated with the operations?
- Who should I contact at the facility if I have a question or concern?
- How will having the facility nearby benefit the area?
- Will there be any noticeable day-to-day effects on the community?
- Which processes generate industrial waste, and what types of waste are generated?
- How will the waste streams be treated or managed?
- What are the construction plans for any proposed containment facilities?
- What are the intended methods for monitoring and detecting emissions or potential releases?
- What are the plans to address accidental releases of chemicals or wastes at the site?
- What are the plans for financial assurance, closure, and post-closure care?
- What are the applicable state regulations?
- How long will it take to issue the permit?
- How will the permit be issued?
- Who should I contact at the state agency if I have questions or concerns about the facility?

At the meeting, industry should invite public and state comments on the proposed change, and tell community members where, and to whom they should send written comments. Industry can choose to respond to comments in several ways. For example, telephone calls, additional fact sheets, or additional meetings can all be used to address comments. Responding promptly to residents' comments and concerns demonstrates an honest attempt to address them.

C. Make Knowledgeable and Responsible People Available for Sharing Information

Having an industry contact(s) available to answer the public's questions and provide information helps assure citizens that the industry is actively listening to their concerns. Having a state contact available to address the public's concerns about the facility can also make sure that concerns are being heard and addressed.

In addition to identifying a contact person, industry and states should consider setting up a telephone line, staffed by employees, for citizens to call and obtain information promptly about the facility. Opportunities for face-to-face interaction between community members and facility representatives include onsite information offices, open houses, workshops, or briefings. Information offices function similarly to information repositories, except that an employee is present to answer

questions. Open houses are informal meetings on-site where residents can talk to company officials one-to-one. Similarly, workshops and briefings enable community members, state officials, and industry representatives to interact, ask questions, and learn about the activities at the facility. Web sites may also serve as a useful tool for industry, state, and community representatives to share information and ask questions.

D. Provide Information About Facility Operations

Providing information about site operations is an invaluable way to help the public understand waste management activities at a site. Facility tours, maintaining a publicly accessible information repository at the site, developing exhibits to explain operations, and distributing information through the publications of established organizations are examples that can serve to inform a community. Appendix II describes some of the public involvement activities that are being conducted by various companies around the country.

Conduct facility tours. Scheduled facility tours allow the community and state to visit the facility and ask questions about how it operates. By seeing a facility first-hand, residents learn how waste is managed and can become more confident that it is being managed safely. Individual citizens, local officials, interest groups, students, and the media might want to take advantage of facility tours. In planning tours, determine the maximum number of people that can be taken through the facility safely, and think of ways to involve tour participants in what they are seeing, such as providing hands-on demonstrations. It is also a good idea to have company individuals available to answer technical questions in an easy-to-understand manner.

Maintain a publicly accessible information repository. An information repository is simply a collection of documents describing the facility and its activities. It can include background information on the facility, the involvement plan (if developed), permits to manage waste on-site, fact sheets, and copies of relevant guidance and regulations. The repository should be in a convenient, publicly accessible place. Repositories are often maintained on-site in a public "reading room" or off-site at a public library, town hall, or public health office. Industry should publicize the existence, location, and hours of the repository and update the information regularly.

Develop exhibits that explain facility operations. Exhibits are visual displays, such as maps, charts, diagrams, or photographs, accompanied by brief text. They provide technical information in an easily understandable way and give an opportunity to illustrate issues of concern creatively and informatively. When developing exhibits, identify the target audience, clarify which issue or aspect of the facility's operations will be the exhibit's focus, and determine where the exhibit will be displayed. Public libraries, convention halls, community events, and shopping centers are all good, highly visible locations for an exhibit.

Use publications and mailing lists of established local organizations. Existing groups and publications often provide access to established communication networks. Take advantage of these networks to minimize the

time and expense required to develop mailing lists and organize meetings. Civic or environmental groups, rotary clubs, religious organizations, and local trade associations might have regular meetings, newsletters, newspapers, or magazines, as well as mailing lists, that could be useful in reaching interested members of the community.

III. Understanding Risk Assessment

Environmental risk communication skills are critical to successful partnerships between industry, the public, and other stakeholders. As more environmental management decisions are made on the basis of risk, it is increasingly important for all interested parties to understand the science behind risk assessment. Encouraging public participation in environmental decision-making means ensuring that all interested parties understand the basic principles of risk analysis and can converse equally on the development of assumptions that underlie the analysis.

A. Introduction to Risk Assessment

This guidance document provides simple-to-use risk assessment tools that can assist in determining the appropriate waste management practices for surface impoundments, landfills, waste piles, and land application units. The guidance tools are based on predicting potential human health impacts from a waste management unit by modeling two possible exposure pathways: releases through volatile air emissions and contaminant migration into ground water. Although applying the guidance tools is simple, it is still essential to understand the basic concepts of risk analysis to be able to interpret the results and understand the nature of any uncertainties associated with the analysis. This section provides a general overview of the scientific principles underlying the methods for quantifying cancer and noncancer risk assessment. Ultimately, understanding the scientific principles will lead to more effective use of the guidance tools.

B. Types of Risk

Risk is a concept used to describe situations or circumstances that pose a hazard to people or things they value. People encounter a myriad of risks during common everyday activities, such as driving a car, investing money, and undergoing certain medical procedures. By definition, risk is comprised of two components: the probability that an adverse event will occur and the magnitude of the consequences of that adverse event. As such, in capturing these two components, risk is typically stated in terms of the probability (e.g., one chance in one million) of a specific harmful "endpoint" (i.e., accident, fatality, cancer).

In the context of environmental management, and in the context of this section in the guidance document, risk is defined as the probability or likelihood that public health may be impacted from exposure to chemicals contained in waste management units. The risk endpoints resulting from the exposure are typically grouped into two major consequence categories: cancer risk and noncancer risk.

As implied, the cancer risk category captures risks associated with exposure to chemicals that may initiate cancer. To determine a cancer risk, one must calculate the probability of an individual developing any type of cancer during his or her lifetime from exposure to carcinogenic hazards. Cancer risk is generally expressed in scientific notation; in this notation, the chance of 1 person in 1,000,000 of

developing cancer would be expressed as 1×10^{-6} or $1E^{-6}$. The noncancer risk category is essentially a catch-all category for the remaining health effects resulting from chemical exposure. Noncancer risk encompasses a diverse set of effects or endpoints, such as weight loss, enzyme changes, reproductive and developmental abnormalities, and respiratory reactions. Noncancer risk is generally assessed by comparing the exposure or average intake of a chemical with a corresponding reference (a health benchmark), thereby creating a ratio. The ratio so generated is referred to as the hazard quotient (HQ). An HQ that is greater than 1 indicates that the exposure level is above the protective level of the health benchmark, whereas, an HQ less than 1 indicates that the exposure is below the protective level established by the health benchmark.

It is important to understand that exposure to a chemical does not necessarily result in an adverse health effect. A chemical's ability to initiate a harmful health effect depends on the toxicity of the chemical as well as the route (i.e., ingestion, inhalation) and dose (the amount that a human intakes) of the exposure. Health benchmark values are used to quantify a chemical's possible toxicity and ability to induce a health effect, and are derived from toxicity data. They represent a "dose-response" estimate that relates the likelihood and severity of adverse health effects to exposure and dose. The health benchmark is used in combination with an individual's exposure level to determine if there is a risk. Because individual chemicals generate different health effects at different doses, benchmarks are chemical specific; additionally, since health effects are related to the route of exposure and the timing of the exposure, health benchmarks are specific to the route (ingestion or inhalation) and the duration (acute, subchronic, or chronic) of the exposure. The definitions of acute, subchronic and chronic exposures vary, but acute typically implies an exposure of less than one day, subchronic generally indicates an exposure of a few weeks to a few months, and chronic exposure can span periods of several months to several years.

The health benchmark for carcinogens is called the cancer slope factor. A cancer slope factor (CSF) is defined as the upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime and is expressed in units of $(mg/kg\text{-}d)^{-1}$. The slope factor is used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to a particular concentration of a carcinogen.

A reference dose (RfD) for oral exposure and reference concentration (RfC) for inhalation exposure are used to evaluate noncancer effects. The RfD and RfC are estimates of daily exposure levels to individuals (including sensitive populations) that are likely to be without an appreciable risk of deleterious effects during a lifetime and are expressed in units of mg/kg-d (RfD) or mg/m^3 (RfC).

Most health benchmarks reflect some degree of uncertainty because of the lack of precise toxicological information on the people who might be most sensitive (e.g., infants, elderly, and nutritionally or immunologically

Example of Health Benchmarks
Acrylonitrile

Chronic:
- inhalation CFS: $0.24(mg/kg/d)^{-1}$
- oral CFS: $0.54\ (mg/kg/d)^{-1}$
- RIC: $0.002\ mg/m^3$
- RfD:0.001 mg/kg/d

Subchronic:
- RfC: $0.02\ mg/m^3$

Acute:
- ATSDR MRL: $0.22\ mg/m^3$

compromised) to the effects of hazardous substances. There is additional uncertainty because most benchmarks must be based on studies performed on animals, as relevant human studies are lacking.

There are several sources for obtaining health benchmarks, some of which are summarized in the text box. Note that from time-to-time benchmark values may be revised to reflect new toxicology data on a chemical. In addition, because many states may have developed their own toxicology benchmarks, both the groundwater and air tools in this guidance enable a user to input an alternative benchmark to those that are provided.

C. Assessing Risk

Typically risk is estimated using the organized process of evaluating scientific data known as risk assessment. Risk assessment ultimately serves as guidance for making management decisions by providing one of the inputs to the decision making process. Risk assessment furnishes beneficial information for a variety of situations, such as determining the appropriate pollution control systems for an industrial site, predicting the appropriateness of different waste management options or alternative waste management unit configurations, or identifying exposures that may require additional attention.

Sources for Health Benchmarks

Integrated Risk Information System (IRIS) The Integrated Risk Information System (IRIS) is the Agency's official repository of Agency-wide consensus chronic human health risk information. IRIS is an EPA data base containing Agency consensus scientific positions on potential adverse human health effects that may result from chronic (or lifetime) exposure to environmental contaminants. IRIS information includes the reference dose for noncancer health effects resulting from oral exposure, the reference concentration for noncancer health effects resulting from inhalation exposure, and the carcinogen assessment for both oral and inhalation exposure.

Health Effects Assessment Summary Tables (HEAST) HEAST is a comprehensive listing compiled by the EPA consisting of risk assessment information relative to oral and inhalation routes for chemicals. HEAST benchmarks are considered secondary to those contained in IRIS. Although the entries in HEAST have undergone review and have the concurrence of individual agency program offices, they have either not been reviewed as extensively as those in IRIS or they do not have as complete a data set as is required for a chemical to be listed in IRIS.

Agency for Toxic Substances and Disease Registry (ATSDR) The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), requires that the Agency for Toxic Substances and Disease Registry (ATSDR) develop jointly with the EPA, in order of priority, a list of hazardous substances most commonly found at facilities on the CERCLA National Priorities List; prepare toxicological profiles for each substance included on the priority list of hazardous substances; ascertain significant human exposure levels (SHELs) for hazardous substances in the environment, and the associated acute, subchronic, and chronic health effects; and assure the initiation of a research program to fill identified data needs associated with the substances. The ATSDR Minimal Risk Levels (MRLs) were developed as an initial response to the mandate. MRLs are based on noncancer health effects only and are not based on a consideration of cancer effects. MRLs are derived for acute (1-14 days), intermediate (15-364 days), and chronic (365 days and longer) exposure durations, for the oral and inhalation routes of exposure.

The risk-evaluation process involves data collection activities, such as identifying and characterizing the source of the environmental pollutant, determining the transport of the pollutant once it is released into the environment, determining the pathways of human exposure, and identifying the extent of exposure for individuals or populations at risk. Performing a risk assessment is complex and requires knowledge in a number of scientific disciplines. Experts in several areas, such as toxicology, geochemistry, environmental engineering, and meteorology, may be involved in performing a risk assessment. For the purpose of this section, and for brevity, the basic components important to consider when assessing risk are summarized in three main categories listed below. A more extensive discussion of these components can be found in the references listed at the end of this section.

The three main categories are:

1. **Hazard Identification:** identifying and characterizing the source of the potential risk (e.g., chemicals managed in a waste management unit).
2. **Exposure Assessment:** determining the accessibility or avenues from the source to an individual (i.e., exposure pathways and exposure routes).
3. **Risk Characterization:** integrating the results of the exposure assessment with information on who is potentially at risk (e.g., location of the person, body weights, etc.) and toxicity information on the chemical.

1. Hazard Identification

For the purpose of this guidance document, the source of the potential risk has already been identified: waste management units. However, there must be a release of chemicals from a waste management unit for there to be exposure and risk. Chemicals may be released from waste management units by a variety of processes, including volatilization (where chemicals in vapor phase are released to the air), leaching to ground water (where chemicals travel through the ground to a ground-water aquifer), particulate emission (where chemicals attached to particulate matter are released in the air when the particulate matter becomes airborne), and run-off and erosion (where chemicals in soil water or attached to soil particles move to the surrounding area).

To consider these releases in a risk assessment, information characterizing the waste management unit is needed. Critical parameters include the size of the unit and its location. For example, larger units tend to produce larger releases. Units located close to the water table might produce greater releases to ground water than units located further from the water table. Units located in a hot, dry, windy climate may produce greater volatile releases than units in a cool, wet, non-windy climate.

2. Exposure Assessment: Pathways, Routes, and Estimation

Individuals and populations may come into contact with environmental pollutants by a variety of exposure mechanisms and processes. The mere presence of a hazard, such as toxic chemicals in a waste management unit, does not denote the existence of a risk. Exposure is the bridge between what is considered a hazard and what actually presents a risk. Assessing exposure involves determining the pathways and extent of human contact with toxic chemicals. The magnitude, frequency, duration, and route of exposure to a substance must be considered when collecting all of the data necessary to construct a complete exposure assessment.

The steps for performing an exposure assessment include identifying the potentially exposed population (receptors); pathways of exposure; environmental media that transport the contaminant; contaminant concentration at a receptor point; and receptor's exposure time, frequency, and duration. The output of the exposure assessment is a numerical estimate of exposure and intake of a chemical by an individual. The intake information is then used in concert with chemical-specific health benchmarks to quantify risks to human health.

Before gathering these data, it is important to understand what information is necessary for conducting an adequate exposure assessment and what type of work may be required. Exposures are commonly determined by using mathematical models of chemical fate and transport to determine chemical movement in the environment in conjunction with models of human activity patterns. The information required for performing the exposure assessment includes site-specific data such as soil type, meteorological conditions, ground-water pH, and location of the nearest receptor. Information must be gathered for the two components of exposure assessment: exposure pathways/routes and exposure quantification/estimation.

a. *Exposure Pathways/Routes*

An exposure pathway is the course the chemical takes from its source to the individual or population it reaches. Chemicals cycle in the environment by crossing through the different types of media which are considered exposure pathways: air, soil, ground water, surface water, and biota (Figure 1). As a result of this movement, a chemical can be present in various environmental media, and human exposure often results from multiple sources. The relative importance of an exposure pathway depends on the concentration of a chemical in the relevant medium and the rate of intake by the exposed individual. In a comprehensive risk assessment, the risk assessor identifies all possible site-specific pathways through which a chemical could move and reach a receptor. This guidance document provides tools to model the transport and movement of chemicals through two environmental pathways: air and ground water.

The transport of a chemical in the environment is facilitated by natural forces: wind and water are the primary physical processes for distributing contaminants. For example, atmospheric transport is frequently caused by ambient wind. The direction and speed of the wind determine where a chemical can be found. Similarly, chemicals found in surface

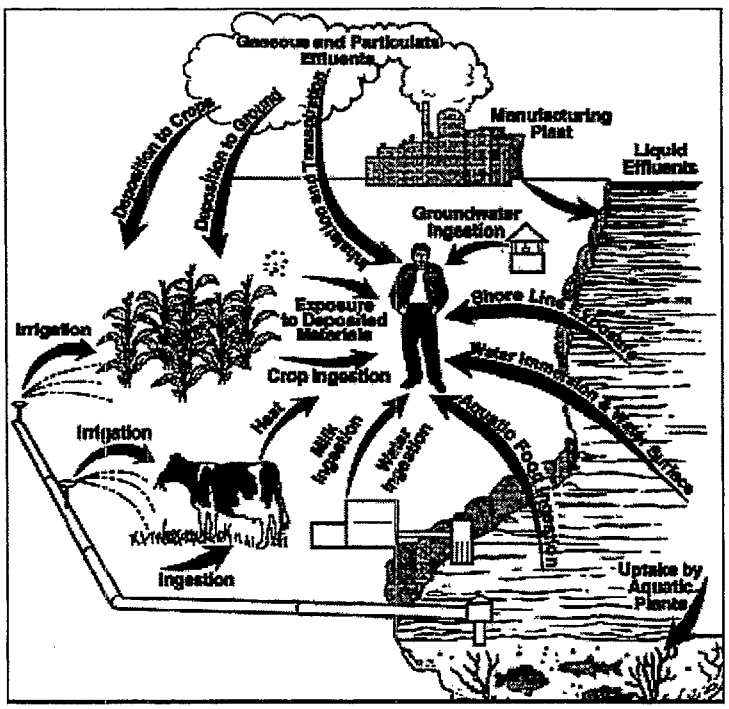


Figure 1. Multiple Exposure Pathways/Routes *(National Research Council, "Frontiers in Assesssing Human Exposure," 1991)*

water and ground water are carried by water currents or sediments suspended in the water. The chemistry of the contaminants and of the surrounding environment, often referred to as the "system," also plays a significant role in determining the ultimate distribution of pollutants in the various types of media. Physical-chemical processes, including dissolution/precipitation, volatilization, and photolytic and hydrolytic degradation, as well as sorption and complexation, can influence the distribution of chemicals among the different environmental media and the transformation from one chemical form to another.[1] An important component of creating a conceptual model for performing a risk assessment is the identification of the relevant processes that occur in a system. These complex processes depend on the conditions at the site and specific chemical properties.

Whereas the exposure pathway dictates the means by which a contaminant can reach an individual, the exposure route is the way in which that chemical enters the body. To generate a health effect, the chemical must come in contact with the body. In environmental risk assessment, three exposure routes are generally considered: ingestion, inhalation, and dermal absorption. As stated earlier, the toxicity of a chemical is specific to the dose received and its means of entry into the body. For example, a chemical that is inhaled may prove to be toxic and

Key Chemical Processes

Sorption: the ability of a chemical to partition between the liquid and solid phase by determining its affinity for adhering to other solids in the system such as soils and sediment. The amount of chemical that "sorbs" to solids and does not move through the environment is dependent upon the characteristics of the chemical, the characteristics of the surrounding soils and sediments, and the quantity of the chemical. A sorption coefficient is the measure of a chemical's ability to sorb. If too much of the chemical is present, the available binding sites on soils and sediments will be filled and sorption will not continue.

Dissolution/precipitation: the extent to which a substance will be found in a soluble form versus a solid form. In dissolution a chemical is taken into solution; precipitation is the formation of an insoluble solid. These processes are a function of the nature of the chemical and its surrounding environment and are dependent on properties such as temperature and pH. A chemical's solubility is characterized by a solubility product. Chemicals that tend to volatilize rapidly are not highly soluble.

Degradation: the propensity and extent a chemical will break down into other substances in the environment. Some degradation processes include biodegradation, hydrolysis, and photolysis. Not all degradation products have the same risk as the "parent" compound. Some chemicals can break into "daughter" products that are more harmful than the parent substance. In performing a risk assessment it is important to consider what the daughter products of degradation may be.

Bioaccumulation: the ability of a substance to be taken up and stored in an organism. Typically, the concentrations of the substance in the organism exceed the concentrations in the environment since the organism will store the substance and not excrete it. A bioaccumulation factor is associated with each chemical.

Volatility: the ability of a compound to partition into a gaseous state. The volatility of a compound is dependent on its water solubility and vapor pressure. The extent to which a chemical can partition into air is described by one of two constants: Henry's Law or Rauolt's Law. Other factors that are important to volatility are atmospheric temperature and waste mixing.

[1]Kolluru, Rao (1996)

result in a harmful health effect, whereas the same chemical may cause no reaction if ingested, or vice-versa. This phenomenon is due to the differences in mechanisms once a chemical enters the body. A chemical that is inhaled reaches the lungs and enters the blood system. A chemical that is ingested may pass through the liver before entering the blood system, where it may be metabolized into a different chemical that may result in a health effect or into another chemical that is soluble and can be excreted.

Some contaminants can also be absorbed by the skin. The skin is not very permeable and usually provides a sufficient barrier against most chemicals. However, some chemicals can pass through the skin in sufficient quantities to induce severe health effects. An example is carbon tetrachloride, which is readily absorbed through the skin and at certain doses can cause severe liver damage. The dermal route is typically considered in worker scenarios in which the worker is actually performing activities that involve skin contact with the chemical of concern. The tools provided in this guidance document do not address the dermal route of exposure.

b. Exposure Quantification/Estimation

Once appropriate fate and transport modeling has been performed for each pathway, providing concentrations of a chemical at an exposure point, the chemical intake by a receptor must be quantified. Quantifying the frequency, magnitude, and duration of exposures that result from the transport of a chemical to an exposure point is critical to the overall assessment. For this step, the risk assessor calculates the chemical-specific exposures for each exposure pathway identified. Exposure estimates are expressed in terms of the mass of a substance in contact with the body per unit body weight per unit time (e.g., milligrams of a chemical per kilogram body weight per day, also expressed as mg/kg-day).

The exposure quantification process requires two main areas of information gathering: the receptor activity patterns and the biological characteristics of receptors (body weight, inhalation rate). Activity patterns and biological characteristics dictate the amount of a constituent that a receptor may intake and the dose that is received per kilogram of body weight. Chemical intake values are calculated using equations that include variables for exposure concentration, contact rate, exposure frequency, exposure duration, body weight, and exposure averaging time. The values of some of these variables depend on the site conditions and the characteristics of the potentially exposed population. For example, the rate of oral ingestion of contaminated food is different for different subgroups of receptors, which might include adults, children, area visitors, subsistence farmers, and subsistence fishers. Children typically drink greater quantities of milk each day than adults per unit body weight. A subsistence fisher would be at a greater risk than another area resident from the ingestion of contaminated fish. Additionally, a child may have a greater rate of soil ingestion than an adult due to playing outdoors or hand-to-mouth behavior patterns. The activities of individuals also determine the duration of exposure. A resident may live in the area for 20 years and be in the area for more than 350 days each year. Conversely, an area visitor or a worker will have shorter exposure times. After the intake values have been estimated, they should be organized by population as appropriate (i.e., children, adult residents) so that the results in the risk characterization can be reported for each population group. To the extent feasible, site-specific values should be used for estimating the exposures; otherwise, default values suggested

by the EPA in *The Exposure Factors Handbook* (EPA, 1995) may be used.

3. Risk Characterization

In the risk-characterization process, the toxicity information (slope factors, reference doses) and the results of the exposure assessment (estimated intake or dose of potentially exposed populations) are integrated to arrive at quantitative estimates of cancer and noncancer risks. To characterize the potential noncarcinogenic effects, comparisons are made between projected intake levels of substances and toxicity values. To characterize potential carcinogenic effects, probabilities that an individual will develop cancer over a lifetime are estimated from projected intake levels and chemical-specific dose-response relationships. This procedure is the final calculation step. This step determines who is likely to be affected and what the likely affects are. Because of all the assumptions inherent in deriving a risk, a risk characterization cannot be considered complete unless the numerical expressions of risk are accompanied by explanatory text interpreting and qualifying the results. The risk characterization step for carcinogens and noncarcinogens is different and is shown in the text box below.

Another consideration during the risk-characterization phase are cumulative effects.

Calculating Risk

Cancer Risks:
Incremental risk of cancer = average daily dose (mg/kg-day) * slope factor $(mg/kg\text{-}day)^{-1}$

Non-Cancer Risks
Hazard quotient = exposure or intake (mg/kg-day) or (mg/m^3)/ RfD (mg/kg-day) or RfC (mg/m^3)

A given population may be exposed to multiple chemicals from several exposure routes and sources. For example, multiple constituents may be managed in a single waste management unit, and by considering one chemical at a time the risks associated with the waste management unit may be underestimated. The EPA (1989a) has developed guidance outlined in the *Risk Assessment Guidance for Superfund, Volume I* to assess the overall potential for cancer and noncancer effects posed by multiple chemicals. The risk assessor, facility manager, and other interested parties should determine the appropriateness of adding the risk contribution of each chemical for each pathway to derive a cumulative cancer risk or noncancer risk. The procedures for adding risks differ for carcinogenic and noncarcinogenic effects.

Cancer Risk Equation for Multiple Substances

$$Risk_T = \Sigma Risk_i$$

where:

$Risk_T$ = the total cancer risk, expressed as a unitless probability

$Risk_i$ = the risk estimate for the i^{th} substance

The cancer-risk equation described in the box above estimates the incremental individual lifetime cancer risk for simultaneous exposure to several carcinogens and is based on EPA (1989a) guidance. The equation combines risks by summing the risks to a receptor from each of the carcinogenic chemicals.

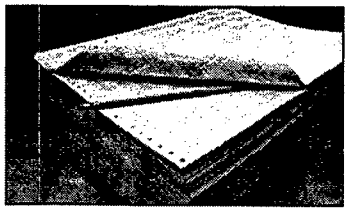
To assess the overall potential for noncarcinogenic effects posed by more than one chemical, a hazard index (HI) approach was developed by the EPA. The approach assumes that the magnitude of an adverse health effect is proportional to the sum of the hazard quotients of each of the chemicals

investigated. Assessing cumulative effects from noncarcinogens is more difficult and contains a greater amount of uncertainty. As discussed earlier, noncarcinogenic risk covers a diverse set of health effects and different chemicals will have different effects. In keeping with EPA's *Risk Assessment Guidance*, hazard quotients should only be added for chemicals that have the same critical effect (e.g., both chemicals effect the liver or both initiate respiratory distress.) As a result, an extensive knowledge of toxicology is needed to sum the hazard quotients to produce a hazard index. Segregation of hazard indices by effect and mechanism of action can be complex, time-consuming, and will have some degree of uncertainty associated with it. This analysis is not simple and should be performed by a toxicologist.

D. Results

The results of a risk assessment provide a basis for making decisions but are only one element of input into the decision process. The risk assessment does not constitute the only basis for management action. Other factors are also important, such as technical feasibility of options, public values, and economics. Understanding and interpreting the results for the purpose of making decisions also requires a thorough knowledge of the assumptions that were applied during the risk assessment. Ample documentation should be constructed to define the scenarios that were evaluated for the risk analysis and any uncertainties there may be in the estimate. Some of the information that should be considered for inclusion in the risk assessment documentation may be: key site-related information such as contaminants evaluated, a description of the risks present (i.e., cancer, noncancer), the level of confidence in the information used in the assessment, the major factors driving the site risks, and the characteristics of the exposed population. The results of a risk assessment are essentially meaningless without the information on how they were generated.

IV. Information on Environmental Releases



Under the Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986, facilities in a designated Standard Industry Code (see 40 CFR §372.22) with more than 10 employees that manufacture or process more than 25,000 pounds, or otherwise use more than 10,000 pounds, of a Toxic Release Inventory (TRI)-listed chemical are required to report their environmental releases annually to EPA and state governments. Environmental releases include the disposal of wastes in landfills, surface impoundments, land application units, and waste piles. EPA compiles these data in the TRI database. TRI data are also being made available through public libraries and reports. You may wish to include TRI data in the facility's information repository.

EPCRA is based on the belief that citizens have a right to know about potential environmental risks caused by facility operations in their communities, including those posed as a result of waste management. TRI data, therefore, provide yet another way for residents to learn about the waste management activities taking place in their neighborhood and to take a more active role in decisions that potentially affect their health and environment. More information on TRI and access to TRI data can be obtained from EPA's Web site **<www.epa.gov/opptintr/tri>.**

Building Partnerships Action Items

- ☐ Develop exhibits that provide a better understanding of facility operations.
- ☐ Identify potentially interested/affected people.
- ☐ Notify the state and public about new facilities or significant changes in facility operating plans.
- ☐ Set up a public meeting for input from the community.
- ☐ Provide interpreters for public meetings.
- ☐ Make knowledgeable and responsible people available for sharing information.
- ☐ Develop an involvement plan based on information gathered in previous steps.
- ☐ Provide access to the facility and to information about its operations.
- ☐ Maintain a publicly accessible information repository or on-site reading room.

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Part I
Getting Started

Chapter 2
Characterizing Waste

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Characterizing Waste

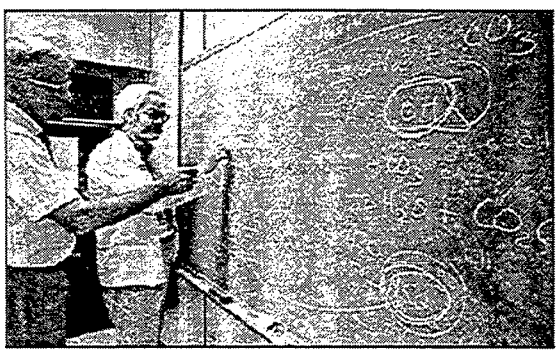
Understand the industrial processes that generate a waste. Determine the waste's physical and chemical properties. Quantify constituent leaching to facilitate ground-water risk analysis. Quantify total constituent concentrations to facilitate air emission analysis, and consideration of pollution prevention and treatment.

Understanding the physical and chemical properties of a waste and sampling and analysis procedures is the cornerstone upon which subsequent steps in this guidance are built. Knowledge of the physical and chemical properties of the waste is crucial in identifying waste reduction opportunities. It is necessary in gauging what risks a waste may pose to surface water, ground water, and air. It drives the selection of a liner or the choice of land application methods. It is needed to determine which constituents to test for if conducting ground-water monitoring. Use knowledge of waste generation processes, analytical testing, or some combination of the two to estimate waste constituent concentrations. Over time when changes are made to the industrial processes or waste management practices, it may be necessary to recharacterize a waste. No matter which approach is used in characterizing a waste, the important goal is to maximize the knowledge available to make the important decisions described in later chapters of this guidance.

This chapter will help address the following questions:

- Can process knowledge be used to characterize waste?
- What constituent concentrations should be quantified?
- What type of leachate test should be used?

I. Waste Characterization Through Process Knowledge



A waste characterization begins with an understanding of the industrial processes that generate a waste. As a starting point, obtain information about the waste itself such as the physical state of the waste, the volume, and the composition. In addition, obtain enough

information about the process to enable proper characterization of the waste. Many industries have thoroughly tested and characterized their wastes over time. Check with trade associations to see if the appropriate information is available for a particular waste.

The following examples of process knowledge may assist in waste characterization by providing information on waste constituents and potential concentrations:

- Chemical engineering designs/plans for the process, showing process input chemicals, expected primary and secondary chemical reactions, and products;
- Material Safety Data Sheets (MSDSs). Note, however, that not all MSDSs contain information on all constituents found in a product;
- Manufacturer's literature;
- Previous waste analyses;
- Literature on similar processes; and
- Preliminary testing results, if available.

A materials balance exercise using process knowledge may be useful in understanding where wastes are generated within a process, and estimating the quantity of chemicals in such wastes. In a material balance, calculate all input streams, such as raw materials fed into the processes, and all output streams, such as products produced and waste generated. Material balances can assist in estimating concentrations of waste constituents where analytical test data are limited. Characterizing waste using material balances can require considerable effort and expense, but may assist in developing a more complete picture of candidate waste generation process(es). Flow diagrams are generally prepared to identify important process steps and sources where wastes are generated.

A thorough assessment of a production processes can also serve as the starting point for a facility-wide waste reduction, recycling, or pollution prevention effort. Such an assessment will provide the information base to explore many opportunities to reduce or recycle the volume or toxicity of wastes. Check the integrating pollution prevention, recycling, and treatment chapter for ideas, tools, and references on how to proceed.

II. Waste Characterization Through Leachate Testing

The intent of leaching and extraction tests is to estimate the release of waste constituents into ground water. The importance of estimating potential constituent concentrations that may leach to ground water is underscored by the fact that the ground water software model, *Industrial Waste Management Evaluation Model,* (IWEM), developed for this guidance document uses expected leachate concentrations to develop recommended liner system designs.

If the total concentration of all the constituents in a waste has been estimated using process or industry knowledge, estimates of the maximum possible concentration of these constituents in leachate can be made using the dilution ratio of the leachate test to be performed. For example, the Toxicity Characteristic Leachate Procedure (TCLP) does allow for a total constituent analysis in lieu of the TCLP extraction. If a waste is 100 percent solid, as defined by the TCLP method, then the results of the total compositional analysis may be divided by twenty to convert the total results into the maximum leachable concentration. This factor is derived from the 20:1 liquid to solid ratio employed in the TCLP. If a waste has filterable liquid,

then the concentration of each phase (liquid and solid) must be determined. The following equation may be used to calculate this value:[1]

$$\frac{[A \times B] + [C \times D]}{B + [20\ (L/kg) \times D]} = E$$

Where:

A = Concentration of the analyte in liquid portion of the sample (mg/L)

B = Volume of the liquid portion of the sample (L).

C = Concentration of the analyte in solid portion of the sample (mg/kg)

D = Weight of the solid portion of the sample (kg)

E = Maximum theoretical concentration in leachate (mg/L)

Because this is only a screening method for identifying an upper-bound TCLP leachate concentration, consult with the state agency to determine whether process knowledge can be used in lieu of leachate testing.

A. Sampling and Analysis Plan

One of the more critical elements in proper waste characterization is the plan for sampling and analyzing the waste. The sampling plan is usually a written document that describes the objectives and details of the individual tasks of a sampling effort and how they will be performed. This plan should be carefully thought out, well in advance of sampling. The more detailed the sampling plan, the less opportunity for error or misunderstanding during sampling, analysis, and data treatment.

To ensure that the sampling plan is designed properly, a wide-range of personnel should be consulted. The end user of the data, an experienced member of the sampling team, a senior analytical chemist, an engineer who understands the manufacturing processes, a statistician, and a quality assurance representative all need to be involved in the development of a sampling plan. It is also wise to consult the analytical laboratory to be used. Development of sampling plans requires background information about the waste and the unit, knowledge of the waste location and situation, decisions as to the types of samples needed, and decisions as to the sampling design required. The plan should address the following considerations:

- Data quality objectives;
- Determination of a representative sample;
- Statistical methods to be employed in the analyses;
- Waste generation and handling processes;
- Constituents/parameters to be sampled;
- Physical and chemical properties of the waste;
- Accessibility of the unit;
- Sampling equipment, methods, and sample containers;
- Quality assurance and quality control (e.g., sample preservation and handling requirements);
- Chain-of-custody; and
- Health and safety of employees.

A number of these factors are discussed below. Additional information on data quality objectives and quality assurance and quality control can be found in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods—SW-846, Guidance for the Data Quality Objectives Process* (EPA600-R-96-055), *Guidance on Quality Assurance Project Plans* (EPA600-R-98-018), and *Guidance for the Data Quality Assessment: Practical Methods for Data Analysis* (EPA600-R-96-084).

[1]SW-846 Methods Team Home page at **<www.epa.gov/sw-846/faqs>**.

Prior to implementing a sampling plan, it is often strategic to walk through the sampling plan mentally, starting with the preparation of the equipment through the time when samples are received at the laboratory. This mental excursion should be in as much detail as can be imagined, because the small details are the ones most frequently overlooked.

1. Representative Waste Sampling

The first step in any analytical testing process is to obtain a sample that is representative of the physical and chemical composition of a waste. The term "representative sample" is commonly used to denote a sample that has the properties and composition of the population from which it was collected and in the same proportions as found in the population. This can be misleading unless dealing with a homogenous waste from which one sample can represent the whole population. Because most industrial wastes are not homogeneous, many different factors should be considered in obtaining samples that are collectively representative of a waste. Examples of factors that should be considered include:

- **Physical state of the waste.** The physical state of the waste affects most aspects of a sampling effort. The sampling device will vary according to whether the sample is liquid, gas, solid, or multiphasic. It will also vary according to whether the liquid is viscous or free-flowing, or whether the solid

More Information on Test Methods for Evaluating Solid Waste, Physical/Chemical Methods—SW-846

EPA has begun replacing requirements mandating the use of specific measurement methods or technologies with a performance-based measurement system (PBMS). The goals of PBMS is to reduce regulatory burden and foster the use of innovative and emerging technologies or methods. PBMS establishes what needs to be accomplished, but does not prescribe specifically how to do it. In a sampling situation, for example, PBMS would establish the data needs, the level of uncertainty acceptable for making decisions, and the required supporting documentation, a specific test method would not be prescribed. This approach allows the analyst the flexibility to select the most appropriate and cost effective test methods or technologies to comply with the criteria. Under PBMS, the analyst is required to demonstrate the accuracy of the measurement method using the specific matrix that is being analyzed. SW-846 serves only as a guidance document and starting point.

SW-846 provides state-of-the-art analytical test methods for a wide array of inorganic and organic constituents, as well as procedures for field and laboratory quality control, sampling, and characteristics testing. The methods are intended to promote accuracy, sensitivity, specificity, precision, and comparability of analyses and test results.

For assistance with the methods described in SW-846, call the EPA Method Information Communication Exchange (MICE) Hotline at 703 821-4690 or send an e-mail to mice@lan828.ehsg.saic.com.

SW-846 is available on line at:
<www.epa.gov/sw-846/main.htm>

A hard copy or CD-ROM version of SW-846 can be purchased by calling the National Technical Information Service (NTIS) at 703 487-4808.

is hard or soft, powdery, monolithic, or clay-like.

- **Composition of the waste.** The samples should represent the average concentration and variability of the waste in time or over space.
- **Waste generation and handling processes.** The waste generation and handling processes to account for in sampling efforts include: if the waste is generated in batches; if there is a change in the raw materials used in a manufacturing process; if waste composition can vary substantially as a function of process temperatures or pressures; and if storage time after generation may vary.
- **Transitory events.** Start-up, shut-down, slow-down, and maintenance transients can result in the generation of a waste that is not representative of the normal waste stream. If a sample was unknowingly collected at one of these intervals, incorrect conclusions could be drawn.

Consult with the state agency to identify any legal requirements or preferences before beginning sampling efforts. Refer to Chapter 9 of SW-846 for detailed guidance on planning, implementing, and assessing sampling events. To ensure that the chemical information obtained from a waste sampling efforts is accurate, it must be unbiased and sufficiently precise. Accuracy is usually achieved by incorporating some form of randomness into the sample selection process and by selecting an appropriate number of samples. Since most industrial wastes are heterogeneous in terms of their chemical properties, unbiased samples and appropriate precision can usually be achieved by simple random sampling. In this type of sampling, all units in the population (essentially all locations or points in all batches of waste from which a sample could be collected) are identified, and a suitable number of samples is randomly selected from the population.

The appropriate number of samples to employ in a waste characterization is at least the minimum number of samples required to generate a sufficiently precise estimate of the true mean concentration of a chemical contaminant in a waste. A number of mathematical formulas exist for determining the appropriate number of samples depending on the statistical precision required.

The type of sampling plan developed will vary depending on the sampling location. Solid wastes contained in a landfill or waste pile may be best sampled using a three-dimensional random sampling strategy. This involves establishing an imaginary three-dimensional grid or sampling points in the waste and then using random-number tables or random-number generators to select points for sampling. Hollow-stem augers combined with split-spoon samplers are frequently appropriate for sampling landfills.

If the distribution of waste components is known or assumed for liquid or semisolid wastes in surface impoundments, then a two-dimensional simple random sampling strategy may be appropriate. In this strategy, the top surface of the waste is divided into an imaginary grid, grid sections are selected using random-number tables or random-number generators, and each selected grid point is then sampled in a vertical manner along the entire length from top to bottom using a sampling device such as a weighted bottle, a drum thief, or Coliwasa. If sampling is restricted due to the size of the impoundment, the sampling strategy should, at a minimum, take sufficient samples to address the potential vertical anomalies in the waste in order to be considered representative. This is because contained wastes tend to display vertical, rather than horizontal, nonrandom heterogeneity due to settling of suspended solids or denser liquid phases.

To facilitate characterization efforts, consult with the state agency and a qualified professional to select a sampling plan and determine the appropriate number of samples, before beginning sampling efforts. Consider conducting a waste-stream specific characterization in sufficient detail so that the information can be used to conduct waste reduction and waste minimization activities.

Additional information concerning sampling plans, strategies, methods, equipment, and sampling quality assurance and quality control is available in chapters 9 and 10 in SW-846. Electronic versions of these chapters have been included on the CD-ROM for this guidance.

2. Representative Waste Analysis

Once a representative sample has been collected, it must be preserved to maintain the physical and chemical properties that it possessed at the time of collection. Sample types, types of sample containers, and their preparation and preservation methods are all important in maintaining the integrity of the sample. The analytical chemist must develop an analytical plan which is appropriate for the sample to be analyzed, the constituents/parameters to be analyzed for, and the end use of the information required. SW-846 contains information on analytical plans and methods. Additional references exist that are useful sources of information regarding the selection of analytical methods and quality assurance/quality control procedures for various compounds. One such web site is **<www.epa.gov/reg3hwmd/brownfld/analytic.htm>**.

B. Leachate Test Selection

Leaching tests are used to estimate potential concentration or amount of waste constituents that may leach from a waste to ground water. Typical leaching tests use a specified leaching fluid mixed with the solid portion of a waste for a specified time. Solids are then separated from the leaching solution and the solution is tested for waste constituent concentrations. The type of leaching test performed may vary depending on the chemical, biological, and physical characteristics of the waste, the environment in which the waste will be placed, as well as the recommendations or requirements of the state agency.

When selecting the most appropriate analytical procedures, consider at a minimum the physical state of the sample using process and generator knowledge, the constituents to be analyzed, detection limits, and the specified holding times of the analytical methods. It may not be cost-effective or useful to conduct a test with detection limits at or greater than the constituent concentrations in a waste. There are several general categories of phases in which samples can be categorized: solids, aqueous, sludges, multiphase samples, ground water, and oil and organic liquid. Select a procedure that is designed for the specific sample type.

What leachate test is appropriate?

Selecting an appropriate leachate test can be summarized in the following four steps.

1. Assess the physical state of the waste using process and generator knowledge.
2. Assess the environment in which the waste will be placed.
3. Consult with the state agency.
4. Select an appropriate leachate test based on the above information.

After assessing the state of the waste, assess the environment in which the waste will be

placed. For example, an acidic environment may require a different test than a non-acidic environment. If the waste management unit is receiving only monofill, then the characteristics of the waste will determine most of the unit's conditions. Conversely, if wastes are being co-disposed, then the conditions created by the co-disposed wastes must be considered, including the constituents that may be leached by the subject waste.

As described in the Phase IV LDR rulemaking (62 FR 25997; May 26, 1998), EPA is undertaking a review of the TCLP test and how it is used to evaluate waste leaching. EPA anticipates that this review will examine the effects of a number of factors on leaching and on approaches to estimating the likely leaching of a waste in the environment. These factors include pH, liquid to solid ratios, matrix effects and physical form of the waste, effects of non-hazardous salts on the leachability of hazardous metal salts, and others. The effects of these factors on leaching may or may not be well reflected in the leaching tests currently available. At the conclusion of the TCLP review, EPA is likely to issue revisions to this guidance that reflect a more complete understanding of waste constituent leaching under a variety of management conditions.

Use a qualified laboratory when conducting analytical testing. The laboratory may be in-house or independent. When using independent laboratories, ensure that they are qualified and competent to perform the required tests. Some laboratories may be proficient in one test but not another. Consult with the laboratory before finalizing the test selection to ensure that it can be performed. When using analytical tests that are not frequently performed, additional quality assurance and quality control practices may be necessary to ensure that the tests were conducted correctly and that the results are accurate.

A brief summary of the TCLP and three other commonly used leachability tests is provided below. The complete procedures for all of these tests are included in SW-846 or in the *Annual Book of ASTM Standards Volume 11.04*. Appendix I provides a summary of over 20 tests designed to help determine the potential for contaminant release.[2] Consult with the state agency to identify the most appropriate test and test procedures for the waste and sample type.

1. Toxicity Characteristic Leaching Procedure

The TCLP is the test required to determine whether a waste is a toxicity characteristic hazardous waste under RCRA in 40 CFR Part 261. The TCLP estimates the leachability of certain hazardous constituents from solid waste under a defined set of laboratory conditions. It evaluates the leaching of metals, volatile and semi-volatile organic compounds, and pesticides from wastes. The TCLP was developed to simulate the leaching of constituents into ground water under conditions found in municipal solid waste (MSW) landfills. The TCLP does not simulate the release of contaminants to nonground-water pathways. The TCLP is most commonly used by EPA and state agencies to evaluate the leaching potential of wastes, and to estimate likely risks to ground water. The TCLP can be found as EPA Method 1311 in SW-846.[3] A copy of Method 1311 has been included on the CD-ROM for this guidance.

In the TCLP, liquid wastes (those containing less than 0.5 percent dry solid material) are filtered through a glass fiber filter. Waste samples containing solids and liquids are handled by separating the liquids from the solid phase, and then reducing solids to particle size. The solids are then extracted with an acetate buffer solution. A liquid-to-solid

[2]EPA has only reviewed and evaluated those test methods found in SW-846. EPA has not reviewed or evaluated the other test methods and cannot recommend any test methods other than those found in SW-846.

[3]The TCLP was developed to replace the Extraction Procedure Toxicity Test method which is designated as EPA Method 1310 in SW-846.

ratio of 20:1 by weight is used for an extraction period of 18 ± 2 hours. After extraction the solids are filtered from the liquid extract, and the liquid extract is combined with any original liquid fraction of the wastes. Analyses are then conducted on the filtrate and leachate to determine the constituent concentrations. If the extract contains any of the constituents listed in Table 1 of 40 CFR Part 261.24 at a concentration equal or greater than the respective value in the Table, unless excluded under §261.4, then the waste is considered to be a hazardous waste under the Toxicity Characteristic (TC).

Check with the state agency to determine whether the TCLP is likely to be the best test for evaluating the leaching potential of a waste, or if another test may better predict the actual leaching of a waste. The TCLP test, like other available leach tests, is designed to simulate, or approximate one set of disposal conditions and waste leaching that might occur under those conditions. It is used by EPA to classify waste as hazardous, and may be conservative in some conditions (although it has also apparently under predicted leaching in other, rather extreme, conditions). When disposal conditions are very different from the TCLP test conditions, another test may provide better short term numerical estimates of leaching.

2. Synthetic Precipitation Leaching Procedure (SPLP)

The SPLP is currently used by several state agencies to evaluate the leaching of constituents from wastes, and has been designated as EPA Method 1312 in SW-846. The SPLP was designed to estimate the leachability of both organic and inorganic analytes present in liquids, soils, and wastes. The SPLP was originally designed to assess how clean a soil was in EPA's clean closure program. The

federal hazardous waste program, however, did not adopt it for use, but the test still may estimate releases from wastes placed in a landfill and subject to acid rain. There may be, however, important differences between soil as a constituent matrix and the matrix of a generated industrial waste. A copy of Method 1312 has been included on the CD-ROM for this guidance.

The SPLP is very similar to the TCLP. Waste samples containing solids and liquids are handled by separating the liquids from the solid phase, and then reducing solids to particle size. The solids are then extracted with a dilute sulfuric acid/nitric acid solution. A liquid-to-solid ratio of 20:1 by weight is used for an extraction period of 18±2 hours. After extraction the solids are filtered from the liquid extract, and the liquid extract is combined with any original liquid fraction of the wastes. Analyses are then conducted on the filtrate and leachate to determine the constituent concentrations.

The sulfuric acid/nitric acid extraction solution used in the SPLP was selected to simulate leachate generation, in part, from acid rain. In both the SPLP and TCLP, oily, and some paint wastes, may clog the filters used to separate the extract from the solids prior to analysis, resulting in under reporting of the extractable constituent concentrations.

3. Multiple Extraction Procedure (MEP)

The MEP is designed to simulate the leaching that a waste will undergo from repetitive precipitation of acid rain on a landfill to reveal the highest concentration of each constituent that is likely to leach in a real world environment. Currently, the MEP is used in EPA's de-listing program and has been designated as EPA Method 1320 in SW-846. A copy of Method 1320 has been included on the CD-ROM for this guidance.

The MEP can be used to evaluate liquid, solid, and multiphase samples. Waste samples are extracted according to the Extraction Procedure (EP)Toxicity Test (Method 1310 of SW-846). A copy of Method 1310 has been included on the CD-ROM for this guidance. The EP Test is very similar to the TCLP Method 1311. In the EP, liquid wastes are filtered through a glass fiber filter. Waste samples containing solids and liquids are handled by separating the liquids from the solid phase, and then reducing the solids to particle size. The solids are then extracted using an acetic acid solution. A liquid-to-solid ratio of 16:1 by weight is used for an extraction period of 24 hours. After extraction the solids are filtered from the liquid extract, and the liquid extract is combined with any original liquid fraction of the wastes. The solid portions of the samples that remain after application of Method 1310 are then re-extracted using a dilute sulfuric acid/nitric acid solution. As in the SPLP, this fluid was selected to simulate leachate generation, in part, from acid rain. This time a liquid-to-solid ratio of 20:1 by weight is used for an extraction period of 24 hours. After extraction solids are once again filtered from the liquid extract, and the liquid extract is combined with the original liquid fraction of the wastes. These four steps are repeated eight additional times. If the concentration of any constituent of concern increases from the 7th or 8th extraction to the 9th extraction, the procedure is repeated until these concentrations decrease.

The MEP is intended to simulate 1,000 years of freeze and thaw cycles and prolonged exposure to a leaching medium. One advantage of the MEP over the TCLP is that the MEP gradually removes excess alkalinity in the waste. Thus, the leaching behavior of metal contaminants can be evaluated as a function of decreasing pH, which increases the solubility of most metals.

4. Shake Extraction of Solid Waste with Water or Neutral Leaching Procedure

Shake Extraction of Solid Waste with Water, or the Neutral Leaching Procedure, was developed by the American Society for Testing and Materials (ASTM) to assess the leaching potential of solid waste and has been designated as ASTM D-3987-85. This test method provides for the shaking of a water extractant and a known weight of waste of specified composition and the separation of the aqueous phase for analysis. The intent of this test method is for the final pH of the extract to reflect the interaction of the extractant with the buffering capacity of the solid waste.

The shake test is performed by mixing the solid sample with test water and agitating continuously for 18±0.25 hours. A liquid-to-solid ratio of 20:1 by weight is used. After agitation the solids are filtered from the liquid extract, and the liquid extract is analyzed.

The water extraction is meant to simulate conditions where the solid waste is the dominant factor in determining the pH of the extract. This test, however, has only been approved for certain inorganic constituents, and is not applicable to organic substances

and volatile organic compounds. Copies of this procedure can be ordered by calling ASTM at 610 832-9585 or via the Internet at **<www.astm.org>.**

III. Waste Characterization of Volatile Organic Emissions

To determine whether volatile organic emissions are of concern at a unit, as described in the protecting air chapter, the concentration of all volatile organics in a waste must be known. Analytical testing may be necessary if organic concentrations cannot be estimated using process knowledge. Many tests have been developed for quantitatively extracting volatile and nonvolatile organic compounds from various sample matrices, for example extracting all of the compound present. These tests tend to be highly dependent upon the physical characteristics of the sample. Consult with the state agency before beginning testing. Refer to SW-846 Method 3500B for general guidance on selection of methods for quantitative extraction or dilution of samples for analysis by one of the semivolatile or nonvolatile determinative methods. After performing the appropriate extraction procedure, further cleanup of the sample extract may be necessary if analysis of the extract is prevented due to interferences coextracted from the sample. Method 3600 of SW-846 provides additional guidance on cleanup procedures. Following preparation of a sample, the sample is ready for further analysis. Most analytical methods are either gas chromatography (GC), high performance liquid chromatography (HPLC), gas chromatography/mass spectrometry (GC/MS), or high performance liquid chromatography/mass spectrometry (HPLC/MS). SW-846 is designed to allow the methods to be mixed-and-matched, so that sample preparation, sample cleanup, and analytical methods can be combined into a sequence, as appropriate for the particular analyte and the matrix. Consult with the state agency before finalizing the selected methodology.

Waste Characterization Action Items

- ☐ Use process knowledge to identify constituents for further analysis.
- ☐ Assess the physical state of the waste using process and generator knowledge.
- ☐ Assess the environment in which the waste will be placed.
- ☐ Consult with the state agency to determine any state specific testing requirements.
- ☐ Select an appropriate leachate test or organic constituent analysis based on the above information.

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Part I
Getting Started

Chapter 3
Integrating Pollution Prevention, Recycling, and Treatment

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Integrating Pollution Prevention, Recycling, and Treatment

Consider pollution prevention, recycling, and treatment options when designing a waste management system. Pollution prevention and recycling reduce waste disposal needs and can minimize impacts across all environmental media. Treatment can reduce the volume and/or toxicity of waste. Pollution prevention, recycling, and treatment can all ease some of the burdens, risks, and liabilities of waste management.

Pollution prevention, waste reduction, waste minimization—these and similar terms describe a variety of practices that go far beyond traditional environmental compliance or single media permits for water, air, or waste management. This guidance is designed to help decide how to manage wastes protectively. Integrating pollution prevention, recycling, and treatment into policies and operations allows for opportunities to reduce the volume and toxicity of wastes, reduce waste disposal needs, and recycle and reuse materials formerly handled as wastes. In addition to the potential to save waste management costs, pollution prevention, recycling, and treatment may improve the interactions among industry, the public, and regulatory agencies; reduce liabilities and risks associated with releases from waste management units; and reduce long-term liabilities and risks associated with closure and post-closure care of waste management units.

This chapter will help address the following questions:

- What are some of the benefits of pollution prevention, recycling, and treatment?
- Where can assistance in choosing and implementing specific pollution prevention, recycling, and treatment activities be obtained?

Pollution prevention is comprehensive and emphasizes a life-cycle approach to assessing physical plant, production processes, and products to identify the best opportunities to minimize environmental impacts across all media. This approach also ensures that actions taken in one area will not increase environmental problems in another area (such as reducing wastewater discharges but increasing airborne emissions of volatile organic compounds). Pollution prevention actively involves a broad cross section of employees in creative problem solving to help achieve environmental goals and at the same time benefit a company in many other ways. For example, redesigning production processes or finding alternative materials inputs can also improve product quality, increase efficiency, and conserve raw materials.

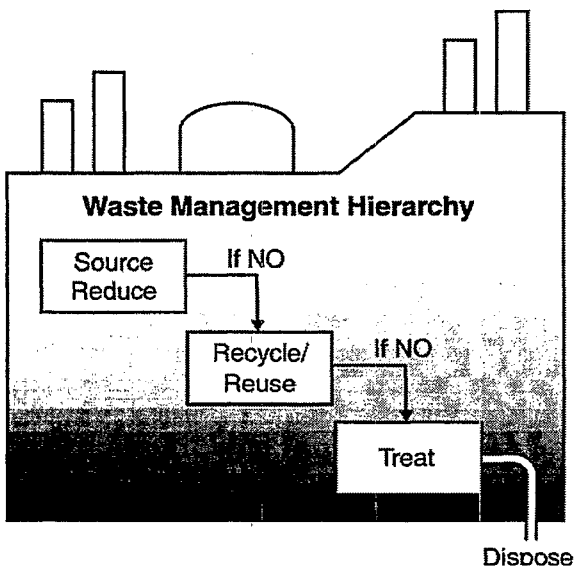
Recycling is similar to pollution prevention in the sense that both require an examination of waste streams and production processes to identify opportunities. Recycling and beneficially reusing wastes can help reduce disposal costs, while using or reusing recycled materials as substitutes for feedstocks can reduce raw materials' costs. Materials exchange programs can assist in finding uses for recycled materials, and identifying effective substitutes for raw materials. Recycling not only helps reduce the overall amount of waste sent for disposal, but also helps conserve natural resources by replacing the need for virgin materials.

Treatment can reduce the toxicity of a waste, its volume, or both. Reducing a waste's volume and toxicity prior to final disposal can result in long-term cost savings. There are a considerable number of levels and types of treatment from which to choose. Selecting the right treatment option can help simplify disposal options and limit future liability.

Throughout this guidance some key steps are highlighted that are good starting points for pollution prevention, recycling, or treatment or where pollution prevention, recycling, or treatment could help reduce waste management costs, increase options, or reduce potential liabilities by reducing risks that the wastes might pose. For example:

Waste characterization is a key component of this guidance. It is also a key component of a pollution prevention opportunity assessment. An opportunity assessment is more comprehensive, since it also covers material inputs, production processes, operating practices, and potentially other areas such as inventory control. When characterizing a waste, consider expanding the assessment to cover these aspects of the business. An opportunity assessment can help identify the most efficient, cost effective, and environmentally friendly combination of options, especially when planning new products, new or changed waste management practices, or facility expansions.

Figure 1. Waste Management Hierarchy



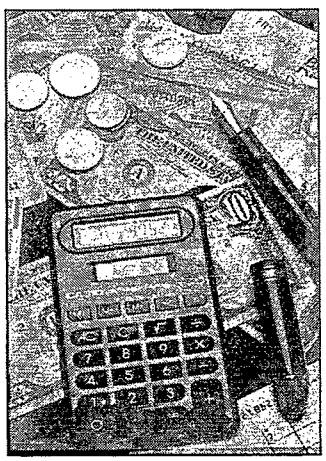
Land application of waste may be a preferred waste management option because land application units can manage wastes with high liquid content, achieve biodegradation, and improve soils with the organic material in the waste. Concentrations of constituents may limit the ability to take full advantage of land application. Reducing the concentrations of constituents in the waste before it is generated or treating the waste prior to land application can provide the flexibility to use land application and ensure that the practice will be protective of human health and the environment and limit future liabilities.

The Pollution Prevention Act of 1990 established a national policy to first, prevent or reduce waste at the point of generation; second, recycle or reuse waste materials; third, treat waste; and finally, dispose of remaining waste in an environmentally protective manner (see Figure 1). Some states and many local governments have adopted similar policies, often with more specific and measurable goals. Over the past 10 years, interest in all aspects of pollution prevention, recycling, and treatment has blossomed, and governments, businesses, academic and research institutions, and individual citizens have dedicated greater resources to it. Many industries are adapting pollution prevention, recycling, and treatment practices to fit their individual operations. Pollution prevention, recycling, and treatment can be successful when flexible problem-solving approaches and solutions are implemented. These steps will be successful when they fit into business and environmental goals.

I. Benefits of Pollution Prevention, Recycling, and Treatment

Pollution prevention, recycling, and treatment activities benefit industry, states, and the public by protecting the environment and reducing health risks, and also provide businesses with financial and strategic benefits.

Cost savings. Many pollution prevention activities make industrial processes and equipment more resource-efficient. This increased production efficiency saves raw material and labor costs, lowers maintenance costs due to newer equipment, and lowers oversight costs due to process simplification. When planning pollution prevention activities, consider the cost of the initial investment for audits, equipment, and labor. This cost will vary depending on the size and complexity of waste reduction activities. In addition, consider the payback time for the investment. Adjust pollution prevention activities to maximize cost savings and environmental and health benefits. Lastly, by reducing the volume and toxicity of waste, treatment activities provide savings through lower disposal costs.



Simpler design and operating conditions and reduced regulatory obligations. Reducing the risks associated with wastes may allow

wastes to be managed under less stringent design and operating conditions or use of other lower-cost management practices. For example, the chapter on assessing groundwater risks may determine that a waste stream requires a composite liner. The assessment also might imply that by implementing a pollution prevention activity that lowered the concentrations of one or two problematic waste constituents in that waste stream, only a compacted clay liner may be necessary. When the risks associated with waste disposal are reduced, the long-term costs of closure and post-closure care may also be reduced.

Improved worker safety. Processes involving less toxic and less physically dangerous (such as corrosive) materials can improve worker safety by reducing work-related injuries and illnesses. In addition to strengthening morale, improved worker safety also reduces health-related costs from lost work days, health insurance, and disability payments.

Lower liability. A well-operated unit minimizes releases, accidents, and unsafe waste-handling practices. Reducing the volume and toxicity of waste decreases the impact of these events if they occur. Reducing potential liabilities, decreases the likelihood of litigation and cleanup costs.

Higher product quality. Many corporations have found that higher product quality results from some pollution prevention efforts. A significant part of waste in some operations consists of products that fail quality inspections, so minimizing waste in those cases is inextricably linked with process changes that improve quality. Often, managers do not realize how easy or technically feasible such changes are until the drive for waste reduction leads to exploration of the possibilities.

Building community relations. Honesty and openness can strengthen credibility between industries, communities and regulatory agencies. If implementing a pollution prevention program, make people aware of it. Environmental protection and economic growth can be compatible objectives. Additionally, dialogue among all parties in the development of pollution prevention plans can help identify and address concerns.

II. Implementing Pollution Prevention, Recycling, and Treatment

When it comes to pollution prevention, recycling, and treatment consider a combination of options that best fits a facility and its products. There are a number of steps common to any facility wide pollution prevention, recycling, and treatment effort. An essential starting point is to make a clear commitment

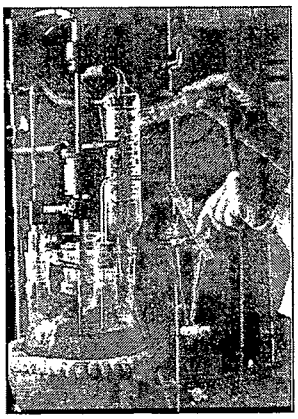
to pollution prevention, recycling, and treatment opportunities. Seek the participation of interested partners, develop a policy statement committing the industrial operation to pollution prevention, recycling, and treatment, and organize a team to take responsibility for it. As a next step, conduct a thorough pollution prevention opportunity assessment. Such an assessment will help set priorities according to which options are the most promising. Another feature common to many pollution prevention programs is some means of measuring the program's progress and make any necessary adjustments.

The core of a program is the actual pollution prevention, recycling, and treatment practices implemented. The following sections give a brief overview of source reduction, recycling, and treatment. To find out more, contact some of the organizations listed in the appendices to this chapter.

A. Source Reduction

Source reduction is the prevention or minimization of waste at the point of generation. Some examples of source reduction activities are: input materials modification, technology modifications, in-process recycling, and various good housekeeping measures.

Input materials modification. One option is to reformulate or modify products and processes to incorporate materials less likely to produce higher-risk wastes. Some of the most common practices include eliminating metals from inks, dyes, and paints; reformulating paints, inks, and adhesives to eliminate synthetic organic solvents; and replacing chemical-based cleaning solvents with water-based or citrus-based products. Purchasing raw materials free from even trace quantities of contaminants, whenever possible, can also help reduce waste at the source.



When substituting materials in an industrial processes, it is important to examine the effect on the entire waste stream. Some changes may shift contaminants to another medium rather than actually reduce waste generation. Switching from solvent-based to water-based cleaners, for example, will reduce solvent volume and disposal cost, but is likely to dramatically increase wastewater volume. Look at the impact of wastewater generation on effluent limits and wastewater treatment sludge production.

Technological modifications. Newer process technologies often include better waste reduction features than older ones. For industrial processes that predate consideration of waste and risk reduction, altering these existing production procedures, adopting new procedures, or upgrading equipment may reduce waste volume, toxicity, and management costs. Some examples include redesigning equipment to cut losses during batch changes or during cleaning and maintenance, changing to mechanical cleaning devices to avoid solvent use, and installing more energy- and material-efficient equipment. State technical assistance centers, trade associations, and other organizations listed in Appendices I through IV can help evaluate the potential advantages and savings of such improvements.

In-process recycling (reuse). In-process recycling reuses materials, such as cutting scraps, as inputs to the same process from which they came, or uses them in other processes or for other uses in the facility. This furthers waste reduction goals by reducing

the need for treatment or disposal and by conserving energy and resources. A common example of in-process recycling is reuse of wastewater.

Good housekeeping procedures. Some of the easiest and most cost-effective waste reduction techniques to implement are simple improvements in housekeeping. Accidents and spills generate avoidable disposal hazards and expenses. They are less likely to occur in clean, neatly organized facilities.

Good housekeeping techniques that reduce the likelihood of accidents and spills include training employees to manage waste and materials properly; keeping aisles wide and free of obstructions; clearly labeling containers with content, handling, storage, expiration, and health and safety information; spacing stored materials to allow easy access; surrounding storage areas with containment berms to control leaks or spills; and segregating stored materials to avoid cross-contamination, mixing of incompatible materials, and unwanted reactions. Proper employee training is crucial to implementing a successful waste reduction program, especially one featuring good housekeeping procedures. Case study data indicate that effective employee training programs can reduce waste disposal volumes by 10 to 40 percent.

Regularly scheduled maintenance and plant inspections are also useful. Maintenance helps avoid the large cleanups and disposal operations that can result from equipment failure. Routine maintenance also ensures that equipment is operating at peak efficiency, saving energy, time, and materials. Regularly scheduled or random unscheduled plant inspections help identify potential problems before they cause waste management problems. They also help identify areas where improving the efficiency of materials management and handling practices is possible. If possible, plant inspections occasionally should be performed by outside inspectors who are less familiar with day-to-day plant operations. These inspectors may notice areas for improvement that are overlooked by employees accustomed to the plant's routine practices.

Storing large volumes of raw materials increases the risk of an accidental spill and the likelihood that the materials will not be used due to changes in production schedules, new product formulations, or material degradation. Many companies are forced to dispose of materials whose expiration dates have passed or that are no longer needed. Efficient inventory control allows a facility to avoid stocking materials in excess of its ability to use them, thereby decreasing disposal volume and cost. Furthermore, some companies have successfully implemented "just-in-time" manufacturing systems to avoid the costs and risks associated with maintaining a large onsite inventory. In a "just-in-time" manufacturing system, raw materials arrive as they are needed and only minimal inventories are maintained on site.

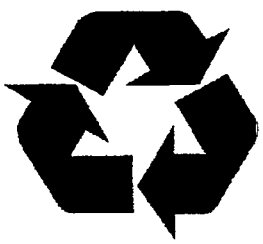
Segregating waste streams is another good housekeeping procedure that enables a facility to avoid contaminating lower risk wastes with hazardous constituents from another source. Based on a waste characterization study, it may be more efficient and cost-effective to manage wastes separately by recycling some, and treating or disposing of others.

Waste segregation can also help reduce the risks associated with handling waste. Separating waste streams may allow some materials to be reused, resulting in additional cost savings. Emerging markets for recovered industrial waste materials are creating new economic incentives to segregate waste streams. Recovered materials are more attractive to potential buyers if it can be ensured that they are not tainted with other waste materials. If wastes from metal-finishing facilities, for example, are segregated by type, metal specific bearing sludge can be recovered more economically and the segregated solvents and waste oils can be recycled.

B. Recycling

Recycling involves collecting, processing, and reusing waste materials. The following discussion highlights a few of the ways to begin this process.

Material exchange programs. Many regions and states have established material exchange programs to facilitate transactions between waste generators and industries that can use wastes as raw materials. Material exchanges are an effective and inexpensive way to find new users and uses for a waste. Most are publicly funded, nonprofit organizations, although some charge a nominal fee to be listed with them or to access their online databases. Some actively work to promote exchanges between generators and users, while others simply publish lists of generators, materials, and buyers. Some waste exchanges also sponsor workshops and conferences to discuss waste-related regulations and to exchange information. More than 60 waste and material exchanges operate in North America. Contact information for some of these exchanges is provided in Appendix III.



Beneficial use. Beneficial use involves substituting a waste material for another material with similar properties. Utility companies, for example, often use coal combustion ash as a construction material, road base, or soil stabilizer. The ash replaces other, nonrecycled materials, such as fill or Portland cement, not only avoiding disposal costs but also generating revenue. Other examples of beneficial use include using wastewaters and sludges as soil amendments (see the chapter on designing a land application program) and using foundry sand for asphalt, concrete, and roadbed construction.

Many regulatory agencies require approval of planned beneficial use activities and may require testing of the materials to be reused. Others may allow certain wastes to be designated for beneficial use, as long as the required analyses is completed. Pennsylvania, for example, allows application of a "coproduct" designation to, and exemption from waste regulations for, "materials which are essentially equivalent to and used in place of an intentionally manufactured product or produced raw material and... [which present] no greater risk to the public or the environment." Generally, regulatory agencies want to ensure that any beneficially used materials are free from significantly increased levels of constituents that may pose a greater risk than the materials they are replacing. Consult with the state agency for criteria and regulations governing beneficial use.[1]

C. Treatment

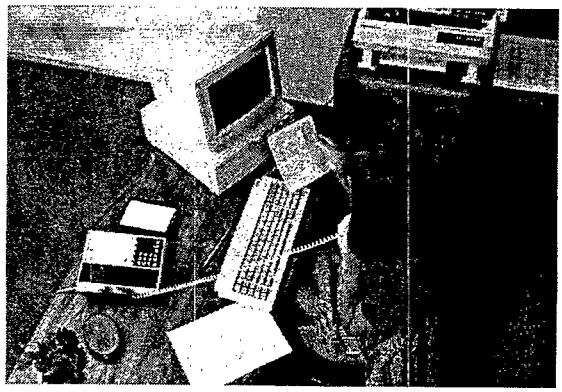
Treating waste helps to reduce its volume and/or toxicity prior to disposal. Treatment can also make a waste amenable for reuse or recycling. The range of treatment methods from which to choose is as diverse as the

[1]Freeman, Harry. 1995. Industrial Pollution Prevention Handbook. McGraw-Hill, Inc. p. 13.

range of wastes to be treated. More advanced treatment will generally be more expensive, but, by reducing the quantity and/or risk level of the waste, costs might be reduced in the long run. Savings could come from not only lower disposal costs, but also lower closure and post-closure care costs. Conversely, more basic treatment is usually less expensive but may leave the final waste management costs higher. Choose the treatment and post-treatment waste management methods that will minimize total cost and environmental impact. Also, be sure to properly manage any treatment residuals, such as sludges, which are wastes themselves. The organizations listed in the appendices may be able to assist in identifying treatment options.

III. Where to Find Out More: Technical and Financial Assistance

There is a wealth of information available to help integrate pollution prevention, recycling, and treatment into an operation. As a starting point, lists of technical and financial resources that identify some of the main places to turn to for assistance are included in the appendices. Use the Internet as a source of background information on the various resources to help narrow the search for assistance. Eventually, a network of contacts to support all the various technical needs can be built. Waste reduction information and technologies are constantly changing. To follow new developments, maintain technical and financial contacts and use the resources even after beginning waste reduction activities.



Where can assistance be obtained?

Several types of organizations offer assistance. These include offices in regulatory agencies, university departments, nonprofit foundations, and trade associations. Additionally, the National Institute of Standards and Technology (NIST) Manufacturing Extension Partnerships (MEPs) also provide waste reduction information. Look for waste reduction staff within the media programs (air, water, solid/hazardous waste) of regulatory agencies or in the state commissioner's office, special projects division, or pollution prevention division. Some states also provide technical assistance for waste reduction activities, such as recycling, through a business advocate or small business technical assistance program.

The listings in the accompanying appendices identify some primary sources for technical assistance but are far from exhaustive. There are many additional organizations that offer waste reduction/pollution prevention assistance on regional, state, and local levels. Some of the organizations listed by state may be able to help contact these other organizations. To help locate the organizations in a state or those most relevant to an industry, the listings are divided into four appendices. Once started, the list of potential contacts can be quickly expand.

- **Appendix I: State Technical Assistance Organizations.** Regulatory and nonregulatory organizations offering various forms of technical assistance within each state.
- **Appendix II: Trade Associations.** Trade associations that can give more industry- or material-specific technical assistance resources.
- **Appendix III: North American Material Exchange Programs.** A sampling of material exchange programs across North America.
- **Appendix IV: Publications, Online Resources, and Software.** An overview of places to find general information about waste reduction options.

As contact information inevitably changes with time, check the local telephone listings or investigate online resources, such as The National Pollution Prevention Roundtable's directory, *The Pollution Prevention Yellow Pages* **<www.p2.org/nppr_yps.html>**, if trying to contact an organization that is no longer available at the number listed.

What types of technical assistance are available?

Many state and local governments have technical assistance programs that are separate from regulatory offices. In addition, nongovernmental organizations implement a wide range of activities to educate businesses about the value of waste reduction. These efforts range from providing onsite technical assistance and sharing industry-specific experiences to conducting research and developing education and outreach materials on waste reduction topics. The following examples illustrate what services are available:

- **NIST technical centers.** There are NIST-sponsored Manufacturing Technology Centers throughout the country as part of the grassroots Manufacturing Extension Partnership (MEP) program. The MEP program helps small and medium-sized companies adopt new waste reduction technologies by providing technical information, financing, training, and other services. The NIST web site **<www.nist.gov>** offers a page that can help find the nearest center.
- **Trade associations.** Trade associations provide industry-specific assistance through publications, workshops, field research, and consulting services.
- **Onsite technical assistance audits.** These audits are for small (and sometimes larger) businesses. The assessments, which take place outside of the regulatory environment and on a strictly voluntary basis, provide businesses with information on how to save money, increase efficiency, and improve community relations.
- **Information clearinghouses.** Many organizations maintain repositories of waste reduction information and serve as starting points to help businesses access this information.
- **Facility planning assistance.** A number of organizations can help businesses develop, review, or evaluate facility waste reduction plans.

State waste reduction programs frequently prepare model plans can implement to minimize waste.

- **Research and collaborative projects.** Academic institutions, state agencies and other organizations frequently participate in research and collaborative projects with industry to foster development of waste reduction technologies and management strategies. Laboratory and field research activities include studies, surveys, database development, data collection, and analysis.
- **Hotlines.** Some states operate telephone assistance services to provide technical waste reduction information to industry and the general public. Hotline staff typically answer questions, provide referrals, and distribute printed technical materials on request.
- **Computer searches and the Internet.** The Internet brings many pollution prevention resources to a user's fingertips. The wide range of resources available electronically can provide information about innovative waste-reducing technologies, efficient industrial processes, current state and federal regulations, and many other pertinent topics. Independent searches can be done on the Internet, and some states perform computer searches to provide industry with information about waste reduction. EPA and many state agencies have web sites dedicated to these topics, with case studies, technical explanations, legal information, and links to other sites for more information.
- **Workshops, seminars, and training.** State agencies, trade associations, and other organizations conduct workshops, seminars, and technical training on waste reduction. These events provide information, identify resources, and facilitate net working.
- Grants and loans. A number of states distribute funds to independent groups that conduct waste reduction activities. These groups often use such support to fund research and to run demonstration and pilot projects.

Action Items for Integrating Pollution Prevention, Recycling, and Treatment

- ☐ Make waste management decisions by considering the priorities full range of options—first, source reduction; second, reuse and recycling; third, treatment; last, disposal.
- ☐ Explore the cost savings and other benefits available through activities that integrate pollution prevention, recycling, and treatment.
- ☐ Develop a waste reduction policy.
- ☐ Conduct a pollution prevention opportunity assessment of facility processes.
- ☐ Research potential pollution prevention, recycling, and treatment activities.
- ☐ Consult with public and private agencies and organizations providing technical and financial assistance for pollution prevention, recycling, and treatment activities.
- ☐ Plan and implement activities that integrate pollution prevention, recycling, and treatment.

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Part I
Getting Started

Chapter 4
Considering the Site

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Considering the Site

Become familiar with environmental, geological, and manmade features that influence siting decisions. Identify nearby areas or land uses that merit buffer zones, and place the unit an appropriate distance from them. Comply with land use and zoning restrictions. Understand existing environmental justice issues when considering a new site. Avoid siting units in problem areas, or design units to address conditions in those areas.

Many hydrologic and geologic settings can be effectively utilized for protective waste management. There are, however, some hydrologic and geologic conditions that are best avoided all together if possible. If they cannot be avoided, special design and construction precautions can minimize risks. Floodplains, earthquake zones, unstable soils, and areas at risk for subsurface movement need to be taken into account just as they would be in siting and constructing a manufacturing plant or home. Catastrophic events associated with these locations could seriously damage or destroy a unit, release contaminants into the environment, and add substantial expenses for cleanup, repair or reconstruction. If problematic site conditions cannot be avoided, engineering design and construction techniques can address some of the concerns raised by these locations.

This chapter will help address the following questions:

- What types of sites need special consideration?
- How is it determined if a unit is in an area requiring special consideration?
- What issues are associated with siting a waste management unit in such areas?
- What actions can be taken if a unit is planned in these areas?

Many state, local, and tribal governments require buffer zones between waste management units and other nearby land uses. Even if buffer zones are not required, they can still provide benefits now and in the future. Buffer zones provide time and space to contain and remedy accidental releases before they reach sensitive environments or sensitive populations. Buffer zones also help maintain good community relations by reducing disruptions associated with noise, traffic, and wind-blown dust, often the source of serious neighborhood concerns.

In considering impacts on the surrounding community, it is important to understand whether the community, especially those with large minority and low income populations,

already face significant environmental impacts from existing industrial activities. Understand a community's current environmental problems and work together to develop plans that can improve and benefit the environment, the community, the state, and the company.

How should a unit site assessment begin?

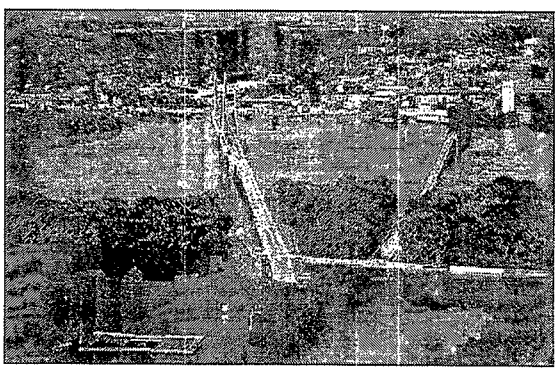
In considering whether to laterally expand a unit or site a new unit, certain factors influence prospective sites. These factors include land availability, distance from waste generation points, ease of access, local climatic conditions, economics, environmental considerations, local zoning requirements, and community impacts. As prospective sites are identified, become familiar with the siting concerns raised in this chapter, and determine how to address them at each site to minimize a unit's adverse impacts on the environment and the environment's adverse impacts on the unit. Choose the site that best balances efficient protection of human health and the environment with meeting operational goals. In addition to issues raised in this chapter, check with state and local regulatory agencies early in the siting process to identify applicable restrictions.

I. General Siting Considerations

Examining the topography of a site is the first step in siting a unit. To obtain topographic information, contact the U.S. Geological Survey (USGS), the Natural Resources Conservation Service (NRCS)[1], the state's geological survey or agency (see Appendix I), or local colleges and universities. Remote sensing data or maps from these organizations can help determine whether a prospective site is located in any of the areas of concern discussed in this section. USGS maps can be downloaded and ordered from their web page at **<mapping.usgs.gov>**. The University of Missouri-Rolla maintains a current list of State Geological Surveys on their web page at **<www.umr.edu/~library/geol/geoloff.htm>.**

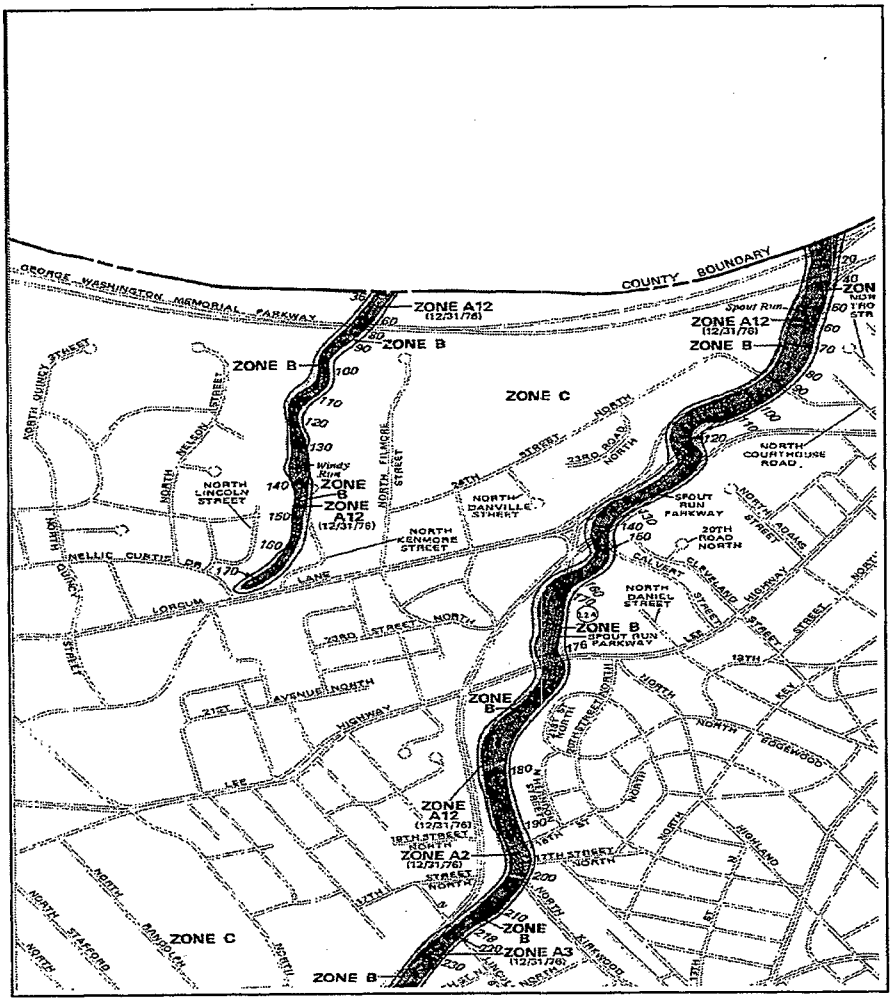
A. Floodplains

A floodplain is a relatively flat, lowland area adjoining inland and coastal waters. The 100-year floodplain—the area susceptible to inundation during a large magnitude flood with a 1 percent chance of recurring in any given year—is usually the floodplain of concern for waste management units. Determine whether a candidate site is in a 100-year floodplain. Siting a unit in a 100-year floodplain increases the likelihood of floods inundating a surface impoundment or land application unit, increases the potential to damage liner and support components of a landfill or waste pile, and presents operational concerns. This, in turn, creates environmental and human health and safety concerns, as well as legal liabilities. It also can be very costly to build a unit to withstand a 100-year flood without washout of waste or damage to the unit, or to reconstruct a unit after such a flood. Further,



Flood waters overflowed from the Mississippi River (center) into its floodplain (foreground) at Quincy, Illinois in the 1993 floods that exceeded 100-year levels in some parts of the Midwest.

[1]This agency of the U.S. Department of Agriculture was formerly known as the Soil Conservation Service (SCS).



FEMA provides flood maps like this one for most floodplains
Source: FEMA, Q3 Flood Data Users Guide **<www.fema.gov/msc>**.

locating a unit in a floodplain may exacerbate the damaging effects of a flood, both upstream and downstream, by reducing the temporary water storage capacity of the floodplain. As such, potential sites located outside the 100-year floodplain are preferable

How is it determined if a prospective site is in a 100-year floodplain?

The first step in determining whether a prospective site is located in a 100-year floodplain is to consult with the Federal Emergency Management Agency (FEMA). FEMA has prepared temporary flood hazard boundary maps for most regions. If a prospective site does not appear to be located in a floodplain, future exploration is not necessary. If uncertainty exists as to whether the prospective site may be in a floodplain, several sources of information are available to help make this determination. More detailed flood insurance rate maps (FIRMs) can be obtained from FEMA that classify areas into three classes: A, B, and C. Class A zones are the most susceptible to flooding while Class C zones are the least susceptible. FIRMs may be obtained from FEMA's web page at **<www.fema.gov/msc/hardcopy.htm>**.

Additional information can be found on flood insurance rate maps in FEMA's publication *How to Read a Flood Insurance Rate Map* (see **<www.fema.gov/NFIP/readmap.htm>**). FEMA also publishes *The National Flood Insurance Program Community Status Book*, which lists communities with flood insurance rate maps or floodway maps. Floodplain maps

can also be obtained through the U.S. Army Corps of Engineers (COE); USGS; NRCS; the Bureau of Land Management; the Tennessee Valley Authority; and state, local, and tribal agencies.[2]

Note that river channels shown in floodplain maps may have changed due to hydropower or flood control projects. As a result, some floodplain boundaries may be inaccurate. If this is suspected to be the case, consult recent aerial photographs to determine how river channels have been modified.

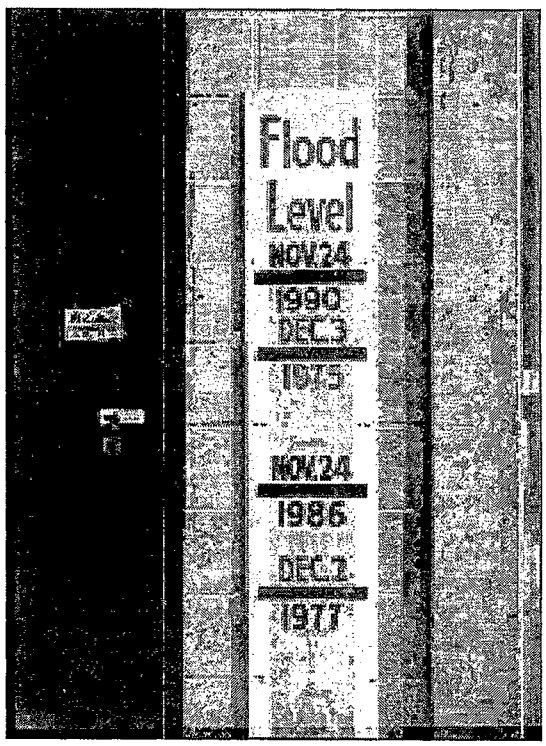
If maps can not be located, and a potential site is suspected to be located in a floodplain, conduct a field study to delineate the floodplain and determine the floodplain's properties. A delineation can draw on meteorological records and physiographic information, such as existing and planned watershed land use, topography, soils and geographic mapping, and aerial photographic interpretation of land forms. Additionally, use the U.S. Water Resource Council's methods of determining flood potential based on stream gauge records, or estimate the peak discharge to approximate the probability of exceeding the 100-year flood.

What can be done if a prospective site is in a floodplain?

If siting a waste management unit in a floodplain, design the unit to prevent the washout of waste, avoid significant alteration of flood flow, and maintain the temporary storage capacity of the floodplain. Use engineering models to estimate a floodplain's storage capacity and floodwater flow velocity. The COE Hydrologic Engineering Center has developed several computer models for simulating flood properties.[3] The models can account for a waste management unit placed in a floodplain and can also simulate flood control structures and sediment transport. If a computer model calculates that placement of the waste management unit in the floodplain raises the base flood level by more than 1 foot, the unit may alter the storage capacity of the floodplain. If designing a new unit, site it to minimize these effects. The impact of a unit's location on the speed and flow of flood waters determines the likelihood of waste washout. To quantify this, estimate the shear stress on the unit's components caused by the impinging flood waters at the depth, velocity, and duration associated with the peak, or highest, flow period of the flood.

Several available options can protect a waste management unit from flood damage and washout.

- Design embankments using materials such as riprap—rock cover used



Knowing the behavior of waters at their peak flood level is important for determining whether waste will wash out.

[2]Copies of flood maps from FEMA are available at Map Service Center, P.O. Box 1038, Jessup, MD 20794-1038, or by phone 800 358-9616 or the Internet at **<www.fema.gov/nfip/readmap.htm>**.

[3]The HEC-1, HEC-2, HEC-5, and HEC-6 software packages are available free of charge through the COE World Wide Web site, **<www.wrc-hec.usace.army.mil/software/software.html>**.

to protect soil in dikes or channels from erosion—and/or geotextiles to minimize erosion.

- Construct dikes to serve as barrier walls to protect the disposal area. This is especially important in the case of surface impoundments.
- Consider erosion control methods, such as gabions—structures formed from crushed rock encased in wire mesh—or paving bricks and mats constructed of natural or geosynthetic materials. These materials can provide erosion protection and allow for vegetative growth.

While these methods may help protect a unit from flood damage and washout, be aware that they may further contribute to decreasing the water storage and flow capacity of the floodplain. This, in turn, may raise the level of flood waters not only in the area but in upstream and downstream locations, increasing the danger of flood damage and adding to the cost of flood control programs. Thus, serious consideration should be given to not siting a waste management unit in a 100-year floodplain.

B. Wetlands

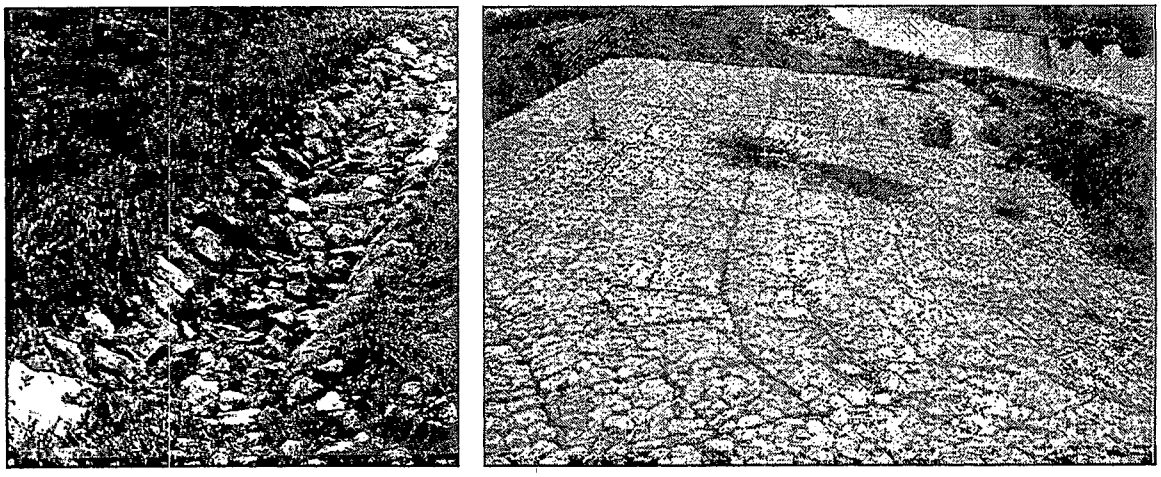
Wetlands, which include swamps, marshes, and bogs, are vital and delicate ecosystems. They are among the most productive biological communities on earth and provide habitat for many plants and animals, including approximately 45 percent of all endangered or threatened species. Wetlands protect water quality by assimilating water pollutants, removing sediments containing heavy metals, and recharging ground-water supplies. Wetlands also prevent potentially extensive and costly floods by temporarily storing flood waters and reducing their velocity. These areas also offer numerous recreational opportunities.

Potential adverse impacts associated with locating a unit in a wetland include dewatering the wetland, contaminating the wetland, and causing loss of wetland acreage. Damage also could be done to important wetland ecosystems by destroying their aesthetic qualities and diminishing wildlife breeding and feeding opportunities. Siting in a wetland also increases the potential for damage to a unit, especially the liner system and structural components, as a result of ground settlement, action of the high water table, and flooding. Alternatives to siting a waste management unit in a wetland should be given serious consideration based upon Section 404 requirements in the Clean Water Act (CWA) discussed below.

If a unit is to be sited in a wetland, the unit will be subject to additional regulations. In particular, CWA Section 404 authorizes the Secretary of the Army, acting through the Chief of Engineers (COE), to issue permits for the discharge of dredged or fill material into wetlands and other waters of the United States.[4] Activities in waters of the United States regulated under this program include fills for development, water resource projects, infrastructure improvements, and conversion of wetlands to uplands for farming and forestry. Section 404 stipulates that no discharge of dredged or fill material can be

> For regulatory purposes under the Clean Water Act, wetlands are defined as 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."
>
> 40 Code of Federal Regulations (CFR) 232.2(r)

[4] 33 United States Code 1344.



Riprap reduces stream channel erosion (left) and gabions help stabilize erodible slopes (right).

Sources: U.S. Department of the Interior, Office of Surface Mining (left); The Construction Site—A Directory To The Construction Industry, **<www.constr.com>** (right).

permitted if a practicable alternative exists that is less damaging to the aquatic environment or if the nation's waters would be significantly degraded. Therefore, in compliance with the guidelines established under Section 404, all permit applicants must:

- Take steps to avoid wetland impacts where practicable;
- Minimize impacts to wetlands where they are unavoidable; and
- Compensate (offset) for any remaining, unavoidable impacts by restoring existing wetlands or creating new wetlands.

EPA and COE jointly administer a review process to issue permits for regulated activities. For projects with potentially significant impacts, an individual permit is usually required. For most discharges with only minimal adverse effects, COE may allow applicants to comply with existing general permits, which are issued on a nationwide, regional, or statewide basis for particular activity categories as a means to expedite the permitting process. In making permitting decisions, the agencies will consider numerous other federal laws that may restrict placement of waste management units in wetlands. These include the Endangered Species Act, the Migratory Bird Conservation Act, the Coastal Zone Management Act, the Wild and Scenic Rivers Act, the Marine Protection, Research and Sanctuaries Act, and the National Historic Preservation Act.

How is it known if a prospective site is in a wetland?

As a first step, determine if the prospective site meets the definition of a wetland. If the prospective site does not appear to be a wetland then no further exploration is necessary. If it is uncertain whether the prospective site is a wetland, then several sources are available to help make this determination and define the boundaries of the wetland. Although this can be a challenging process, it will help avoid future liability since filling a wetland without the appropriate federal, state, or local permit is a violation of the law. It may be possible to learn the extent of wetlands

Spruce bog (left) and Eco Pond in the Florida Everglades (right): different types of wetlands.

without performing a new delineation, since many wetlands have previously been mapped. The first step, therefore, should be to determine whether wetland information is available for the area. At the federal level, four agencies are principally involved with wetlands identification and delineation: COE, EPA, the U.S. Fish and Wildlife Service (FWS), and NRCS. EPA also has a Wetlands Protection Hotline (800 832-7828) and a wetlands web page at **<www.epa.gov/owow/wetlands>** which provides information about EPA's wetlands program; facts about wetlands; the laws, regulations, and guidance affecting wetlands; and science, education, and information resources for wetlands. The local offices of NRCS (in agricultural areas) or COE (see Appendix II for contact information) may know whether wetlands in the vicinity of the potential site have already been delineated. Additionally, FWS maintains the National Wetlands Inventory (NWI) Program[5], from which wetlands mapping for much of the United States is obtainable. This mapping, however, is based on aerial photography, which is not reliable for specific field determinations. If a site has recently been purchased, the previous property owner may know whether any delineation has been completed that may not be on file with these agencies. Even if existing delineation information for the site is found, it still may be prudent to contact a qualified wetlands consultant to verify the wetland boundaries, especially if the delineation is not a field determination or is more than a few years old.

If the existence of a wetland is uncertain, obtain a wetlands delineation. This procedure should be performed only by a qualified professional wetlands delineator[6] using standard federal delineation procedures or applicable state or local delineation standards. The delineation procedure, with which to become familiar with before hiring a delineator, involves collecting maps, aerial photographs, plant data, soil surveys, stream gauge data, land use data, and other information. Delineation for Section 404 permitting purposes should be conducted in accordance with the 1987 *U.S. Army Corps of Engineers Wetlands Delineation Manual.*[7] (HQUACE, 27 Aug. 91). The manual provides guidelines and methods to determine whether an area is a wetland for purposes of Section

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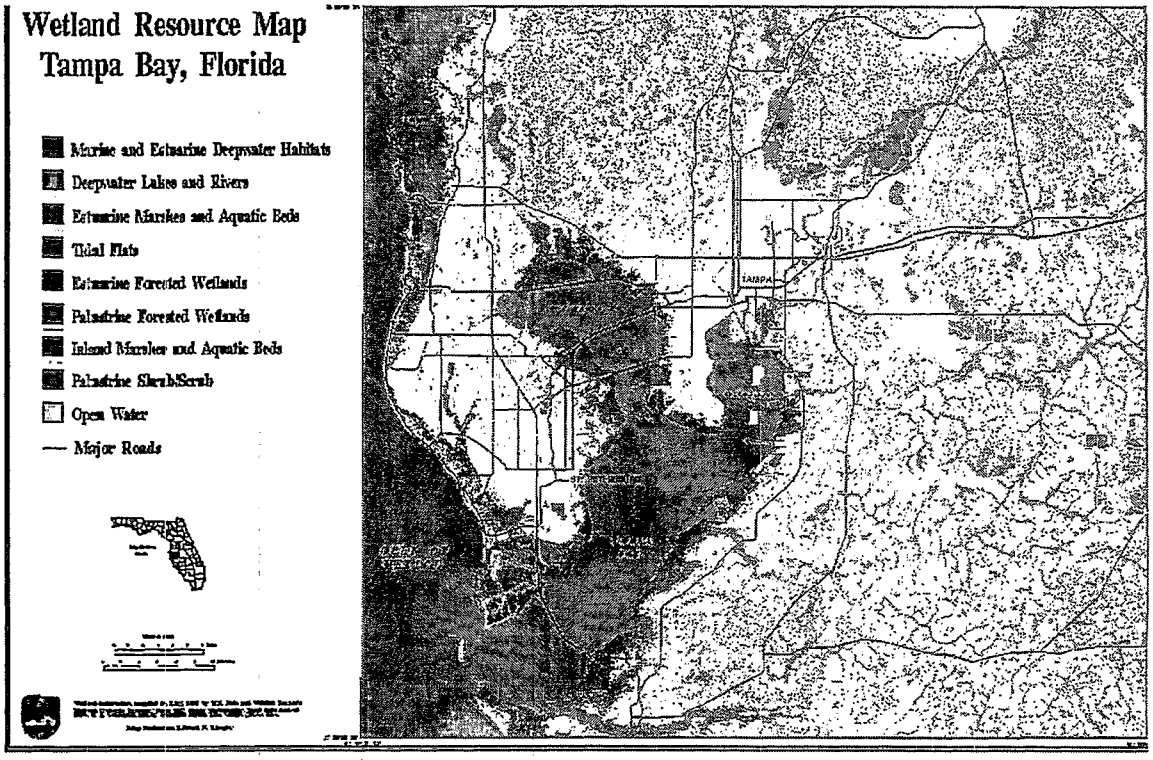
[5]To contact NWI, write to National Wetlands Inventory, 9720 Executive Center Drive, Suite 101, Monroe Building, St. Petersburg, FL 33702; or call 813 570-5412; or fax 813 570-5420. For additional information online or to search for maps of an area, connect to **<www.nwi.fws.gov>**.

[6]In March 1995, COE proposed standards for a Wetlands Delineator Certification Program (WDCP). Until these standards are finalized, there is no federal certification program. Once the WDCP standards are implemented, use WDCP-certified wetland consultants.

[7]The 1987 manual can be obtained from NTIS (see References section below) or online at **<www.wes.army.mil/el/wetlands/wlpubs.html>**.



NWI wetland resource maps like this one show the locations of various different types of wetlands and are available for many areas.

Source: NWI web site, sample GIS Think Tank maps page, **<www.nwi.fws.gov/maps_tank.html>**.

404. The manual outlines a three-parameter approach that determines the presence and location of hydrophytic vegetation, wetland hydrology, and hydric soils.

What can be done if a prospective site is in a wetland?

Before building a waste management unit in a wetland area, consider whether the unit can be located elsewhere. If an alternative location can be identified, strongly consider pursuing such an option. Section 404 of the CWA requires this. As wetlands are important ecosystems that should be protected, identifying practicable alternatives to locating a unit in a wetland area is a necessary step in the siting process. Even if no viable alternative locations are identified, it may be beneficial to keep a record of investigated alternatives, noting why they were not acceptable. Such records may be useful during the interaction between industries, states, and members of the community.

If no alternatives are available, consult with state and local governments about wetland permits. Most states operate permitting programs under the CWA, and state authorities can help navigate the permitting process. To obtain a permit, the state might require an operator to assess wetland impacts and then:

- Prevent contamination from leachate and run-off;
- Minimize dewatering effects;

- Compensate the loss of wetland acreage by creating new wetlands or restoring existing ones; and
- Protect the waste management unit against settling.

C. Active Fault Areas

Faults occur when stresses in a geologic material exceed its ability to withstand them. Areas surrounding faults are subject to earthquakes and ground failures, such as landslides or soil liquefaction. Fault movement may weaken or destroy structures directly, or seismic activity associated with faulting may cause damage to structures through vibrations. Any damage to the waste management unit could result in the release of contaminants. In addition, fault movement might create avenues to ground-water supplies, increasing the risk of ground-water contamination.

Liquefaction is another common problem encountered in areas of seismic activity. The vibrating motions caused by an earthquake tend to rearrange the sand grains in soils. If the grains are saturated, the saturated granular material turns into a viscous fluid, a process referred to as liquefaction. This diminishes the bearing capacity of the soils and may lead to foundation and slope failures.

To avoid these hazards, do not build or expand a unit within 200 feet of an active fault. If it is not possible to site a unit more than 200 feet from an active fault, design the unit to withstand the potential ground movement associated with the fault area. A fault is considered active if there has been movement along the fault within the last 10,000 to 12,000 years.

How is it known if a prospective site is in a fault area?

A series of USGS maps, *Preliminary Young Fault Maps, Miscellaneous Field Investigation 916*, identifies active faults.[8] These maps may not be completely accurate due to recent shifts in fault lines. If a prospective site is well outside the 200 foot area of concern, no fault area considerations would exist. If it is unclear how close a prospective site is to an active fault, more evaluation will be necessary. A geologic reconnaissance of the site and surrounding areas may be useful in verifying that the site is free of active faults.

If a prospective site is in an area known or suspected to be prone to faulting, conduct a fault characterization to determine if the site is near a fault. A characterization includes identifying linear features that suggest the presence of faults within a 3,000-foot radius of the site. Such features might be shown or described on maps, aerial photographs,[9] logs, reports, scientific literature, or insurance claim reports, or identified by a detailed field reconnaissance of the area.

If the characterization study reveals faults within 3,000 feet of the proposed unit, conduct further investigation to determine whether any of the faults are active within 200 feet of the unit. This investigation may involve drilling and trenching the subsurface to locate fault zones and evidence of faulting. Use perpendicular trenching on any fault within 200 feet of the proposed unit to examine the seismic epicenter for indications of recent movement.

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[8]Information about ordering these maps is available by calling 800 USA-MAPS or 303 236-7477.

[9]The National Aerial Photographic Program and the National High Altitude Program, both administered by USGS, are good national sources of aerial photographs for prospective sites. To order from USGS, call 605 594-6151. For more information, visit **<www.mapping.usgs.gov/esic/aphowto.html>**. Local aerial photography firms and surveyors are also good sources.

What can be done if a prospective site is in a fault area?

If an active fault exists on the site where the unit is planned, consider placing the unit 200 feet back from the fault area. Even with such setbacks, only place a unit in a fault area if it is possible to ensure that no damage to the unit's structural integrity would result. A setback of less than 200 feet might be adequate if ground movement would not damage the unit.

If a lateral expansion or a new unit will be located in an area susceptible to seismic activity, there are two issues to consider: horizontal accelerations and movements affecting side slopes. Horizontal acceleration becomes a concern when a location analysis reveals that the site is in a zone of increased risk of horizontal acceleration in the range of 0.1 g to 0.75 g (g = acceleration of gravity). In these zones, the unit design should incorporate measures to protect the unit from potential ground shifts. To address side slope concerns, conduct a seismic stability analysis to determine the most effective materials and gradients for protecting the unit's slopes from any seismic instabilities. Further, design the unit to withstand the impact of vertical accelerations.

If an investigation reveals that a unit is in an area susceptible to liquefaction, consider ground improvement measures. These measures include grouting, dewatering, heavy tamping, and/or excavation. See Table 1 for examples of currently available techniques.

Further engineering options for fault areas include the use of flexible pipes for run-off and leachate collection and redundant containment systems. In the event of foundation soil collapse or heavy shifting, flexible run-off and leachate collection pipes—along with a bedding of gravel or permeable material—can absorb some of the shifting-related stress to which the pipes may be subjected. Consider also a secondary containment measure, such as an additional liner system. In earthquake-like conditions, a redundancy of this nature may be necessary to prevent contamination of the surrounding area if the primary liner system fails.

In this aerial view, the best-known fault in the U.S., the San Andreas, slices through the Carrizo Plain east of San Luis Obispo, California. Source: USGS

D. Seismic Impact Zones

A seismic impact zone is an area having a 10 percent or greater probability that the maximum horizontal acceleration caused by an earthquake at the site will exceed 0.1 g in 250 years. This seismic activity may damage

Table 1
Examples of Improvement Techniques for Liquefiable Soil Foundation Conditions

Method	Principle	Most Suitable Soil Conditions/Types	Applications
Blasting	Shock waves and vibrations cause limited liquefaction, displacement, remolding, and settlement to higher density.	Saturated, clean sands; partly saturated sands and silts after flooding.	Induce liquefaction in controlled and limited stages and increase relative density to potentially nonliquefiable range.
Vibrocompaction	Densification by vibration and compaction of backfill material of sand or gravel.	Cohesionless soils with less than 20 percent fines.	Induce liquefaction in controlled and limited stages and increase relative densities to nonliquefiable condition. The dense column of backfill provides (a) vertical support, (b) drainage to relieve pore water pressure, and (c) shear resistance in horizontal and inclined directions. Used to stabilize slopes and strengthen potential failure surfaces.
Compaction piles	Densification by displacement of pile volume and by vibration during driving, increase in lateral effective earth pressure.	Loose sandy soils; partly saturated clayey soils; loess.	Useful in soils with fines. Increases relative densities to nonliquefiable range. Provides shear resistance in horizontal and inclined directions. Useful to stabilize slopes and strengthen potential failure surfaces.
Displacement and compaction grout	Highly viscous grout acts as radial hydraulic jack when pumped in under high pressure.	All soils.	Increase in soil relative density and horizontal effective stress. Reduce liquefaction potential. Stabilize the ground against movement.
Mix-in-place piles and walls	Lime, cement, or asphalt introduced through rotating auger or special in-place mixer.	Sand, silts, clays, all soft or loose inorganic soils.	Slope stabilization by providing shear resistance in horizontal and inclined directions, which strengthens potential failure surfaces or slip circles. A wall could be used to confine an area of liquefiable soil.
Heavy tamping (dynamic compaction)	Repeated application of high -intensity impacts at surface.	Cohesionless soils best, other types can also be improved.	Suitable for some soils with fines; usable above and below water. In cohesionless soils, induces liquefaction in controlled and limited stages and increases relative density to potentially nonliquefiable range.

Source: RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities. EPA600-R-95-051

leachate collection, detection, and removal systems or other unit structures through excessive bending, shearing, tension, and/or compression. If a unit's components fail, leachate may contaminate surrounding areas. For safety reasons, therefore, it is recommend that a unit not be located in a seismic impact zone. If a unit must be sited in a seismic impact zone, the unit should be designed to withstand earthquake-related hazards, such as landslides, slope failures, soil compaction, ground subsidence, and soil liquefaction.

Additionally, if a unit is built in a seismic impact zone, avoid rock and soil types that are especially vulnerable to earthquake shocks. These include very steep slopes of weak, fractured, and brittle rock or unsaturated loess, which are vulnerable to transient shocks caused by tensional faulting. Avoid loess and saturated sand as well, because seismic shocks can liquefy them, causing sudden collapse of structures. Similar effects are possible in sensitive cohesive soils when natural moisture exceeds the soil's liquid limit. (See the "Soil Properties" section in the chapter on designing and installing liners for a discussion of liquid limits.) Earthquake-induced ground vibrations can also compact loose granular soils. This could result in large uniform or differential settlements of the ground surface.

How is it known if a prospective site is in a seismic impact zone?

If a prospective site is in an area with no history of earthquakes, then seismic impact zone considerations may be unnecessary. If it is unclear whether the area has a history of seismic activity, then further evaluation will be necessary. As a first step, consult the USGS field study map series MF-2120, *Probabilistic Earthquake Acceleration and Velocity Maps for the United States and Puerto Rico*.[10] It provides state- and county-specific information about seismic impact zones. Additional information is available from the USGS National Earthquake Information Center (NEIC),[11] which maintains a database of known earthquake and fault zones.

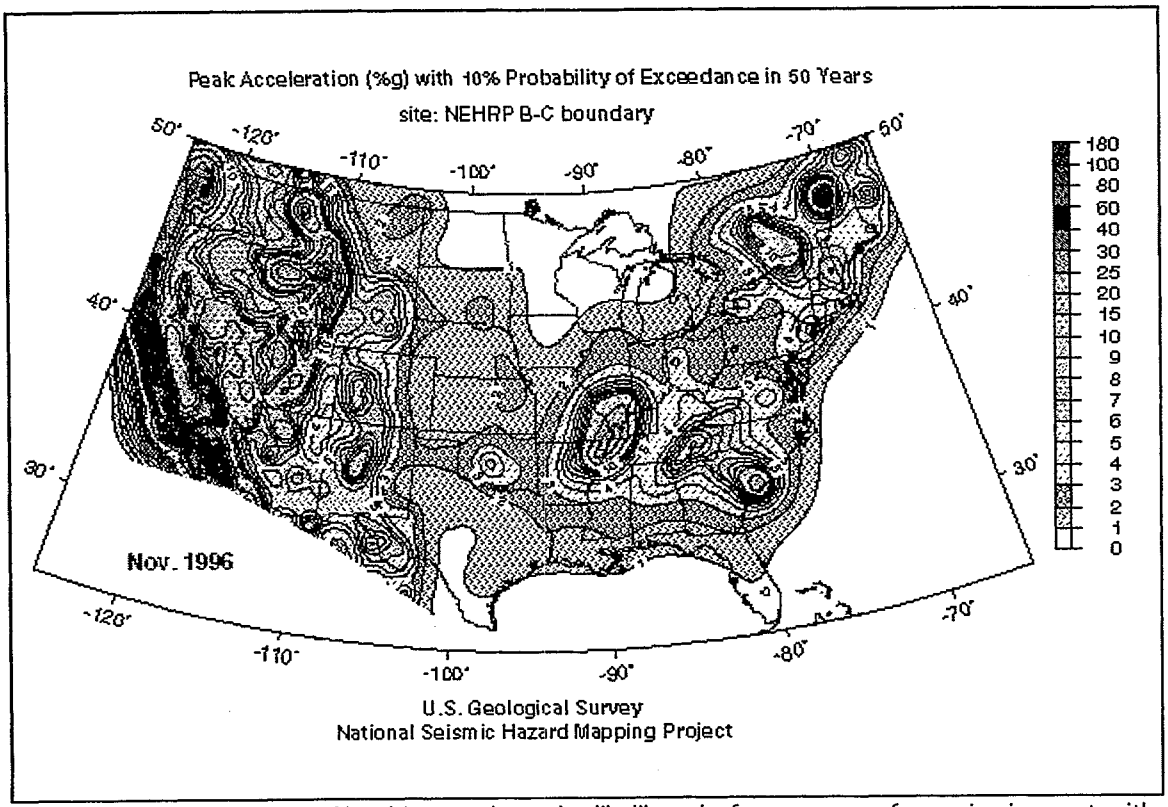
If a site is or may be in a seismic impact zone, it also is useful to analyze the effects of seismic activity on soils in and under a unit. Computer software programs are available that can evaluate soil liquefaction potential. Liquefaction is the process by which soils change from solid to liquid state due to repeated shearing during or following an earthquake. LIQUFAC, a software program developed by the Naval Facilities Engineering Command in Washington, DC, can calculate safety factors for each soil layer in a given soil profile and the corresponding one dimensional settlements due to earthquake loading.

What can be done if a prospective site is in a seismic impact zone?

If a waste management unit cannot be sited outside a seismic impact zone, structural components of the unit—including liners, leachate collection systems, and surface-water control systems—should be designed to resist the earthquake-related stresses expected in the local soil. Consult professionals experienced in seismic analysis and design to ensure that the unit is designed appropriately. To determine the potential effects of seismic activity on a structure, the seismic design specialist should evaluate soil behavior with respect to earthquake intensity. This evaluation should account for soil strength, degree of compaction, sorting (organization of the soil

[10]For information on ordering these maps, call 800 HELP-MAP; or write: USGS Information Services, Box 25286, Denver, CO 80225; or fax 303 202-4693. On-line information is available at **<www.mapping.usgs.gov/esic/to_order.html>.**

[11]To contact NEIC, call 303 273-8500; or write: United States Geological Survey, National Earthquake Information Center, Box 25046, DFC, MS 967, Denver, Colorado 80225; or fax 303 273-8450; or e-mail sedas@gldfs.cr.usgs.gov. For on-line information, see **<www.neic.cr.usgs.gov>.**



USGS seismic impact maps like this one show the likelihood of occurance of an seismic event with a specified peak acceleration.

Source: USGS National Earthquake Information Center **<www.neic.cr.usgs.gov>**.

particles), and saturation, as well as peak acceleration of the potential earthquake.

After an evaluation of soil behavior, choose appropriate earthquake protection measures. These might include shallower slopes, dike and run-off control designs using conservative safety factors, and contingency plans or backup systems for leachate collection should the primary systems be disrupted. Unit components should be able to withstand the additional forces imposed by an earthquake within acceptable margins of safety.

Additionally, well-compacted, cohesionless embankments or reasonably flat slopes in insensitive clay (clay that maintains its compression strength when remolded) are less likely to fail under moderate seismic shocks (up to 0.15 g and 0.20 g). Embankments made of insensitive, cohesive soils founded on cohesive soils or rock may withstand even greater seismic shocks. For earthen embankments in seismic regions, consider designs with internal drainage and core materials resistant to fracturing. Prior to or during unit construction in a seismic impact zone, evaluate excavation slope stability to determine the appropriate grade of slopes to minimize potential slip.

For landfills and waste piles, use shallower waste side slopes, as steep slopes are more vulnerable to slides and collapse during earthquakes. Use fill sequencing techniques that avoid concentrating waste in one area of the unit for an extended period of time. This

prevents waste side slopes from becoming too steep and unstable and alleviates differential loading of the foundation components. Placing too much waste in one area of the unit may lead to catastrophic shifting during an earthquake or heavy seismic activity. Shifting of this nature may cause failure of crucial system components or of the unit in general.

In addition, seismic impact zones have design issues in common with fault areas, especially concerning soil liquefaction and earthquake-related stresses. To address liquefaction, employ the soil improvement methods described in Table 1. Treating liquefiable soils in the vicinity of the unit will improve foundation stability and help prevent uneven settling or possible collapse of heavily saturated soils underneath or near the unit.

To protect against earthquake-related stresses, consider redundant liners and special leachate collection and removal system components, such as secondary liner systems, composite liners, and leak detection systems combined with a low permeability soil layer. These measures function as backups to the primary containment and collection systems and provide a greater margin of safety for units during possible seismic stresses. Examples of special leachate systems include high-strength, flexible materials for leachate containment systems; geomembrane liner systems underlying leachate containment systems; and perforated polyvinyl chloride or high-density polyethylene piping in a bed of gravel or other permeable material.

E. Unstable Areas

Unstable areas are locations susceptible to naturally occurring or human-induced events or forces capable of impairing the integrity of a waste management unit. Naturally occurring unstable areas include regions with poor soil foundations, regions susceptible to mass movement, or regions containing karst terrain, which may include hidden sinkholes. Unstable areas caused by human activity may include areas near cut or fill slopes, areas with excessive drawdown of ground water, and areas where significant quantities of oil or natural gas have been extracted. Siting in an unstable area may make monitoring a site or performing remediation, if necessary, impossible to do. Siting in an unstable area should be avoided. If necessary, technical and construction techniques should be considered to mitigate against potential damage.

The three primary types of failure that can occur in an unstable area are settlement, loss of bearing strength, and sinkhole collapse. Settlement can result from soil compression if a unit is, or will be, located in an unstable area over a thick, extensive clay layer. The unit's weight may force water from the compressible clay, compacting it and allowing the unit to settle. Settlement may increase as waste volume increases and may result in structural failure of the unit if it was not properly engineered. Settlement beneath a waste management unit should be assessed and compared to the elongation strength and flexibility properties of the liner and leachate collection pipe system. Even small amounts of settlement can seriously damage leachate collection piping and sumps. Engineer a unit to minimize the impacts of settlement if it is, or will be in an unstable area.

Loss of bearing strength is a failure mode that occurs in soils that tend to expand and rapidly settle or liquefy. Soil contractions and expansions may increase the risk of leachate or waste release. Another example of loss of bearing strength occurs when excavation near the unit reduces the mass of soil at the toe of the slope, thereby reducing the overall strength (resisting force) of the foundation soil.

Catastrophic collapse in the form of sinkholes can occur in karst terrain. As water,

Sinkholes, like this one that occurred just north of Orlando, Florida in 1981, are a risk of Karst terrain. Left: aerial view (note baseball diamond for scale); right: ground-level view. Photos courtesy of City of Winter Park, Florida public relations office.

especially acidic water, percolates through limestone, the soluble carbonate material dissolves, leaving cavities and caverns. Land overlying caverns can collapse suddenly, resulting in sinkholes that can be more than 100 feet deep and 300 feet wide.

How is it known if a prospective site is in an unstable area?

Before designing a waste management unit on a prospective site whose stability has not previously been assessed, a stability assessment study should be conducted by a qualified professional. The qualified professional should assess natural conditions, such as soil geology and geomorphology, as well as both surface and subsurface human-induced features or events that could cause differential ground settlement. Naturally unstable conditions can become more unpredictable and destructive if amplified by human-induced changes to the environment. If a unit is to be built at an assessed site that exhibits stability problems, tailor the design to account for any instability detected. A stability assessment may include the following steps:

Screen for expansive soils. Such soils may lose their ability to support a foundation when subjected to certain natural events, such as heavy rain, or human-made events, such as explosions. Expansive soils usually are clay-rich and, because of their molecular structure, tend to swell and shrink by taking up and releasing water. Such soils include smectite (montmorillonite group) and vermiculite clays. In addition, soils rich in white alkali (sodium sulfate), anhydrite (calcium sulfate), or pyrite (iron sulfide) also may swell as water content increases. These soils are more common in the arid western states.

Check for soil subsidence. Soils subject to rapid subsidence include loesses, unconsolidated clays, and wetland soils. Loess is a wind-deposited, moisture-deficient silt that tends to compact when wet. Unconsolidated clays can undergo considerable compaction when oil or water is removed. Similarly, wetland soils, which by their nature are water-bearing, are also subject to subsidence when water is withdrawn.

Subsidence, slippage, and other kinds of slope failure can damage structures.

Look for areas subject to mass movement or slippage. Such areas are often situated on slopes and tend to have rock or soil conditions conducive to downhill sliding. Examples of mass movements include avalanches, landslides, and rock slides. Some sites may require cutting or filling slopes during construction. Such activities may cause existing soil or rock to slip.

Search for karst terrain. Karst features are areas containing soluble bedrock, such as limestone or dolomite, that has been dissolved and eroded by water, leaving characteristic physiographic features including sinkholes, sinking streams, caves, large springs, and blind valleys. These areas are subject to extreme incidents of differential settlement, including complete ground collapse. Karst features also can hamper detection and control of leachate, which can move rapidly through hidden conduits beneath the unit. Karst maps, such as Engineering Aspects of Karst, Scale 1:7,500,000, Map No. 38077-AW-NA-07M-00, produced by the USGS[12] and state specific geological maps can be reviewed to identify karst areas.

Scan for evidence of excessive drawdown or oil and gas extraction. Removing underground water can increase the effective overburden on the foundation soils underneath the unit. Excessive drawdown of water might cause settlement or bearing capacity failure on the foundation soils. Extraction of oil or natural gas can have similar effects.

Investigate the geotechnical and geological characteristics of the site. It is important to establish soil strengths and other engineering properties. A geotechnical engineering consultant can accomplish this by performing standard penetration tests, field vane shear tests, and laboratory tests. This information will determine how large a unit can be placed safely on the site. Other soil properties to examine include water content, shear strength, plasticity, and grain size distribution.

Examine the liquefaction potential. The liquefaction potential of embankments, slopes, and foundation soils must be determined. Highly liquefiable soils are less conducive to safe operation of a waste management unit. Consult Section C above for more information about liquefiable soils.

What can be done if a prospective site is in an unstable area?

It is advisable not to locate or expand a waste management unit in an unstable area. If a unit is, or will be located in such an area, safeguard the structural integrity of the unit by incorporating appropriate measures into the design. If this is not done, the integrity of the unit may be jeopardized. For example, to safeguard the structural integrity of side slopes in an unstable area, reduce slope height, flatten slope angle, excavate a bench in the upper portion of the slope, or buttress slopes with compacted earth or rock fill. Alternatively, build retaining structures, such as retaining walls or slabs and piles. Other approaches include geotextiles and geogrids to provide additional strength, wick and toe

[12]For information on ordering this map, call 800 USA-MAPS; or write: USGS Information Services, Box 25286, Denver, CO 80225; or fax 303 202-4693. On-line information is available at **<www-atlas.usgs.gov/atlasmap.html>**.

drains to relieve excess pore pressures, grouting, and vacuum and wellpoint pumping to lower ground-water levels. In addition, surface drainage may be controlled to decrease infiltration, thereby reducing the potential for mud and debris slides.

Additional engineering concerns arise in the case of waste management units in areas containing karst terrain. The principal concern with karst terrains is progressive or catastrophic subsurface failure due to the presence of sinkholes, solution cavities, and subterranean caverns. The unpredictable and sometimes catastrophic nature of subsidence in these areas makes them difficult and expensive to develop. Extensive subsurface characterization studies should be completed before designing and building in these areas. Subsurface drilling, sinkhole monitoring, and geophysical testing are direct means that can be used to characterize a site. Geophysical techniques include electromagnetic conductivity, seismic refraction, ground-penetrating radar, and electrical resistivity. Use more than one technique to confirm and correlate findings and anomalies, and have a qualified geophysicist interpret the results of these explorations.

Remote sensing techniques, such as aerial photograph interpretation, can provide additional information on karst terrains. Surface mapping can help provide an understanding of structural patterns and relationships in karst terrains. An understanding of local carbonate geology and stratigraphy can help with the interpretation of both remote sensing and geophysical data.

Incorporate adequate engineering controls into any waste management unit located in karst terrain. In areas where karst development is minor, loose soils overlying the limestone may be excavated or heavily compacted to achieve the needed stability. Similarly, in areas where the karst voids are relatively small, the voids may be filled with slurry cement grout or other material.

Engineering solutions can try to compensate for the weak geologic structures by providing ground supports. For example, ground modifications, such as grouting or reinforced raft foundations, could compensate for a lack of ground strength in some karst areas. Raft constructions, which are floating foundations consisting of a concrete footing extending over a very large area, reduce and evenly distribute waste loads where soils have a low bearing capacity or where soil conditions are variable and erratic. Note, however, that raft foundations may not always prevent the extreme collapse and settlement that can occur in karst areas. In addition, due to the unpredictable and catastrophic nature of ground failure in unstable areas, the construction of raft foundations and other ground modifications tends to be complex and can be costly, depending on the size of the area.

F. Airport Vicinities

The vicinity of an airport includes not only the facility itself but also large reserved open areas beyond the ends of runways. If a unit is intended to be sited near an airport, be aware of issues that take on added importance in such areas and become familiar with Federal Aviation Administration (FAA) regulations and guidelines. The chief concern associated with waste management units near airports is the hazard posed to aircraft by birds, which often feed at units managing putrescible waste. Planes can lose propulsion when birds are sucked into jet engines, and may sustain other damage in collisions with birds. Another area of concern for landfills and waste piles near airports is the height of the accumulated waste. In such situations, exercise caution when managing waste in units that are significantly above ground level. Industrial waste management units that do

not receive putrescible wastes should not have a problem with birds.

How is it known if a prospective site is in an airport vicinity?

If the prospective site is not located near any airports, additional evaluation is not necessary. If there is uncertainty whether the prospective site is located near airports, obtain local maps of the area using the Internet or from the state and identify any nearby public use airports. Topographic maps available from USGS also provide a suitable basis for determining airport locations. If necessary, FAA can provide information on the location of all public-use airports. In accordance with FAA guidance, if a new unit or an expansion of an existing unit will be within 5 miles of the end of a public-use airport runway, the affected airport and the regional FAA office should be notified to provide them an opportunity for review and comment.

What can be done if a prospective site is in an airport vicinity?

If a unit is, or will be located within 10,000 feet of an airport used by jet aircraft or within 5,000 feet of an airport used only by piston-type aircraft, design and operate the unit so it does not pose a bird hazard to aircraft and, for above-ground units, does not interfere with flight patterns. If it appears that height may be a concern, consider entrenching the unit or choosing a site outside the airport's flight patterns. The types of waste handled at most nonhazardous industrial units do not usually include attractive food sources for birds, but if a unit handles waste that may potentially attract birds, precautions should be taken to prevent birds from becoming an aircraft hazard. Discourage congregation of birds near a unit by preventing water from collecting on site; eliminating or covering wastes that might serve as a food source; constructing physical barriers, such as a canopy of fine wires or nets strung around the disposal and storage areas; using visual deterrents, including realistic models of the expected scavenger birds' natural predators; employing sound deterrents, such as cannon sounds, distress calls of scavenger birds, or the sounds of the birds' natural predators; or removing nesting and roosting areas (unless such removal is prohibited by the Endangered Species Act).

G. Wellhead Protection Areas

Wellhead protection involves sheltering the ground-water resources that supply public drinking water systems. A wellhead protection area (WHPA) is the area most susceptible to contamination surrounding a wellhead. WHPAs are designated and often regulated to prevent public drinking water sources from becoming contaminated. The technical definition, delineation, and regulation of WHPAs vary from state to state. Contact the state environmental agency to determine what wellhead protection measures are in place near prospective sites. Section II of this chapter provides examples of how some states specify minimum allowable distances between waste management units and public water supplies, as well as drinking water wells. Locating a waste management unit in a WHPA can create a potential avenue for drinking water contamination through accidental release of leachate, contaminated run-off, or waste.

How is it known if a prospective site is in a wellhead protection area?

If the prospective site is not located near a WHPA, further evaluation is not necessary. If there is uncertainty regarding the proximity of the prospective site to a WHPA, contact the state environmental agency. A list of state wellhead protection program contacts is available on EPA's web page at **<www.epa.gov/ogwdw000/wellne616a.html>**, and is included in Appendix III. Also, USGS and NRCS both can provide maps that help in delineating WHPAs. For further expertise, contact local water authorities, or universities.

What can be done if a prospective site is in a wellhead protection area?

If a new unit or lateral expansion will be located in a WHPA or suspected WHPA, consider design modifications to help prevent any ground-water contamination. For waste management units placed in these areas, work with state regulatory agencies to ensure that appropriate ground-water barriers are installed between the unit and the ground-water table. These barriers should be designed using materials of extremely low permeability, such as geomembrane liners or low permeability soil liners. The purpose of such barriers is to prevent any waste, or water that has percolated through the waste, from reaching the ground water and possibly affecting the public drinking water source.

In addition to ground-water barriers, consider using leachate collection, leak detection, and run-off control systems. Leachate contamination is possibly the greatest threat to a public ground-water supply posed by a waste management unit. Incorporating leachate collection, leak detection, and run-off control systems should further minimize leachate from escaping into the ground water.

Control systems that separate storm-water run-on from any water that has contacted waste should also be provided. Proper control measures that redirect storm water to the supply source area should help alleviate this tendency.

II. Buffer Zone Considerations

Many states require buffer zones between waste management units and other nearby land uses, such as schools. The size of a buffer zone often depends on the type of waste management unit and the land use in the surrounding areas. Consult with state regulatory agencies and local advisory boards about buffer zones before constructing a new unit or expanding an existing unit.

Buffer zones provide time and space to mitigate situations where accidental releases may cause adverse human health or environmental impacts. These zones provide four primary benefits: maintenance of quality of the surrounding ground water, prevention of contaminant migration off site, protection of drinking water supplies, and minimization of nuisance conditions perceived in surrounding areas. The size of the buffer zone will be directly related to the intended benefit.

Protecting ground water should be the primary concern for all involved parties. Ensure that materials processed and disposed of at a unit are isolated from ground-water resources. Placing a unit further from the water table, and increasing the number of physical barriers between the unit and the

Many nearby areas and land uses, such as schools, call for consideration of buffer zones.

water table, improves ground-water protection. It is therefore advised that in addition to incorporating a liner system into a waste management unit's design, a site where an adequate distance separates the bottom of a unit from the water table should be selected (see Appendix IV: State Buffer Zone Considerations: Table 5 for a summary of the most common minimum separation distances between the bottom of a waste management unit and the water table). In the event of a release, this separation distance will allow for dilution and natural attenuation to protect ground water.[13]

Additionally, in the event of an unplanned release, an adequate buffer zone will allow time for remediation activities to control contaminants before they spread off site. It also will provide additional protection for drinking water supplies. Drinking water supplies include ground water, individual and community wells, lakes, reservoirs, and municipal water treatment facilities.

Finally, buffer zones help maintain good relations with the surrounding community by protecting surrounding areas from noise, dust, and odor that may be associated with a unit. Buffer zones also help prevent access by unauthorized people. For units located near property boundaries, houses, or historic areas, evergreen trees or earthen berms can provide a buffer to reduce noise and odors. Planting trees around a unit can also improve the aesthetics of a unit, obstruct any view of unsightly waste, and help protect property values in the surrounding community.

A. Recommended Buffer Zones

Check with state and local officials to determine what buffer zones may apply to industrial waste management units.[14]

Property boundaries. Waste management units can present noise, odor, and dust problems for residents or businesses located on adjacent property, thereby diminishing property values. Additionally, proximity to property boundaries can invite increased trespassing, vandalism, and scavenging.

Drinking water wells, surface-water bodies, and public water supplies. Locating a unit near or within the recharge area, for sole source aquifers and major aquifers, coastal areas, surface-water bodies, or public water supplies, such as a community well or water treatment facility, also raises concerns. Releases from a waste management unit may pose serious threats to human health not only where water is used for drinking, but also where surface waters are used for recreation.

[13]Natural attenuation may be defined as chemical and biological processes that reduce contaminant concentrations.

[14]Appendix IV presents a summary of some state buffer zone recommendations.

Buffer zones can help protect endangered species and their habitats.

Contamination of surface waters also threatens plants and animals and their habitats.

Houses or buildings. To minimize adverse effects on adjacent properties, consider incorporating a buffer zone or separation distance into unit design. Consider planting trees or bushes to provide a natural buffer between a unit and adjacent properties.

B. Additional Buffer Zones

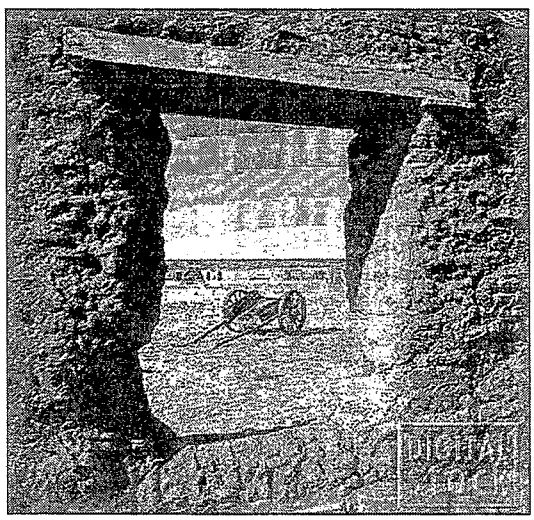
There are several other areas for which to consider establishing buffer zones, including critical habitats, park lands, public roads, and historic or archaeological sites.

Critical habitats. These are geographical areas occupied by endangered or threatened species. These areas contain physical or biological features essential to the proliferation of the species. When designing a unit near a critical habitat, it is imperative that the critical habitat be conserved. A buffer zone can help prevent the destruction or adverse modification of a critical habitat and minimize harm to endangered or threatened species.[15]

Parklands. A buffer between a unit and park boundaries helps maintain the aesthetics of the park land. Park lands provide recreational opportunities and a natural refuge for wildlife. Locating a unit too close to these areas can disrupt recreational qualities and natural wildlife patterns.

Public roads. A buffer zone will help reduce unauthorized access to a unit, reduce potential odor concerns, and improve aesthetics for travelers on the nearby road.

Historic or archaeological sites. A waste management unit located in close proximity to one of these sites may adversely impact the aesthetic quality of the site. These areas include historic settlements, battlegrounds, cemeteries, and Indian burial grounds. Check also whether a prospective site itself has historical or archaeological significance.



Historic sites call for careful consideration of buffer zones.

[15]For the full text of the Endangered Species Act, go to the U.S. House of Representatives Internet Law Library at **<law.house.gov/16.htm>**.

In summary, check with local authorities to ensure that placement of a new waste management unit or lateral expansion of an existing unit will not conflict with any local buffer zone criteria. Also, review any relevant state regulations that may specify buffer zones for industrial waste management units. For new units or lateral expansions of existing units located near any sensitive areas as described in this section, consider measures to minimize any possible health, environmental, and nuisance impacts.

III. Local Land Use and Zoning Considerations

In addition to location and buffer zone considerations, become familiar with any local land use and zoning requirements. Local governments often classify the land within their communities into areas, districts, or zones. These zones represent different use categories, such as residential, commercial, industrial, or agricultural. Zoning protects public health and safety, property values, and development trends. Consider the compatibility of a unit with nearby existing and future land use and contact local authorities early in the siting process. Local planning, zoning, or public works officials can discuss the development of a unit, compliance with local regulations, and available options. Local authorities may impose conditions for protecting adjacent properties from potential adverse impacts of unit.

Addressing local land use and zoning issues during the siting process may prevent these issues from becoming prominent concerns later in the process. Land use and zoning restrictions often address impacts on community and recreational areas, historical areas, and other critical areas. Consider the proximity of a unit to such areas and evaluate any potential adverse effects it may have on these areas. For example, noise, dust, fumes, and odors from construction and operation of a unit could be considered a nuisance and legal actions may be brought by local authorities or nearby property owners.

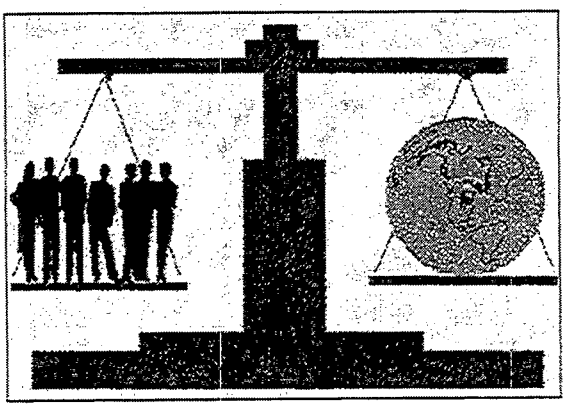
In situations where land use and zoning restrictions may cause difficulties in expanding or siting a unit, work closely with local authorities to learn about local land use and zoning restrictions and minimize potential problems. Misinterpreting or ignoring such restrictions can cause complications with intended development schedules or designs. In many cases, the use of vegetation, fences, or walls to screen activities may reduce impacts on nearby properties. In addition, it may be possible to request amendments, rezonings, special exceptions, or variances to restrictions. These administrative mechanisms allow for flexibility in use and development of land. Learning about local requirements as early as possible in the process will maximize the time available to apply for variances or rezoning permits, or to incorporate screening into the plans for a unit.

IV. Environmental Justice Considerations

In the past several years, there has been growing recognition from communities and federal and state governments that some socioeconomic and racial groups may bear a disproportionate burden of adverse environmental effects from waste management activities. President Clinton issued Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*, on February 11,

1994. To be consistent with the definition of environmental justice in this executive order, identify and address, as appropriate, disproportionately high and adverse human health or environmental effects of waste management programs, policies, and activities on minority populations and low-income populations.

One of the criticisms made by advocates of environmental justice is that local communities endure the potential health and safety risks associated with waste management units without enjoying any of the economic benefits. During unit siting or expansions, address environmental justice concerns in a manner that is most appropriate for the operations, the community, and the state. Look for opportunities to minimize environmental impacts, improve the surrounding environment, and pursue opportunities to make the waste management facility an asset to the community. When planning these opportunities, it is beneficial to maintain a relationship with all involved parties based on honesty and integrity, utilize cross-cultural formats and exchanges, and recognize industry, state, and local knowledge of the issues. It is also important to take advantage of all potential opportunities for developing partnerships.



Examples of activities that incorporate environmental justice issues include tailoring activities to specific needs; providing interpreters, if appropriate; providing multilingual materials; and promoting the formation of a community/state advisory panel.

Tailor the public involvement activities to the specific needs. Good public involvement programs are site-specific—they take into account the needs of the facility, neighborhood, and state. There is no such thing as a "one-size-fits-all" public involvement program. Listening to each other carefully will identify the specific environmental justice concerns and determine the involvement activities most appropriate to address those needs.

Provide interpreters for public meetings. Interpreters can be used to ensure the information is exchanged. Provide interpreters, as needed, for the hearing impaired and for any languages, other than English, spoken by a significant percentage of the audience.

Provide multilingual fact sheets and other information. Public notices and fact sheets should be distributed in as many languages as necessary to ensure that all interested parties receive necessary information. Fact sheets should be available for the visually impaired in the community on tape, in large print, or braille.

Promote the formation of a community/state advisory panel to serve as the voice of the community. The Louisiana Department of Environmental Quality, for example, encourages the creation of environmental justice panels comprised of community members, industry, and state representatives. The panels meet monthly to discuss environmental justice issues and find solutions to any concerns identified by the group.

Considering the Site Action Items

General Location Considerations

- ☐ Check to see if the proposed unit site is
  - — In a 100-year floodplain;
  - — Near a wetland;
  - — Within 200 feet of an active fault;
  - — In a seismic impact zone;
  - — In an unstable area;
  - — Close to an airport; or
  - — Within a wellhead protection area.

- ☐ If the proposed unit site is in any of these areas,
  - — Attempt to site the unit elsewhere first; or
  - — Design the unit to account for the area's characteristics and mitigate the unit's impacts on such areas.

Buffer Zones

(Many states require buffer zones between waste management units and other nearby land uses.)

- ☐ Check to see if the proposed unit site is near
  - — A property boundary;
  - — A drinking water well;
  - — A public water supply, such as a community well, reservoir, or water treatment facility;
  - — A surface-water body, such as a lake, stream, river, or pond;
  - — Houses or other buildings;
  - — Critical habitats for endangered or threatened species;
  - — Park lands;
  - — A public road; or
  - — Historic or archaeological sites.

- ☐ If the proposed unit site is near any of these areas or land uses, determine how large a buffer zone, if any, is appropriate between the unit and the area or land use.

Considering the Site Action Items (cont.)

Local Land Use and Zoning Restrictions

- ☐ Contact local planning, zoning, and/or public works agencies to discuss restrictions that may apply to the unit.

- ☐ Comply with any applicable restrictions, or obtain the necessary variances or exceptions.

Environmental Justice Issues

- ☐ Determine whether minority or low-income populations would bear a disproportionate burden of any environmental effects of the unit's waste management activities.

- ☐ Work with the community to devise strategies to minimize any potential disproportionate burdens.

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Part II
Protecting Air Quality

Chapter 5
Protecting Air Quality

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Protecting Air Quality

Airborne particulates and toxic air emissions can cause human health risks and damage the environment. Adopt controls to minimize particulate emissions. If a facility's waste management units are not addressed by requirements under the Clean Air Act, assess risks associated with toxic air emissions using the model in this guidance, and implement pollution prevention, treatment, or controls to reduce risks. For facilities that must obtain a Clean Air Act Title V permit, the permit is a good vehicle to address air emissions from waste management units.

Health effects from airborne pollutants can be minor and reversible (such as eye irritation), debilitating (such as asthma), or chronic and potentially fatal (such as cancer). Potential impacts depend on many factors, including the quantity of air pollution to which people are exposed, the duration of exposures, and the effects associated with specific pollutants. An air risk assessment takes these factors into account to project risks posed at a particular site or facility. Air releases from waste management units include particulates or windblown dust and toxic or hazardous contaminants. Toxic air pollutants are those pollutants known or suspected to cause cancer or other serious health effects such as reproductive effects or birth defects, or to cause adverse environmental effects.[1]

This chapter will help you address the following questions:

- Is a particular facility subject to CAA requirements?
- What is an air risk assessment?
- Do waste management units pose risks from volatile air emissions?
- What controls will reduce particulate and volatile emissions from a facility?

We recommend that every facility implement controls to address emissions of airborne particulates. Particulates have immediate and highly visible impacts on surrounding neighborhoods. They can affect human health and may carry hazardous constituents off site as well. Generally, controls are consistent with good operating practices, and may not be too costly.

For toxic air releases from industrial solid waste management units, there are two sets of questions you need to pursue. First, what regulatory requirements under the Clean air Act (CAA) apply to the facility, and do those requirements address waste management units? The second question for facilities whose waste management units are not addressed by CAA requirements, is "are there risks from toxic air releases that should be controlled?"

[1]From "Taking Toxics Out of the Air: Progress in Setting Maximum Achievable Control Technology: Standards Under the Clean Air Act" U.S. EPA, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711, EPA451-K-98-001, February 1998.

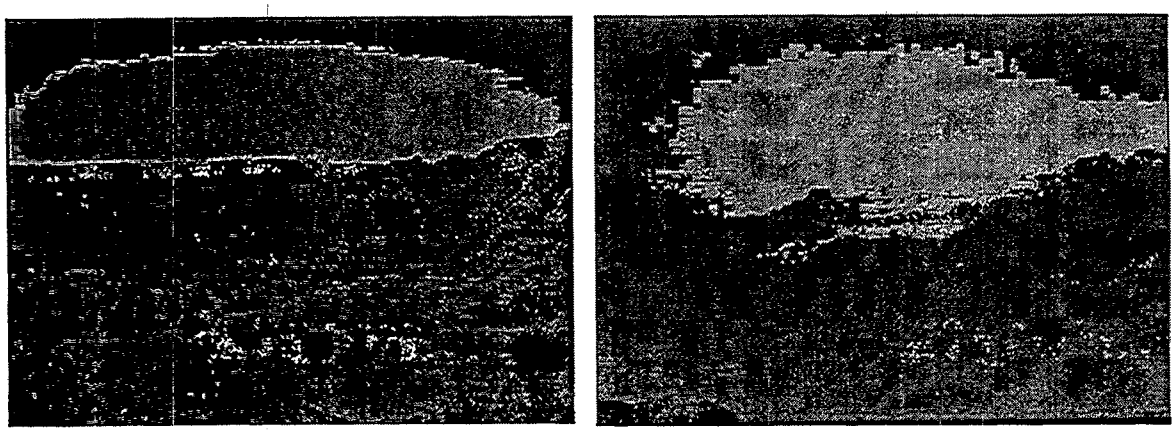
This Guide provides two tools to help you answer these questions. First, this chapter includes an overview of the major emission control requirements under the CAA and a decision guide to evaluate which of these may apply to a facility. Each facility subject to any of these requirements must obtain a CAA Title V operating permit. The decision guide will help you to clarify some of the key facility information you need to identify applicable CAA requirements.

If your answers in the decision guide indicate that the facility is or might be subject to specific regulatory obligations, the next step is to consult with EPA, state, or local air quality program staff. Some CAA regulations are industry-specific and operation-specific within an industry, others are pollutant specific or specific to a geographic area. EPA, state, or local air quality managers can help you precisely determine applicable requirements and whether waste management units are addressed by those requirements.

You may find that waste management units are not addressed or that a specific facility clearly does not fit into any regulatory category under the CAA. It is then prudent to look beyond immediate permit requirements to assess risks associated with volatile organic compounds (VOCs) released from the unit. We recommend a two-tiered approach to this assessment, depending on the complexity and amount of site specific data you have.

Limited site-specific air assessment: The CD ROM version of this Guide contains the Industrial Waste Air Model (IWAIR). If a waste contains any of the 95 constituents included in the model, you can use this risk model to assess whether VOC emissions pose a risk that warrants additional emission controls or that could be addressed more effectively with pollution prevention or waste treatment before placement in the waste management unit.

Comprehensive Risk Assessment: This assessment relies on a comprehensive analysis of waste and site-specific data and use of models designed to assess multi-pathway exposures to airborne contaminants. There are a number of modeling tools available for this analysis. Consult closely with your air quality management agency as you proceed.



Airborne emissions are responsible for the loss of visibility between the left and right photographs of the Grand Canyon. Source: National Park Service, Air Resources Division.

I. Federal Airborne Emission Control Programs

Four major federal programs address airborne emissions that can degrade air quality. For more information about the CAA and EPA's implementation of it, see Appendix I or visit the Technology Transfer Network, EPA's premier technical web site for information transfer and sharing related to air pollution topics, at **<www.epa.gov/ttn>**.

If the facility is subject to any CAA requirements, the owners must obtain a permit under Title V of CAA and/or other state air permitting programs. As part of the permitting process, develop an emissions inventory for the facility. Some states have additional permitting requirements. Whether or not emissions from a waste management unit(s) will be specifically addressed through the permit process depends on a number of factors, including the type of facility and state permitting resources and priorities. It is prudent, however, where there are no applicable air permit requirements to assess whether there may be risks associated with waste management units and to address these risks.

A. National Ambient Air Quality Standards

The CAA authorizes EPA to establish emission limits to achieve National Ambient Air Quality Standards (NAAQS).[2] EPA has designated NAAQS for the following criteria pollutants: ozone, sulfur dioxide, nitrogen dioxide, lead, particulate matter (PM), and carbon monoxide. The NAAQS establish individual pollutant concentration ceilings that should be rarely exceeded in a predetermined geographical area (National Ambient Air Quality District (NAAQD)). NAAQS are not enforced directly by EPA. Instead, each state must submit a State Implementation Plan (SIP) describing how it will achieve or maintain NAAQS. Many SIPs call for airborne emission limits on industrial facilities.

If a waste emits VOCs, which can be precursors to ozone, the waste management unit could be affected by EPA's revised NAAQS for ground-level ozone.[3] EPA will phase out and replace the previous 1-hour averaging time ozone standard with a new 8-hour averaging time standard to protect over longer exposure periods. The previous 1-hour standard of 0.12 parts per million (ppm) will be replaced with a new 8-hour standard of 0.08 ppm. Phasing in the new standard will take place in several ways. States or areas of states that have not been able to comply with current 0.12 ppm 1-hour standard will not be subject to more stringent requirements until they meet the 1-hour standard for three consecutive years. States and areas already achieving the 1-hour standard may be eligible to participate in regional emission control strategies or submit early SIPs to address the new 8-hour standard. Consult with your state to determine whether efforts to comply with the ozone NAAQS involve VOC emission limits that apply to a specific facility.

B. New Source Performance Standards

New Source Performance Standards (NSPSs) may apply to any building, structure, facility, or installation which emits or may emit an air pollutant for which a NAAQS (criteria pollutants) exists. For industry categories, NSPSs establish national technology-based emission limits for criteria air pollutants,[7] such as particulate matter (PM), or for their precursors, such as VOCs. States have primary responsibility for assuring that the NSPSs are followed. These standards are distinct from

[2] 42 U.S.C. § 7409
[3] 62 *FR* 38856 (July 18, 1997)

NAAQS because they establish direct national emission limits for specified sources, while NAAQS establish air quality targets that states meet using a variety of measures that include emission limits. Table 1 lists industries for which NSPSs have been established and locations of the NSPSs in the Code of Federal Regulations. Check to see if any of the 74 New Source Performance Standards (NSPSs)[4] apply to the facility.[5] Any facility subject to a NSPS must obtain a Title V operating permit (see section D below.).

C. National Emission Standards for Hazardous Air Pollutants

Waste streams that are not hazardous waste under RCRA may generate air pollutants that have a hazardous air pollutant (HAP) regulatory status under the CAA. Section 112 of the CAA Amendments of 1990[6] requires EPA to establish national standards to reduce HAP emissions. Section 112(b) contains a list of 188 HAPs (see Table 2) to be regulated by National Emission Standards for Hazardous Air Pollutants (NESHAPs) or Maximum Achievable Control Technology (MACT) standards, that are generally set on an industry-by-industry basis.

MACT standards apply only to major sources. A major source is defined as any stationary source or group of stationary sources that (1) is located within a contiguous area and under common control, and (2) emits or has the potential to emit at least 10 tons per year (tpy) of any single HAP or at least 25 tpy of any combination of HAPs. All fugitive emissions, including emissions from waste management units, are to be taken into account in determining whether a stationary source is a major source. Each MACT standard limits specific operations, processes, and/or wastes that are covered. Some MACT standards specifically cover waste management units, others do not. If a facility is covered by a MACT standard, it must be permitted under Title V (see below).

EPA has identified approximately 170 industrial categories and subcategories that are or will be subject to MACT standards. The CAA calls for EPA to promulgate the standards in four phases. Standards already promulgated in the first two phases are listed in Table 3. The schedule for the last two phases extends through 2000 (see Appendix I).

CAA also requires EPA to assess the risk to public health remaining after the implementation of NESHAPs and MACT standards. EPA must determine if more stringent standards are necessary to protect public health with an ample margin of safety. As a first step in this process the CAA requires EPA to submit a Report to Congress on its methods for making the health risks from residual emissions determination. A draft of this report was submitted to Congress on April 14, 1998, and the final version is due February 1, 1999. If significant residual risk exists after application of a MACT, EPA must promulgate health-based standards for that source category to further reduce HAP emissions. EPA must set residual risk standards within 9 years after promulgation of each NESHAP in the first phase group and within 8 years for all other phases of source categories.

D. Title V Operating Permits

For many facilities, the new federal operating permit program established under Title V of the CAA will cover all sources of airborne emissions. It requires a permit for any facility

[4]40 CFR Part 60

[5]While NSPSs apply to new facilities, EPA also established emissions guidelines for existing facilities.

[6]42 U.S.C. § 7412.

Table 1
Industries for Which NSPSs Have Been Established

For electronic versions of the 40 CFR Part 60 subparts referenced below, visit **<earth1.epa.gov/epacfr40/chapt-I.info/subch-C/40P0060/>**. Be sure to check the *Federal Register* for updates that may have been published after this guidance.

Facility	40 CFR Part 60 Subpart
Ammonium Sulfate Manufacture	PP
Asphalt Processing & Asphalt Roofing Manufacture	UU
Auto/Id Truck Surface Coating Operations	MM
Basic Oxygen Process Furnaces after 6/11/73	N
Beverage Can Surface Coating Industry	WW
Bulk Gasoline Terminals	XX
Calciners and Dryers in Mineral Industry	UUU
Coal Preparation Plants	Y
Electric Utility Steam Generating Units after 9/18/78	DA
Equipment Leaks of VOC in Petroleum Refineries	GGG
Equipment Leaks of VOC in SOCMI	VV
Ferroalloy Production Facilities	Z
Flexible Vinyl & Urethane Coating & Printing	FFF
Fossil-fuel Fired Steam Generators after 8/17/71	D
Glass Manufacturing Plants	CC
Grain Elevators	DD
Graphic Arts: Publication Rotogravure Printing	QQ
Hot Mix Asphalt Facilities	I
Incinerators	E
Industrial Surface Coating, Plastic Parts	TTT
Industrial Surface Coating-Large Appliances	SS
Industrial-Commercial-Institutional Steam Gen. Unit	DB
Kraft Pulp Mills	BB
Large Municipal Waste Combustors after 9/20/94	EB
Lead-Acid Battery Manufacturing Plants	KK
Lime Manufacturing	HH
Magnetic Tape Coating Facilities	SSS
Medical Waste Incinerators (MWI) after 6/20/96	EC
Metal Coil Surface Coating	TT
Metallic Mineral Processing Plants	LL
Municipal Solid Waste Landfills after 5/30/91	WWW
Municipal Waste Combustors (MWC)	EA
New Residential Wood Heaters	AAA
Nitric Acid Plants	G
Nonmetallic Mineral Processing Plants	OOO
Onshore Natural Gas Processing Plants, VOC Leaks	KKK
Onshore Natural Gas Processing: SO_2 Emissions	LLL
Petroleum Dry Cleaners, Rated Capacity ≥ 84 Lb	JJJ
Petroleum Refineries	J
Petroleum Refinery Wastewater Systems	QQQ
Phosphate Fertilizer-Wet Process Phosphoric Acid	T
Phosphate Fertilizer-Superphosphoric Acid	U
Phosphate Fertilizer-Diammonium Phosphate	V
Phosphate Fertilizer-Triple Superphosphate	W
Phosphate Fertilizers: GTSP Storage Facilities	X
Phosphate Rock Plants	NN
Polymer Manufacturing Industry	DDD
Polymeric Coating of Supporting Substrates Fac.	VVV
Portland Cement Plants	F
Pressure Sensitive Tape & Label Surface Coating	RR
Primary Aluminum Reduction Plants	S
Primary Copper Smelters	P
Primary Lead Smelters	R
Primary Zinc Smelters	Q
Rubber Tire Manufacturing Industry	BBB
Secondary Brass and Bronze Production Plants	M
Secondary Lead Smelters	L
Sewage Treatment Plants	O
Small Indust./Comm./Institut. Steam Generating Units	DC
SOCMI - Air Oxidation Processes	III
SOCMI - Distillation Operations	NNN
SOCMI Reactors	RRR
SOCMI Wastewater	YYY
Stationary Gas Turbines	GG
Steel Plants: Elec. Arc Furnaces after 08/17/83	AAA
Steel Plants: Electric Arc Furnaces	AA
Storage Vessels for Petroleum Liquids	K
Storage Vessels for Petroleum Liquids	KA
Sulfuric Acid Plants	H
Surface Coating of Metal Furniture	EE
Synthetic Fiber Production Facilities	HHH
Volatile Storage Vessel (Incl. Petroleum) after 7/23/84	KB
Wool Fiberglass Insulation Manufacturing Plants	PPP

Table 2
HAPs Defined in Section 112 of the CAA Amendments of 1990

CAS#	CHEMICAL NAME
75070	Acetaldehyde
60355	Acetamide
75058	Acetonitrile
98862	Acetophenone
53963	2-Acetylaminofluorene
107028	Acrolein
79061	Acrylamide
79107	Acrylic acid
107131	Acrylonitrile
107051	Allyl chloride
92671	4-Aminobiphenyl
62533	Aniline
90040	o-Anisidine
1332214	Asbestos
71432	Benzene (including benzene from gasoline)
92875	Benzidine
98077	Benzotrichloride
100447	Benzyl chloride
92524	Biphenyl
117817	Bis(2-ethylhexyl) phthalate (DEHP)
542881	Bis(chloromethyl)ether
75252	Bromoform
106990	1,3-Butadiene
156627	Calcium cyanamide
133062	Captan
63252	Carbaryl
75150	Carbon disulfide
56235	Carbon tetrachloride
463581	Carbonyl sulfide
120809	Catechol
133904	Chloramben
57749	Chlordane
7782505	Chlorine
79118	Chloroacetic acid
532274	2-Chloroacetophenone
108907	Chlorobenzene
510156	Chlorobenzilate
67663	Chloroform
107302	Chloromethyl methyl ether
126998	Chloroprene
1319773	Cresols/Cresylic acid (isomers and mixture)
95487	o-Cresol
108394	m-Cresol
106445	p-Cresol
98828	Cumene
94757	2,4-D, salts and esters
3547044	DDE
334883	Diazomethane
132649	Dibenzofurans
96128	1,2-Dibromo-3-chloropropane
84742	Dibutylphthalate
106467	1,4-Dichlorobenzene(p)
91941	3,3-Dichlorobenzidene
111444	Dichloroethyl ether (Bis(2-chloroethyl)ether)
542756	1,3-Dichloropropene
62737	Dichlorvos
111422	Diethanolamine
121697	N,N-Diethyl aniline (N,N-Dimethylaniline)
64675	Diethyl sulfate
119904	3,3-Dimethoxybenzidine
60117	Dimethyl aminoazobenzene
119937	3,3'-Dimethyl benzidine
79447	Dimethyl carbamoyl chloride
68122	Dimethyl formamide
57147	1,1-Dimethyl hydrazine
131113	Dimethyl phthalate
77781	Dimethyl sulfate
534521	4,6-Dinitro-o-cresol, and salts
51285	2,4-Dinitrophenol
121142	2,4-Dinitrotoluene
123911	1,4-Dioxane (1,4-Diethyleneoxide)
122667	1,2-Diphenylhydrazine
106898	Epichlorohydrin (l-Chloro-2,3-epoxypropane)
106887	1,2-Epoxybutane
140885	Ethyl acrylate
100414	Ethyl benzene
51796	Ethyl carbamate (Urethane)
75003	Ethyl chloride (Chloroethane)
106934	Ethylene dibromide (Dibromoethane)
107062	Ethylene dichloride (1,2-Dichloroethane)
107211	Ethylene glycol
151564	Ethylene imine (Aziridine)
75218	Ethylene oxide
96457	Ethylene thiourea
75343	Ethylidene dichloride (1,1-Dichloroethane)
50000	Formaldehyde
76448	Heptachlor
118741	Hexachlorobenzene
87683	Hexachlorobutadiene
77474	Hexachlorocyclopentadiene
67721	Hexachloroethane
822060	Hexamethylene-1,6-diisocyanate
680319	Hexamethylphosphoramide
110543	Hexane
302012	Hydrazine
7647010	Hydrochloric acid
7664393	Hydrogen fluoride (Hydrofluoric acid)
123319	Hydroquinone
78591	Isophorone
58899	Lindane (all isomers)
108316	Maleic anhydride
67561	Methanol
72435	Methoxychlor
74839	Methyl bromide (Bromomethane)
74873	Methyl chloride (Chloromethane)
71556	Methyl chloroform (1,1,1-Trichloroethane)
78933	Methyl ethyl ketone (2-Butanone)
60344	Methyl hydrazine
74884	Methyl iodide (Iodomethane)
108101	Methyl isobutyl ketone (Hexone)
624839	Methyl isocyanate
80626	Methyl methacrylate
1634044	Methyl tert butyl ether
101144	4,4-Methylene bis(2-chloroaniline)
75092	Methylene chloride (Dichloromethane)
101688	Methylene diphenyl diisocyanate (MDI)
101779	4,4'-Methylenedianiline
91203	Naphthalene
98953	Nitrobenzene
92933	4-Nitrobiphenyl
100027	4-Nitrophenol
79469	2-Nitropropane
684935	N-Nitroso-N-methylurea
62759	N-Nitrosodimethylamine
59892	N-Nitrosomorpholine
56382	Parathion
82688	Pentachloronitrobenzene (Quintobenzene)
87865	Pentachlorophenol

Table 2 (continued)
HAPs Defined in Section 112 of the CAA Amendments of 1990

CAS#	CHEMICAL NAME	CAS#	CHEMICAL NAME	CAS#	CHEMICAL NAME
108952	Phenol	79345	1,1,2,2-Tetrachloroethane	1330207	Xylenes (isomers and mixture)
106503	p-Phenylenediamine	127184	Tetrachloroethylene (Perchloroethylene)	95476	o-Xylenes
75445	Phosgene	7550450	Titanium tetrachloride	108383	m-Xylenes
7803512	Phosphine	108883	Toluene	106423	p-Xylenes
7723140	Phosphorus	95807	2,4-Toluene diamine	[none]	Antimony Compounds
85449	Phthalic anhydride	584849	2,4-Toluene diisocyanate	[none]	Arsenic Compounds (inorganic including arsine)
1336363	Polychlorinated biphenyls (Aroclors)	95534	o-Toluidine	[none]	Beryllium Compounds
1120714	1,3-Propane sultone	8001352	Toxaphene (chlorinated camphene)	[none]	Cadmium Compounds
57578	beta-Propiolactone	20821	1,2,4-Trichlorobenzene	[none]	Chromium Compounds
123386	Propionaldehyde	79005	1,1,2-Trichloroethane	[none]	Cobalt Compounds
114261	Propoxur (Baygon)	79016	Trichloroethylene	[none]	Coke Oven Emissions
78875	Propylene dichloride (1,2-Dichloropropane)	95954	2,4,5-Trichlorophenol	[none]	Cyanide Compounds[a]
75569	Propylene oxide	88062	2,4,6-Trichlorophenol	[none]	Glycol ethers[b]
75558	1,2-Propylenimine (2-Methyl aziridine)	121448	Triethylamine	[none]	Lead Compounds
91225	Quinoline	582098	Trifluralin	[none]	Manganese Compounds
106514	Quinone	540841	2,2,4-Trimethylpentane	[none]	Mercury Compounds
100425	Styrene	108054	Vinyl acetate	[none]	Fine mineral fibers[c]
96093	Styrene oxide	593602	Vinyl bromide	[none]	Nickel Compounds
1746016	2,3,7,8-Tetrachlorodibenzo-p-dioxin	75014	Vinyl chloride	[none]	Polycylic Organic Matter[d]
		75354	Vinylidene chloride (1,1-Dichloroethylene)	[none]	Radionuclides (incl. radon)[e]
				[none]	Selenium Compounds

NOTE: For all listings above which contain the word "compounds" and for glycol ethers, the following applies: Unless otherwise specified, these listings are defined as including any unique chemical substance that contains the named chemical (i.e., antimony, arsenic, etc.) as part of that chemical's infrastructure.

[a]X'CN where X = H' or any other group where a formal dissociation may occur. For example KCN or Ca(CN)2.

[b]Includes mono- and di-ethers of ethylene glycol, diethylene glycol, and triethylene glycol R-(OCH2CH2)n-OR' where n = 1, 2, or 3, R = alkyl or aryl groups, and R' = R, H, or groups which, when removed, yield glycol ethers with the structure: R-(OCH2CH)n-OH. Polymers are excluded from the glycol category.

[c]Includes mineral fiber emissions from facilities manufacturing or processing glass, rock, or slag fibers (or other mineral derived fibers) of average diameter 1 micrometer or less.

[d]Includes organic compounds with more than one benzene ring, and which have a boiling point greater than or equal to 100 °C.

[e]A type of atom which spontaneously undergoes radioactive decay.

emitting or having the potential to emit more than 100 tpy of any air pollutants.[7] Permits are also required for all sources subject to MACT or NSPS standards. All airborne emission requirements that apply to an industrial facility, including emission limitations as well as operational, monitoring, and reporting requirements, will be incorporated in its operating permit. A Title V permit provides a single tool to address all emissions from facilities subject to CAA requirements.

Under the new program, operating permits that meet federal requirements will generally be issued by state agencies. In developing individual permits, states can determine whether to explicitly apply emission limitations and controls to waste management units. See section F (A Decision Guide to Applicable CAA Requirements), and consult with federal, state, and local air program staff to determine if your waste management unit is subject to airborne emission limits and

[7]Under CAA Section 302(g), "air pollutant" is defined as any pollutant agent or combination of agents, including any physical, chemical, biological, or radioactive substance or matter which is emitted into or otherwise enters the ambient air.

Table 3
Source Categories With MACT Standards*

Source Category	Federal Register Page
Non-Ferrous Metals Processing	
Secondary Lead Smelting	60 FR 32587 (6/23/95)
Primary Aluminum Reduction	62 FR 52383 (10/7/97)
Primary Copper Smelting	63 FR 19582 (4/20/98)(P)
Primary Lead Smelting	63 FR 19200 (4/17/98)(P)
Ferrous Metals Processing	
Coke Ovens	58 FR 57898 (10/27/93)
Steel Pickling HCI Process	62 FR 49051 (9/18/97)(P)
Mineral Products Processing	
Mineral Wool Production	62 FR 25369 (5/8/97) (P)
Portland Cement Manufacturing	63 FR 14181 (3/24/98)(P)
Wool Fiberglass Manufacturing	62 FR 15227 (3/21/97) (P)
Petroleum and Natural Gas Production and Refining	
Oil & Natural Gas Production	63 FR 06288 (2/6/98)(P)
Natural Gas Transmission and Storage	63 FR 06288 (2/6/98)(P)
Petroleum Refineries	60 FR 43244 (8/18/95)
Liquids Distribution	
Gasoline Distribution	59 FR 64303 (12/14/95)
Marine Vessel Loading	60 FR 48399 (9/19/95)
Surface Coating Processes	
Aerospace Industries	60 FR 45948 (9/1/95)
Magnetic Tapes	59 FR 64580 (12/15/94)
Printing/Publishing	61 FR 27132 (5/30/96)
Shipbuilding and Repair	60 FR 64330 (12/15/95)
Wood Furniture	60 FR 62930 (12/7/95)
Waste Treatment and Disposal	
Off-Site Waste and Recovery Operations	61 FR 34141 (7/1/96)
Agricultural Chemicals Production	
Agricultural Chemicals Production	62 FR 60565 (11/10/97) (P)
Pharmaceutical Production Processes	
Pharmaceutical Production	62 FR 15753 (4/2/97) (P)
Polymers and Resins Production	
Acrylonitrile-Butadiene-Styrene	61 FR 48207 (9/12/96)
Butyl Rubber	61 FR 46905 (9/5/96)
Epichlorohydrin Elastomers	61 FR 46905 (9/5/96)
Epoxy Resins Production	60 FR 12670 (3/8/95)
Ethylene-Propylene Rubber	61 FR 46905 (9/5/96)
Flexible Polyurethane Foam	61 FR 68405 (12/27/96) (P)
Hypalon™	61 FR 46905 (9/5/96)
Methyl Methacrylate-Acrylonitrile-Butadiene-Styrene	61 FR 48207 (9/12/96)
Methyl Methacrylate-Butadiene-Styrene Terpolymers	61 FR 48207 (9/12/96)
Neoprene	61 FR 46905 (9/5/96)
Nitrile Butadiene Rubber	61 FR 46905 (9/5/96)
Nitrile Resins Production	61 FR 48207 (9/12/96)
Non-Nylon Polyamides	60 FR 12670 (3/8/95)
Polybutadiene Rubber	61 FR 46905 (9/5/96)
Polyether Polyols	62 FR 46803 (9/4/97) (P)
Polyethylene Terephthalate	61 FR 48207 (9/12/96)
Polystyrene	61 FR 48207 (9/12/96)
Polysulfide Rubber	61 FR 46905 (9/5/96)
Styrene-Acrylonitrile	61 FR 48207 (9/12/96)
Styrene-Butadiene Rubber, Latex	61 FR 46905 (9/5/96)
Production of Inorganic Chemicals	
Phosphate Fertilizers Production	61 FR 68429 (12/27/96) (P)
Phosphoric Acid Manufacturing	61 FR 68429 (12/27/96) (P)
Production of Organic Chemicals	
Synthetic Organic Chemicals Manufacturing	59 FR 19402 (4/22/94), 62 FR 2721 (1/17/97)
Miscellaneous Processes	
Chromic Acid Anodizing	60 FR 4947 (1/25/95)
Commercial Dry Cleaning (Perchloroethylene)	58 FR 49353 (9/22/93)
Commercial Sterilization Facilities	59 FR 62585 (12/6/94)
Decorative Chromium Electroplating	60 FR 4948 (1/25/95)
Halogenated Solvent Cleaners	59 FR 61801 (12/2/94)
Hard Chromium Electroplating	60 FR 4948 (1/25/95)
Industrial Cleaning (Perchloroethylene)	58 FR 49353 (9/22/93)
Industrial Dry Cleaning (Perchloroethylene)	58 FR 49353 (9/22/93)
Industrial Process Cooling Towers	59 FR 46339 (9/8/94)
Pulp and Paper Production	63 FR 18503 (4/15/98)
Tetrahydrobenzaldehyde Production	62 FR 44614 (8/22/97) (P)

* This table contains final rules and proposed rules (P) promulgated as of May 1998. It does not identify corrections or clarifications to rules.

controls under CAA regulations. (See Appendix II for a listing of EPA regional and state air pollution control agency contacts.)

E. Federal Airborne Emission Regulations for Solid Waste Management Activities

While EPA has not established airborne emission regulations for nonhazardous industrial waste management units under RCRA, standards developed for hazardous waste management units and municipal solid waste landfills (MSWLFs) may serve as a guide in evaluating the need for controls at specific units.

1. Hazardous Waste Management Unit Airborne Emission Regulations

Under Section 3004(n) of RCRA, EPA established standards for monitoring and control of airborne emissions from hazardous waste treatment, storage, and disposal facilities. Subparts AA, BB, and CC of 40 CFR Part 265 address VOC releases from process vents, equipment leaks, tanks, surface impoundments, and containers. (See Appendix III for a more detailed discussion of Subparts AA, BB, and CC.) Subpart CC establishes requirements for hazardous waste surface impoundments containing waste with volatile organic content greater than 500 ppm by weight. It exempts units managing wastes that have been treated to reduce concentrations of organics. For non-exempt surface impoundments, Subpart CC requires the use of covers and closed vent systems that reduce VOC emissions by 95 percent. Closed vent systems include vapor recovery units, flares, and other combustion units.

2. Municipal Solid Waste Landfill Airborne Emission Regulations

On March 12, 1996, EPA promulgated airborne emission regulations for new and existing MSWLFs.[8] These regulations apply to all new MSWLFs constructed on or after May 30, 1991 and to existing landfills with total design capacities of 2.5 million megagrams per year (Mg/yr) (approximately 2.75 million tpy) that have accepted waste on or after November 8, 1987. In addition to methane, MSWLFs potentially emit criteria pollutants and HAPs in the gases generated during waste decomposition, as well as in combustion of the gases in control devices, and from other sources, such as dust from vehicle traffic and emissions from leachate treatment facilities or maintenance shops. Under the regulations, any affected MSWLF that emits more than 50 Mg/yr (55 tpy) of nonmethane organic compounds (NMOC) is required to install controls.

Best demonstrated technology requirements for both new and existing municipal landfills prescribe installation of a well-designed and well-operated gas collection system and a control device. The collection system should be designed to allow expansion for new cells that require controls. The control device (presumed to be a combustor) must demonstrate either an NMOC reduction of 98 percent by weight in the collected gas or an outlet NMOC concentration of no more than 20 parts per million by volume (ppmv).

3. Off-Site Waste and Recovery Operations NESHAP

On July 1, 1996, EPA established standards for off-site waste and recovery operations (OSWRO) that emit HAPs.[9] To be covered by OSWRO, a facility must emit or have the potential to emit at least 10 tpy of any single HAP or at least 25 tpy or any combination of HAPs. It must receive waste, used oil, or used

[8] 61 FR 9905

[9] 61 FR 34139

solvents from off-site that contain one or more HAPs.[10] In addition, the facility must operate one of the following: a hazardous waste treatment, storage, or disposal facility; RCRA-exempt hazardous wastewater treatment operation, nonhazardous wastewater treatment facility other than a publicly owned treatment facility; RCRA-exempt hazardous waste recycling or reprocessing operation, used solvent recovery operation, or used oil recovery operation.

OSWRO contains MACT standards to reduce HAP emissions from tanks, surface impoundments, containers, oil-water separators, individual drain systems, other material conveyance systems, process vents, and equipment leaks. For example, OSWRO establishes two levels of air emission controls for tanks depending on tank design capacity and the maximum organic HAP vapor pressure of the off-site material in the tank. For process vents, control devices must achieve a minimum of 95 percent organic HAP emission control. To control HAP emissions from equipment leaks, the facility must implement leak detection and repair work practices and equipment modifications for those equipment components containing or contacting off-site waste having a total organic HAP concentration greater than 5 percent by weight.

F. A Decision Guide to Applicable CAA Requirements

The following series of questions is designed to help you identify CAA requirements that may apply to a facility. This will not give you definitive answers, but can provide a useful starting point for consultation with federal, state, or local permitting authorities to determine which requirements apply to a specific facility and whether such requirements address waste management units at the facility. If a facility is clearly not subject to CAA requirements, we recommend that you assess potential risks from VOC emissions at a waste management unit using the IWAIR or a site-specific risk assessment.

The following steps provide a walk through of this evaluation process:

1. Determine emission from the unit:

a) Determine VOC's present in the waste (waste characterization). Then assume all the VOC's are emitted from the unit; or

b) Estimate emissions using an emissions model. This also requires waste characterization. The CHEMDAT8 model is a logical model for these types of waste units. You can use the EPA version on the Internet or the one contained in the modeling tool for this guidance; or

c) Measure emissions from the unit. This is the most resource intensive alternative.

2. Is the waste management unit part of an industrial facility which is subject to a CAA Title V operating permit?

A facility is subject to a Title V operating permit if it is considered a major source of air pollutants, or is subject to a NSPS, NESHAP, or Title IV acid rain provision.[11] As part of the permitting process, the facility should develop an emissions inventory. Some states have additional permitting requirements. If a facility is subject to a Title V operating permit, all airborne emission requirements that apply to an industrial facility, including emission limitations as well as operational, monitoring, and reporting requirements, will be incorporated in its operating permit. Consult with appropriate federal, state, and local air program staff to determine whether your waste management unit is subject to air emission limits and controls.[12]

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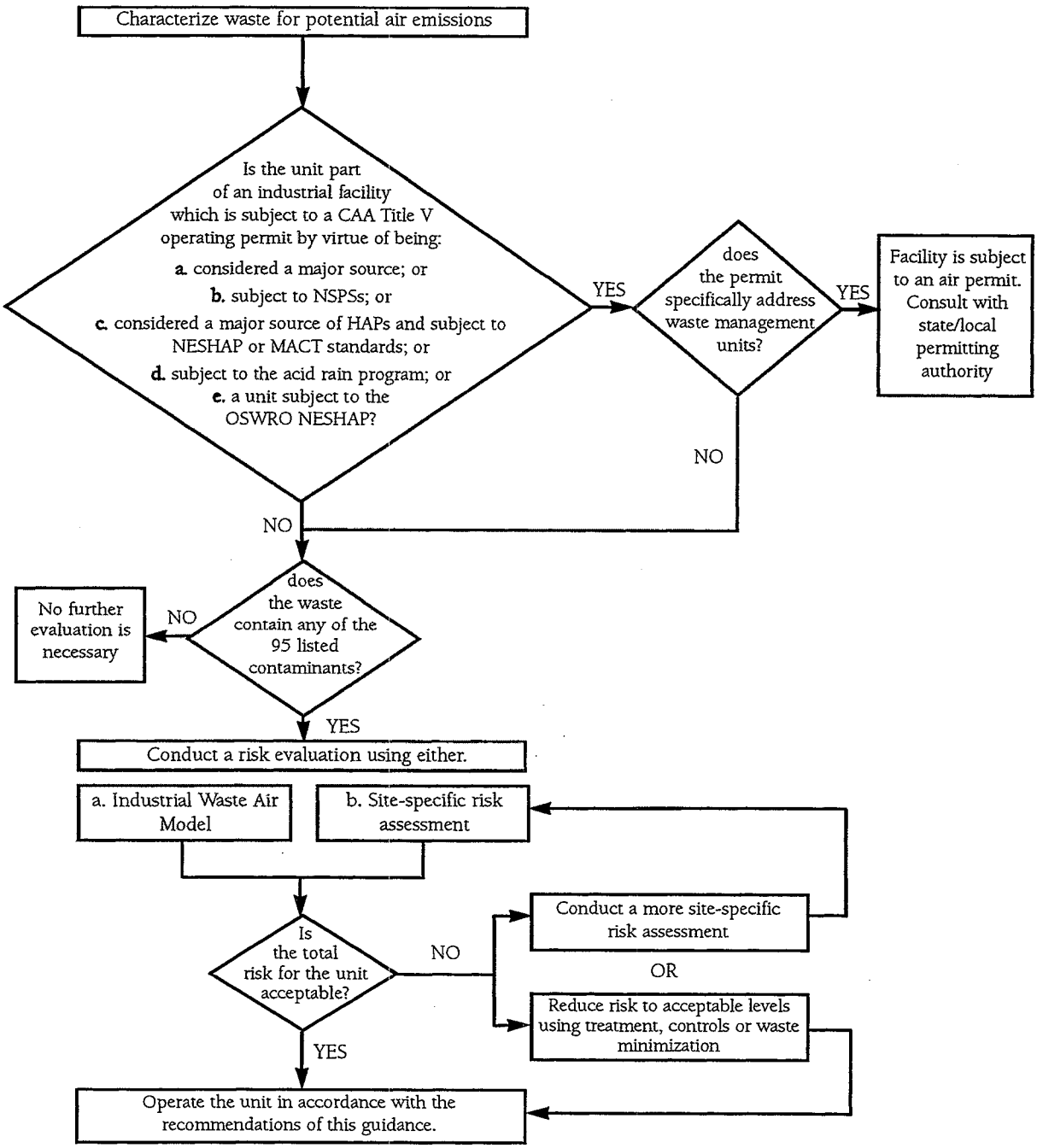
[10]OSWRO identified aproximately 10 HAPs to be covered, This HAP list is a subject of the CAA Section 112 list

[11]EPA can designate additional source categories subject to Title V operating permit requirements.

[12]Implementation of air emission controls may generate new residual waste. Ensure that these wastes are managed appropriately, in compliance with state requirements and consistent with this guidance.

Figure 1. Evaluating VOC Emission Risk



If you answer yes to any of the questions in items a. through e. below, the facility is subject to a Title V operating permit. Consult with the appropriate federal, state, and/or local permitting authority.

Whether or not emissions from waste management unit(s) will be specifically addressed through the permit process depends on a number of factors, including the type of facility and CAA requirements and state permitting resources and priorities. It is prudent, however, to look where there are not applicable air permit requirements, to assess whether there may be risks associated with waste management units and to address these potential risks.

If you answer no to all the questions below, continue to Step 3.

a. Is the facility considered a major source?

If the facility meets any of the following three definitions, it is considered a major source (under 40 CFR § 70.2) and subject to Title V operating permit requirements.

1. Any **stationary source** or group of stationary sources that emits or has the potential to emit at least 100 tpy of any **air pollutant**.

2. Any stationary source or group of stationary sources that emits or has the potential to emit at least 10 tpy of any single HAP or at least 25 tpy of any combination of HAPs.

Stationary source is defined as any buidling, structure, facility, or installation which emits or may emit any air pollutant that is located within a contiguous area and under common control.

An **air pollutant** is defined as any air pollutant agent or combination of agents, including a physical, chemical, biological, radioactive substance or matter which is emitted into or otherwise enters the ambient air

3. A stationary source or group of stationary sources subject to the nonattainment area provisions of CAA Title I that emits, or has the potential to emit, above the threshold values for its nonattainment area category. The nonattainment area category and the source's emission levels for VOCs and NO_x, particulate matter (PM-10), and carbon monoxide (CO) determine whether the stationary source meets the definition of a "major source." For nonattainment areas, stationary sources are considered "major sources" if they emit or have the potential to emit at least the levels found in Table 4.

If yes, the facility is subject to a Title V

Table 4.
Major Source Determination in Nonattainment Areas

Nonattainment Area Category[13]	VOCs or NOx	PM-10	CO
Marginal or Moderate	100 tpy	100 tpy	100 tpy
Serious	50 tpy	70 tpy	50 tpy
Severe	25 tpy	—	—
Extreme	10 tpy	—	—

[13]The nonattainment categories are based upon the severity of the area's pollution problems. The five categories for VOCs and NOx range from Moderate to Extreme. Moderate areas are the closest to meeting the attainment standard, and require the least amount of action. Nonattainment areas with more serious air quality problems must implement various control measures. The worse the air quality, the more controls areas will have to implement. PM-10 and CO have only two categories, Moderate and Serious.

operating permit. Consult with the appropriate federal, state, and/or local permitting authority.

If no, continue to determine whether the facility is subject to a Title V operating permit.

b. Is the facility subject to NSPSs?

Any stationary source subject to a standard of performance under 40 CFR Part 60 is subject to NSPS. (A list of NSPSs can be found in Table 1.)

If yes, the facility is subject to a Title V operating permit. Consult with the appropriate federal, state, and/or local permitting authority.

If no, continue to determine if the facility is subject to a Title V operating permit.

c. Is the facility a major source of HAPs as defined by Section 112 of CAA and subject to a NESHAP or MACT standard?

Under Title V of CAA, an operating permit is required for all facilities subject to a MACT standard. NESHAPs or MACT standards are national standards to reduce HAP emissions. Each MACT standard specifies particular operations, processes, and/or wastes that are covered. EPA has identified approximately 170 source categories and subcategories that are or will be subject to MACT standards. (Table 3 above lists the source categories for which EPA has promulgated MACT standards during the first two phases of MACT standard promulgation.) To be subject to a MACT standard, you must be a **major source** or an **area source** (see sidebar for definitions).

If yes, the facility should be permitted under CAA Title V. Consult with the appropriate federal, state, and/or local permitting authority.

If no, continue to determine if the facility is subject to a Title V operating permit.

A **major source** is defined as any stationary source or group of stationary sources that emits or has the potential to emit at least 10 tpy of any single hazardous air pollutant (HAP) or at least 25 tpy of any combination of **HAPs**.

An **area source** is any stationary source which is not a major source but which may be subject to controls. Area sources represent a collection of facilities and emission points for a specific geographic area. Most area sources are small, but the collective volume of large numbers of facilities can be a concern in densely developed areas, such as urban neighborhoods and industrial areas. Examples of areas sources subject to MACT standards include chromic acid anodizing, commercial sterilization facilities, decorative chromium electroplating, hard chromium electroplating, secondary lead smelting, and halogenated solvent cleaners.

HAPs are any of the 188 pollutants listed in Section 112(b) of CAA. (Table 2 above identifies the 188 HAPs.)

d. Is the facility subject to the acid rain program under Title IV of CAA?

If the facility, such as a fossil-fuel fired power plant, is subject to emission reduction requirements or limitations under the acid rain program, it is subject to a Title V operating

permit (40 CFR § 72.6). The acid rain program focuses on the reduction of annual sulfur dioxide and nitrogen oxides emissions.

If yes, the facility is subject to CAA Title V permitting. Consult with the appropriate federal, state, and/or local permitting authority.

When you consult with the appropriate permitting authority, be sure to clarify whether waste management units at the facility are addressed by the requirements. If waste management units will not be addressed through the permit process, we recommend that you evaluate VOC emission risks.

If no, continue to determine if the facility is subject to a Title V operating permit.

e. Is the waste management unit subject to the OSWRO NESHAP?

This is just an example of the types of questions you will need to answer to determine whether a NESHAP or MACT standard covers your facility.

To be covered by the OSWRO standards, your facility must meet all these conditions:

1. Be identified as a **major source** of HAP emissions

2. Receive **waste, used oil,** or **used solvents** from off site that contain one or more HAPs.[14]

3. Operate one of the following six types of waste management or recovery operations (see 40 CFR § 63.680):

- Hazardous waste treatment, storage, or disposal facility;
- RCRA-exempt hazardous wastewater treatment operation;
- Nonhazardous wastewater treatment facility other than a publicly owned treatment facility;
- RCRA-exempt hazardous waste recycling or reprocessing operation;
- Used solvent recovery operations; or
- Used oil recovery operations.

If yes, the unit should be covered by the OSWRO standards and Title V permitting. Consult with the appropriate federal, state, and/or local permitting authority.

If no, continue to Step 3. The next series of questions will help you consider options for conducting an air risk evaluation.

3. Conduct a risk evaluation using one of the following options:

a. Use IWAIR included in this guidance if your unit contains any of the 95 contaminants that are covered in the model.

b. Initiate a site-specific risk assessment for individual units. (For surface impoundments, a methodology is set forth in *Preferred and Alternative Methods for Estimating Air Emissions from Wastewater Collection and Treatment,* Volume II: Chapter 5, Emission Inventory Improvement Program, March 1997.) Total all target constituents from all applicable units and consider emissions from other sources at the facility as well.

II. Assessing Risk

The air in our atmosphere is ubiquitous and essential for biotic life. Additionally, it acts as a medium for the transport of airborne contamination and, therefore, constitutes an exposure pathway of potential concern. Models that can predict the fate and transport of chemical emissions in the atmosphere can provide an important tool for evaluating and

[14]OSWRO identified approximately 100 HAPs to be covered. This HAP list is a subset of the CAA Section 112 list.

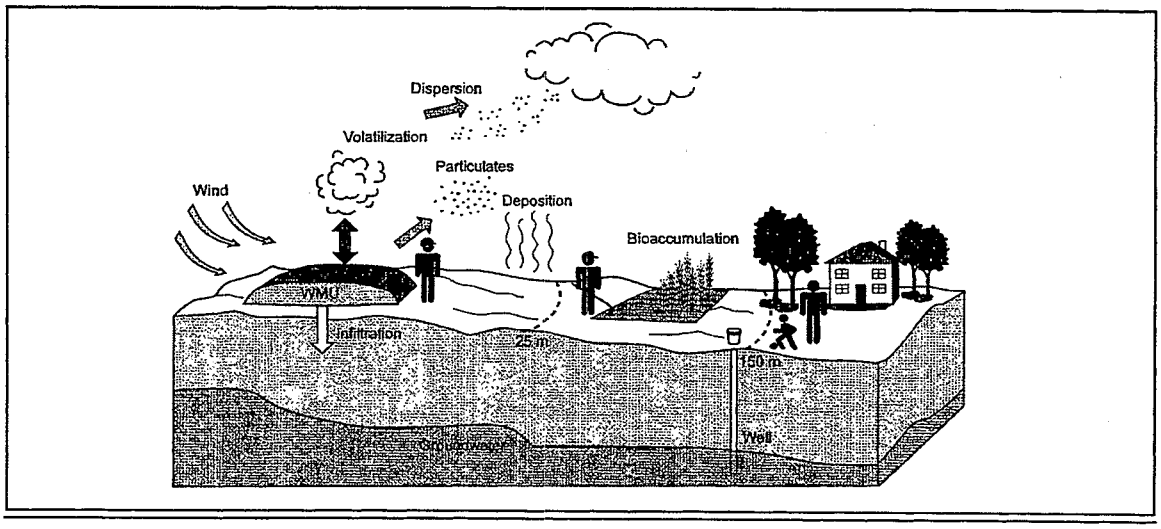
protecting air quality. Included in this guidance is the Industrial Waste Air Model (IWAIR). This model was developed to assist facility managers, regulatory agency staff, and the public in evaluating inhalation risks from waste management unit emissions. Although IWAIR is simple to use, it is still essential to understand the basic concepts of atmospheric modeling to be able to interpret the results and understand the nature of any uncertainties. The purpose of this section is to provide general information on the atmosphere, chemical transport in the atmosphere, and evaluation of risks associated with inhalation of chemicals so you can understand important factors to consider when performing a risk assessment for the air pathway.

From a risk perspective, it is unquestionable that humans are continuously exposed to air and the presence of chemicals in air is important to consider in any type of assessment. If pollutants build up to high concentrations in a localized area, human health may be compromised. The concentration of chemicals in a localized area and the resulting air pollution that may occur in the atmosphere is dependent upon the quantity and the rate of the emissions stream from a source and the ability of the air to disperse the chemicals. Both meteorological and geographic conditions in a local area will influence the emission rate and subsequent dispersion of a constituent. For example, the meteorologic stability of the atmosphere, a factor dependent on air temperature, influences whether the emission stream will rise and mix with a larger volume of air (resulting in the dilution of pollutants) or if the emissions stream will remain close to the ground. Figure 2 is a conceptual diagram of a waste site showing potential paths of human exposure through air.

A. Assessing Risks Associated with Inhalation of Ambient Air

In any type of risk assessment, there are basic steps that are necessary for gathering and evaluating data. These steps include: identification of chemicals of concern, source characterization, exposure assessment, and risk characterization. Each of these steps is described below as it applies specifically to risk resulting

Figure 2. Conceptual Site Diagram



from the inhalation of organic chemicals emitted from WMUs to the ambient air. This overview is presented to assist you in understanding conceptually the information discussed in the IWAIR section (Section II), since many of these steps will be automatically performed for you by the model.

Identification of Chemicals of Concern

A preliminary step in any risk assessment is the identification of chemicals of concern. These are the chemicals present that are anticipated to have potential health effects as a result of their concentrations and/or toxicity factors. An assessment is performed for a given source, to evaluate chemical concentrations and toxicity of different chemicals. Based on these factors along with potential mechanisms of transport and exposure pathways, the decision is made to include or exclude chemicals in the risk assessment. Toxicity benchmarks are identified in this step as well.

Source Characterization

In this step, the critical aspects of the source (e.g., type of WMU, size, chemical concentrations, location) are described. When modeling an area source, such as those included in this guidance, the amount of a given chemical that volatilizes and disperses from a source is critically dependent on the total surface area exposed. The source characterization should include information on the surface area and elevation of the unit. The volatilization is also dependent on other specific attributes related to the waste management practices. Waste management practices of importance include application frequency in land application units and the degree of aeration that occurs in a surface impoundment. The overall content of the waste being deposited in the WMU is also important in projecting volatilization since the nonvolatile component can, depending on its chemical characteristics, bind volatiles and prevent their emission to the ambient air. Source characterization involves defining each of these key parameters for the WMU being modeled. The accuracy of projections concerning volatilization of chemicals from WMUs into ambient air is improved if more site-specific information is used in characterizing the source.

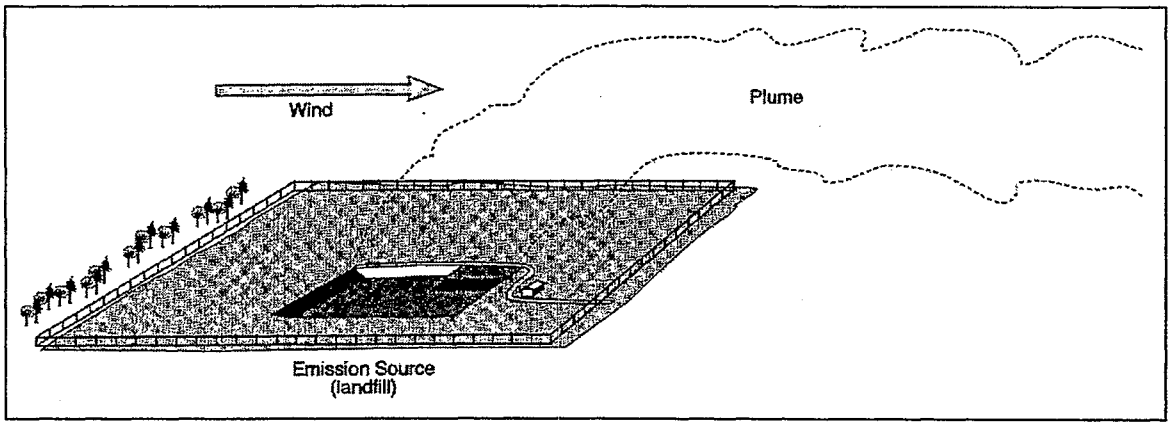
Exposure Assessment

The goal of an exposure assessment is to estimate the amount of a constituent that is available and is taken in by an individual, typically referred to as a receptor. An exposure assessment is performed in two steps: 1) the first step uses fate and transport modeling to determine the constituents concentration in air at a specified receptor location and, 2) the second step estimates the amount of the constituent the receptor will intake by identifying life-style activity patterns. The first step, the fate and transport modeling, uses a combination of an emission and dispersion model to estimate the amount of chemical that individuals residing and/or working within the vicinity of the source are exposed to through inhalation of ambient air. When a chemical volatilizes from a WMU into the ambient air, it is subjected to a number of forces that result in its diffusion and transport away from the point of release.

In modeling the movement of the volatile chemical away from the WMU, it is often assumed that the chemical behaves as a plume (i.e., the chemical is continuously emitted into the environment) whose movement and diffusion are modeled to produce estimated air concentrations at points of interest. This emission is illustrated in Figure 3.

The pattern of diffusion and movement of chemicals that volatilize from WMUs depends on a number of interrelated factors.

Figure 3. Emissions from a WMU



The ultimate concentration and fate of emissions to the air are most significantly impacted by three meteorologic conditions: atmospheric stability, wind speed, and wind direction. These meteorologic factors interact to determine the ultimate concentration of a pollutant in a localized area.

Atmospheric stability: The stability of the atmosphere is influenced by the vertical temperature structure of the air above the emission source. In a stable environment, there is little or no movement of air parcels, and, consequently, little or no movement and mixing of contaminants. In such a stable air environment, chemicals become "trapped" and unable to move. Conversely, in an unstable environment there is significant mixing and therefore greater dispersion and ultimately, dilution of the plume.[15]

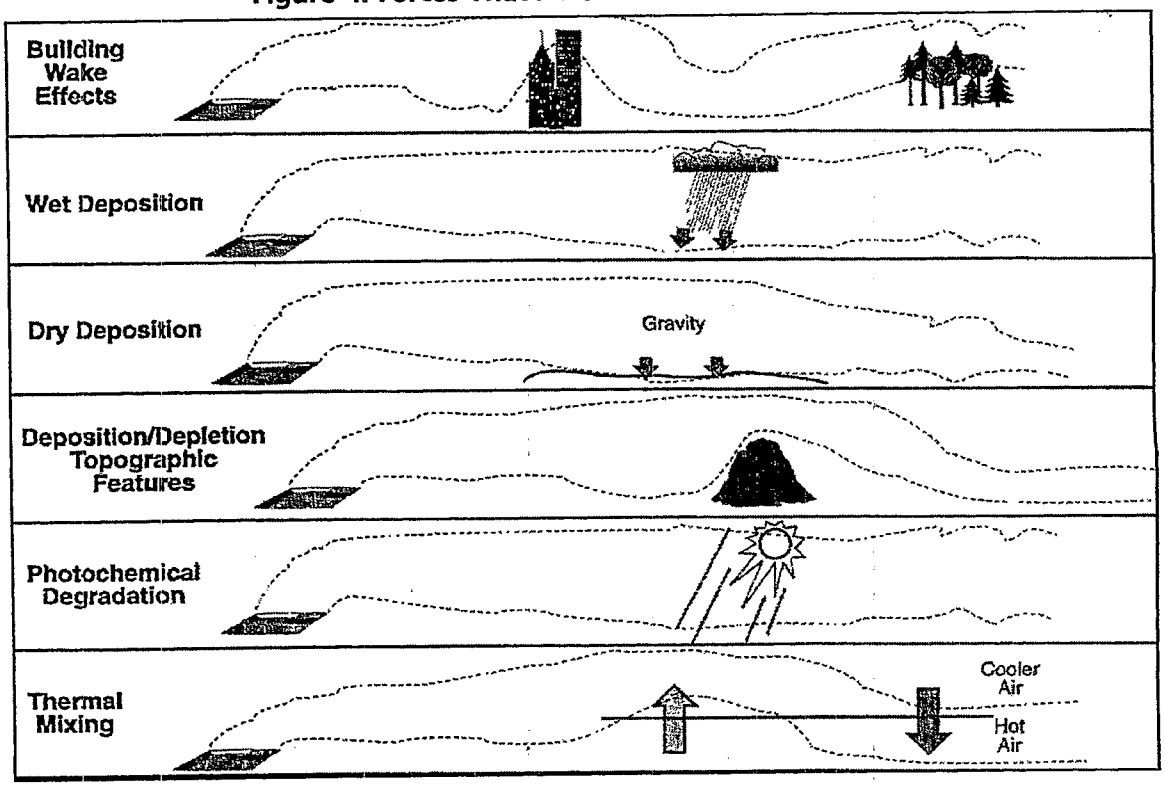
Prevailing wind patterns and their interaction with land features: The nature of the wind patterns immediately surrounding the WMU can significantly impact the local air concentrations of airborne chemicals. Prevailing wind patterns combine with topographic features such as hills and buildings to affect the movement of the plume. Upon release, the initial direction that emissions will travel is the direction of the wind. The strength of the wind will determine how dilute the concentration of the pollutant will be in that direction. For example, if a strong wind is present at the time the pollutants are released, it is likely the pollutants will rapidly leave the source and become dispersed quickly into a large volume of air.

In addition to these factors affecting the diffusion and transport of a plume away from its point of release, the concentration of specific chemicals in a plume can also be affected by depletion. As volatile chemicals are transported away from the WMU, they can be removed from the ambient air through a number of depletion mechanisms including wet deposition (the removal of chemicals due to precipitation) and dry deposition (the removal of chemicals due to the forces of gravity and impacts of the plume on features such as vegetation). Chemicals can also be transformed chemically as they come in contact with the sun's rays (i.e., photochemical degradation). Figure 4 illustrates the forces acting to transport and deplete the contaminant plume.

Because the chemicals being considered in IWAIR are volatiles and semi-volatiles and the distances of transport being considered are relatively short, the removal mechanisms shown in the figure are likely to have a relatively minor effect on plume concentration (both wet and dry deposition have significantly greater effects on airborne particulates)

[15]An example of an unstable air environment is one in which the sun shining on the earth's surface has resulted in warmer air at the earth's surface. This warmer air will tend to rise, displacing any cooler air that is on top of it. As these air parcels essentially switch places, significant mixing occurs.

Figure 4. Forces That Affect Contaminant Plumes.



and therefore are not considered.

Once the constituent's ambient outdoor concentration is determined, the receptor's extent of contact with the pollutant must be characterized. This step involves determining the location and activity patterns relevant to the receptor being considered. In IWAIR, the receptors are defined as residents and workers located at fixed distances from the WMU, and the only route of exposure considered for these receptors is the inhalation of volatiles. The activity patterns are used to determine the intake of the constituent. Intake estimates quantify the extent to which the individual is exposed to the contaminant and are a function of the breathing rate, exposure concentration, exposure duration, exposure frequency, exposure averaging time (for carcinogens), and body weight. Estimated exposures are presented in terms of the mass of the chemical per kilogram of receptor body weight per day.

Risk Characterization

The concentrations that an individual takes into his or her body that were determined during the exposure assessment phase are combined with toxicity values to generate risk estimates. Toxicity values used in IWAIR include inhalation-specific cancer slope factors (CSFs) for carcinogenic effects and reference concentrations (RfCs) for noncancer effects. These are explained in the general risk section under the building partnerships chapter. Using these toxicity values, risk estimates are generated for carcinogenic effects and noncancer effects. Risk estimates for carcinogens are summed by IWAIR.

B. IWAIR Model

IWAIR is an interactive computer program with three main components: an emissions model; a dispersion model to estimate fate and transport of constituents through the atmosphere and determine ambient air concentrations at specified receptor locations; and a risk model to calculate either the risk to exposed individuals or the waste constituent concentrations that can be protectively managed in the unit. The program requires only a limited amount of site-specific information, including facility location, WMU characteristics, waste characteristics, and receptor information. A brief description of each component follows. The IWAIR Technical Background Document contains a more detailed explanation of each.

1. Emissions Model

The emissions model uses waste characterization, WMU, and facility information to estimate emissions for 95 constituents. The emission model selected for incorporation into IWAIR is EPA's CHEMDAT8 model. This model has undergone extensive review by both EPA and industry representatives and is publicly available from EPA's Web page, **<www.epa.gov/ttn/chief/software.html>**.

To facilitate emission modeling with CHEMDAT8, IWAIR prompts the user to provide the required waste- and unit-specific data. Once these data are entered, the model calculates and displays chemical-specific emission rates. If users decide not to develop or use the CHEMDAT8 rates, they can enter their own site-specific emission rates (g/m^2-s).

2. Dispersion Model

IWAIR's second modeling component estimates dispersion of volatilized contaminants and determines air concentrations at specified receptor locations, using default dispersion factors developed with EPA's Industrial Source Complex, Short-Term Model, version 3 (ISCST3). ISCST3 was run to calculate dispersion for a standardized unit emission rate (1 $\mu g/m^2$ - s) to obtain a unitized air concentration (UAC), also called a dispersion factor, which is measured in μ/m^3 per $\mu g/m^2$ -s. The total air concentration estimates are then developed by multiplying the constituent-specific emission rates derived from CHEMDAT8 (or from another source) with a site-specific dispersion factor. Running ISCST3 to develop a new dispersion factor for each location/WMU is very time consuming and requires extensive meteorological data and technical expertise. Therefore IWAIR incorporates default dispersion factors developed by ISCST3 for many separate scenarios designed to cover a broad range of unit characteristics, including:

- 29 meteorological stations, chosen to represent the nine general climate regions of the continental U.S.;
- 4 unit types;
- 14 surface area sizes for landfills, land application units and surface impoundments, and 7 surface area sizes and 2 heights for waste piles;
- 6 receptor distances from the unit (25, 50, 75, 150, 500, 1000 meters) placed in...
- 16 directions in relation to the edge of the unit.

The default dispersion factors were derived by modeling many scenarios with various combinations of parameters, then choosing as the default the maximum dispersion factor for each waste management unit/surface area/meteorological station/receptor distance combination.

Based on the size and location of a unit, as specified by a user, IWAIR selects an

appropriate dispersion factor from the default dispersion factors in the model. If the user specifies a unit surface area that falls between two of the sizes already modeled, a linear interpolation method will estimate dispersion in relation to the two closest unit sizes.

Alternatively, a user may enter a site-specific dispersion factor developed by conducting independent modeling with ISCST3 or with a different model and proceed to the next step, the risk calculation.

3. Risk Model

The third component to the model combines the constituent's air concentration with receptor exposure factors and toxicity benchmarks to calculate either the risk from concentrations managed in the unit or the waste concentration (C_w) in the unit that should not be exceeded to protect human health. In calculating either estimate, the model applies default values for exposure factors, including inhalation rate, body weight, exposure duration, and exposure frequency. These default values are based on data presented in EPA's *Exposure Factors Handbook* (U.S. EPA, 1997) and represent average exposure conditions. IWAIR maintains standard health benchmarks (cancer slope factors for carcinogens and reference concentrations for noncarcinogens) for 95 constituents. These health benchmarks are from the Integrated Risk Information System (IRIS) and the Health Effects Assessment Summary Tables (HEAST) (U.S. EPA, 1997a, 1998). The IWAIR uses these data to perform either a forward calculation to obtain risk estimates or a backward calculation to obtain protective waste concentration estimates.

4. Estimation Process

Figure 5 provides an overview of the step-wise approach the user follows to calculate risk or protective waste concentration estimates with IWAIR. The seven steps of the estimation process are shown down the right side of the figure, and the user input requirements are specified to the left of each step. As the user provides input data, the program proceeds to the next step. Each step of the estimation process is discussed below.

a. Select Calculation Method. Select one of two calculation methods. Use the forward calculation to arrive at chemical-specific and cumulative risk estimates if the user knows the concentrations of constituents in the waste. Use the backward calculation method to estimate protective waste concentrations not to be exceeded in new units. The screen where this step is performed is shown in Figure 6.

b. Identify Waste Management Unit. Four WMU types can be modeled: surface impoundments (SIs), land application units (LAUs), active landfills (LFs), and wastepiles (WPs). For each WMU, you will be asked to specify some design and operating parameters such as surface area, depth for surface impoundments and landfills, height for wastepiles, and tilling depth for LAUs. The amount of unit specific data needed as input will vary depending on whether the user elects to develop CHEMDAT8 emission rates. IWAIR provides default values for several of the operating parameters that the user may choose, if appropriate.

c. Define Waste Managed. Specify constituents and concentrations in the waste if you choose a forward calculation to arrive at chemical specific risk estimates. If you choose a backward calculation to estimate protective waste concentrations, then specify constituents of concern. The screen where this step is performed is shown in Figure 7.

Figure 5. IWAIR Approach for Developing Risk or Protective Waste Concentrations: This figure shows the steps in the tool to assist the user in developing risk or protective waste concentration estimates.

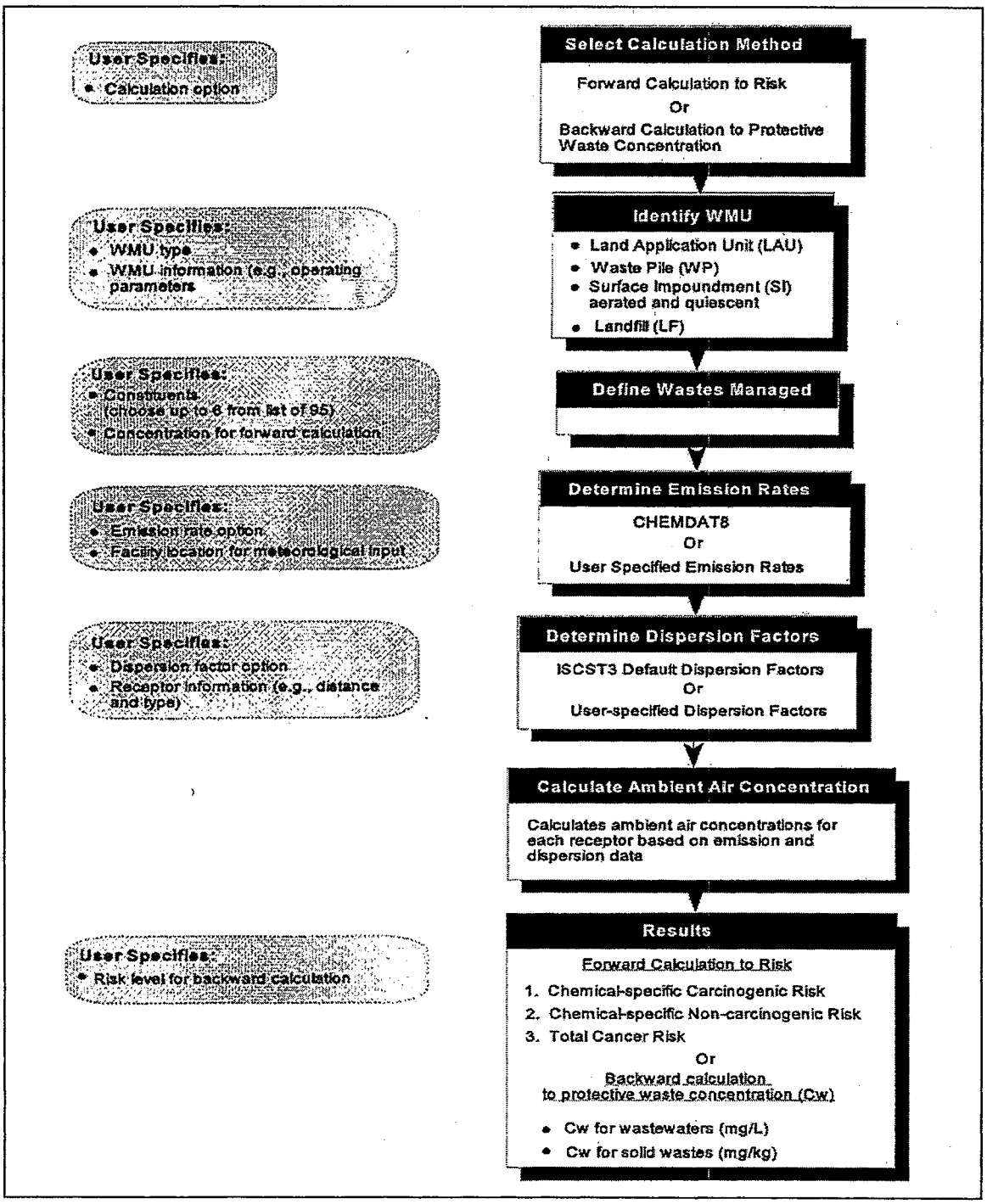


Figure 6. Screen 1, Method, Met Station. WMU.

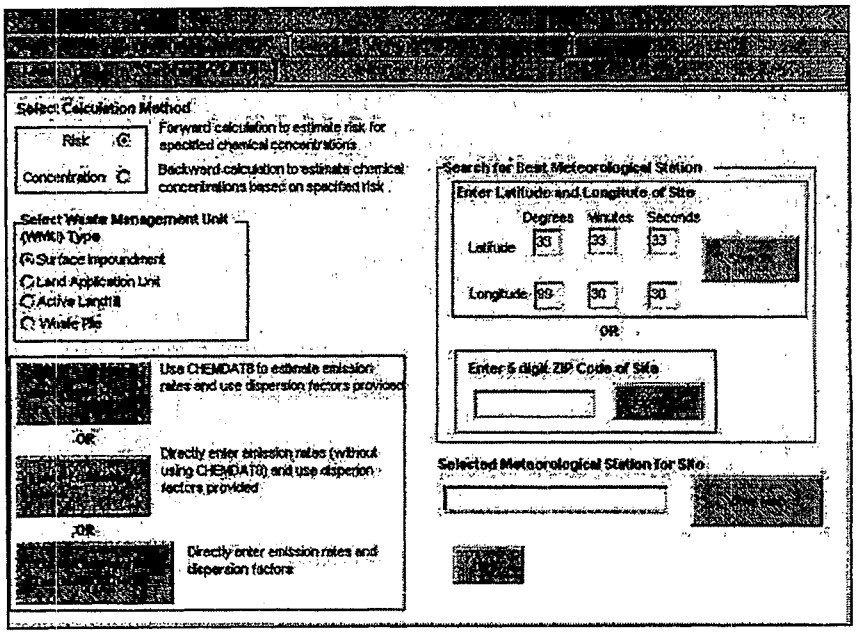
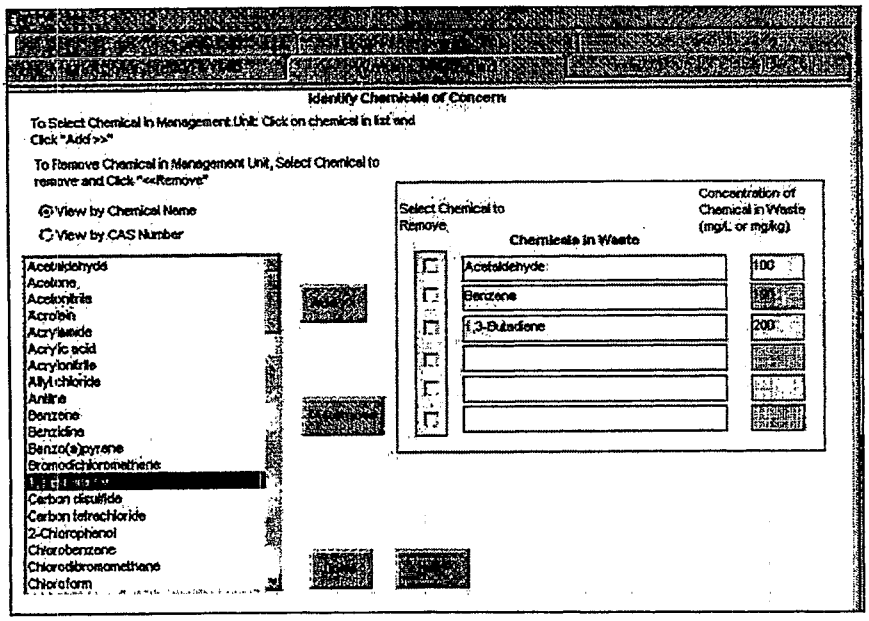


Figure 7. Screen 2, Waste Managed.



d. Determine Emission Rates. You can elect to develop CHEMDAT8 emission rates or provide your own site-specific emission rates for use in calculations. IWAIR will also ask for facility location information to link the facility's location to one of the 29 IWAIR meteorological stations. Data from the meteorological stations provide wind speed and temperature information needed to develop emission estimates. In some circumstances the user may already have emissions information from monitoring or a previous modeling exercise. As an alternative to using the CHEMDAT8 rates, a user may provide their own site-specific emission rates developed with a different model or based on emission measurements.

e. Determine Dispersion. The user can provide site-specific unitized dispersion factors ($\mu g/m^3$ per $\mu g/m^2$-s) or have the model develop dispersion factors based on user-specified WMU information and the IWAIR default dispersion data. Because a number of assumptions were made in developing the IWAIR default dispersion data (for example, flat terrain was assumed), you may elect to provide site-specific dispersion factors which can be developed by conducting independent modeling with ISCST3 or with a different model. Whether you use IWAIR or provide dispersion factors from another source, specify distance to the receptor from the edge of the WMU and the receptor type (i.e., resident or worker). These data are used to define points of exposure.

f. Calculate Ambient Air Concentration. For each receptor, the model combines emission rates and dispersion data to estimate ambient air concentrations for all waste constituents of concern.

g. Calculate Results. The model calculates results by combining estimated ambient air concentrations at a specified exposure point with receptor exposure factors and toxicity benchmarks. Presentation of results depends on whether you chose a forward or backward calculation:

Forward calculation: Results are estimates of cancer and non-cancer risks from inhalation exposure to volatilized constituents in the waste. If risks are too high, options are: 1) implement unit controls to reduce volatile air emissions; 2) implement pollution prevention or treatment to reduce volatile organic compound (VOC) concentrations before the waste enters the unit; or 3) conduct a full site-specific risk assessment to more precisely characterize risks from the unit.

Backward calculation: Results are estimates of constituent concentrations in waste that can be protectively managed in the unit so as not to exceed a defined risk level (e.g., 1×10^{-6} or hazard quotient of 1) for specified receptors. This information should be used to determine preferred characteristics for wastes entering the unit. There are several options if it appears that planned waste concentrations may be too high: 1) implement pollution prevention or treatment to reduce VOC concentrations in the waste; 2) modify waste management practices to better control VOCs (for example, use closed tanks rather than surface impoundments); or 3) conduct a full site-specific risk assessment to more precisely characterize risks from the unit.

5. Capabilities and Limitations of the Model

In many cases, IWAIR will provide a reasonable alternative to conducting a full-scale site-specific risk analysis to determine if a WMU poses unacceptable risk to human health. However, because the model can

accommodate only a limited amount of site-specific information, it is important to understand it's capabilities and recognize situations when it may not be appropriate - when another model would be a better choice.

Capabilities

- The model provides a reasonable, conservative representation of VOC inhalation risks associated with waste management units.
- The model is easy-to-use and requires a minimal amount of data and expertise.
- The model is flexible and provides features to meet a variety of user needs:
  - A user can enter emission and/or dis persion factors derived from another model (perhaps to avoid some of the limitations below) and still use IWAIR to conduct a risk evaluation.
  - The model can run a forward calculation from the unit or a backward calculation from the receptor point.
  - A user can modify health benchmarks (HBNs) and target risk level, when appropriate and in consultation with other stakeholders.

Limitations

- **Chemicals of Concern.** If waste contains chemicals that (1) are not included in the model and (2) have human health effects and may be present in concentrations sufficient to pose a risk to public health via inhalation exposure, the model will not fully characterize risks for that WMU since these additional chemicals would be excluded from consideration.
- **Release Mechanisms and Exposure Routes.** The model considers exposures from breathing ambient air. It does not address potential risks attributable to particulate releases nor does it address risks associated with indirect routes of exposure (i.e, non-inhalation routes of exposure). Additionally, in the absence of user-specified emission rates, volatile emission estimates are developed with CHEMDAT8 based on unit- and waste-specific data. The CHEMDAT8 model was developed to address only volatile emissions from waste management units. Competing mechanisms such as runoff, erosion, and leaching are not accounted for in the model. In so much as these competing processes actually occur, the model would tend to slightly overestimate the volatile emissions. On the other hand, one could interpret this situation as being representative of WMUs that have leachate controls, such as liners, or erosion and runoff controls. Such controls would tend to inhibit these processes and result in more volatile emissions.
- **Waste Management Practices.** The user specifies a number of unit-specific parameters that significantly impact the inhalation pathway (e.g., size, type, and location of WMU, which is important in identifying meteorological conditions). However, the model cannot accommodate information concerning control technologies such as covers that might influence the degree of volatilization (e.g., whether a wastepile is covered immediately after application of new waste). In this case, it may be necessary to generate site-specific emission rates and enter those into IWAIR.
- **Terrain and Meteorological Conditions.** If a facility is located in an area of intermediate or complex terrain or with unusual meteorological conditions, it may be necessary to either (1) generate site-specific

air dispersion modeling results for the site and enter those results into the program, or (2) use a site-specific risk modeling approach different from IWAIR. The model will inform the user which of the 29 meteorological stations is used for a facility. If the local meteorological conditions are very different from the site chosen by the model, it would be more accurate to choose a different model.

The terrain type surrounding a facility can impact air dispersion modeling results and ultimately risk estimates. In performing air dispersion modeling to develop the IWAIR default dispersion factors, it was assumed that the facility was located in an area of simple or flat terrain. The Guideline on Air Quality Models (U.S. EPA, 1993) can assist users in determining whether a facility is in an area of simple, intermediate, or complex terrain.

- **Receptor Type and Location.** IWAIR has predetermined adult worker and resident receptors, six receptor locations, and predetermined exposure factors. The program cannot be used to characterize risk for other possible exposure scenarios. For example, the model can not evaluate receptors that are closer to the unit than 25 meters or those that are further from the unit that 1000 meters.

C. Site-specific Risk Analysis

IWAIR is not the only model that may be applicable to a site. In some cases, a site-specific risk assessment may be more advantageous. A site-specific approach can be tailored to accommodate the individual needs of a particular WMU. Such an approach would rely on site-specific data and on the application of existing fate and transport models.

Table 5 summarizes available emissions and/or dispersion models that may be applied in a site-specific analysis. Practical considerations include the source of the model(s), the ease in obtaining the model(s), and the nature of the model(s) (i.e., is it proprietary), and the availability of site-specific data required for use of the model. Finally, the model selection process should determine whether or not the model has been verified against analytical solutions, other models, and/or field data. Proper models can be selected based on the physical and chemical attributes of the site in question. However, as with all modeling, the state authority should be consulted prior to investing significant resources in a site-specific analysis. The state may have preferred models and/or may be able to help plan the analysis.

III. Emission Control Techniques

A. Controlling Particulate Matter (PM)

PM consists of airborne solid and liquid particles. When PM is very small, it is easily inhaled and trapped in the lungs, where it can cause various health problems. PM also impacts the environment by decreasing visibility and harming plants as well as transporting hazardous constituents offsite. We recommend that facilities adopt controls to address emissions of airborne particulates.

Solid PM that becomes airborne directly or indirectly as a result of human activity, is referred to as fugitive dust[16] and it can be generated from a number of different sources. The most common sources of fugitive dust at waste management units include vehicular traffic on unpaved roads and land-based units, wind erosion from land-based units, and waste handling procedures. Developing a fugitive dust

[16]Fugitive emissions are defined as emissions not caught by a capture system and therefore exclude PM emitted from exhaust stacks with control devices.

Table 5
Source Characterization Models

Model Name	Summary
CHEMDAT8	The CHEMDAT8 model allows the user to conduct source and chemical specific emissions modeling. CHEMDAT8 is a Lotus 1-2-3 spreadsheet that includes analytical models to estimate volatile organic compound emissions from treatment, storage, and disposal facility processes under user-specified input parameters. CHEMDAT8 calculates the fractions of waste constituents of interest that are distributed among pathways (partition fractions) applicable to the facility under analysis. Emissions modeling using CHEMDAT8 is conducted using data entered by the user for unit-specific parameters. The user may choose to override the default data and enter their estimates for these unit-specific parameters. Thus, modeling emissions using CHEMDAT8 can be done with a limited amount of site-specific information. Available at **<www.epa.gov/ttn/chief/software.html>**, hotline at (919) 541 5610 for more information.
ISCST3	A steady-state Gaussian plume dispersion model that can estimate concentration, dry deposition rates (particles only), and wet deposition rates. Is applicable for continuous emissions , industrial source complexes, rural or urban areas, simple or complex terrain, transport distances of less than 50 km, and averaging times from hourly to annual Available at **<www.epa.gov/scram001/>**
COMPDEP	The COMPDEP model was developed to calculate air concentration and deposition fluxes, particularly in areas of complex terrain. This model uses standard meteorological data to produce estimates of annual average concentration, total annual dry deposition, and wet deposition flux at individual receptor sites. COMPDEP accounts for pollutant deposition and terrain adjustments. This model was developed for and is only applicable in rural areas. Available at **<www.epa.gov/scram001/>**
Toxic Screening Model (TSCREEN)	Performs emission rate, pool evaporation , and natural and dense gas dispersion calculations. TSCREEN uses simple methods, and therefore is primarily used for screening. Little or no modeling experience is required to use this model.

Source: **<www.epa.gov/rgytgrnj/programs/artd/toxics/arpp/etools.htm>**

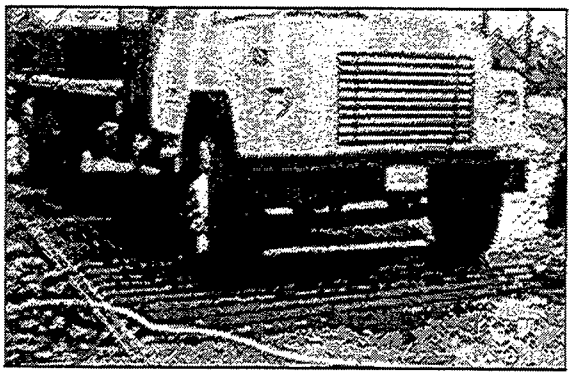
control plan is an efficient way to tackle these problems. The plan should include a description of all operations conducted at the unit, a map, a list of all fugitive dust sources at the unit, and a description of the control measures that will be used to minimize fugitive dust emissions. OSHA has established standards for occupational exposure to dust (see 29 CFR § 1910.1000). Check to see if the state also has regulations or guidance concerning dust or fugitive emission control.

PM emissions at waste management units vary with the physical and chemical characteristics of waste streams; the volume of waste handled; the size of the unit, its location, and associated climate; and waste transportation and placement practices. The subsections below discuss the main PM-generating operations and identify emission control techniques.

1. Vehicular Operations

Waste and cover material are often transported to units using trucks. If the waste has the potential for PM to escape to the atmosphere during transport, cover the waste with tarps or place wastes in containers such as double bags or drums[17]

A unit may also use vehicles to construct lifts in landfills, apply liquids to land application units, or dredge surface impoundments. Consider using "dedicated" equipment—vehicles that operate only within the unit and are not routinely removed from the unit to perform other activities. This practice reduces the likelihood that equipment movement will spread contaminated PM outside the unit. To control PM emissions when equipment must be removed from the landfill unit, such as for maintenance, a wash station can remove any contaminated material from the equipment before it leaves the unit. Ensure that this is done in a curbed wash area where wash water is captured and properly handled.



To minimize PM emissions from all vehicles, construct temporary roadways with gravel or other coarse aggregate material to reduce silt content and thus, dust generation. In addition, consider regularly cleaning paved roads and other travel surfaces of dust, mud, and contaminated material.

In land application units, the entire application surface is often covered with a soil-waste mix. The most critical preventive control measure, therefore, involves minimizing contact between the application surface and waste delivery vehicles. If possible, allow only dedicated application vehicles on the surface, restricting delivery vehicles to a staging or loading area where they deposit waste into application vehicles or holding tanks. If delivery vehicles must enter the application area, ensure that mud and waste are not tracked out and deposited on roadways, where they can dry and then be dispersed by wind or passing vehicles.

2. Waste Placement and Handling

PM emissions from waste placement and handling activities are less likely if exposed material has a high moisture content. Therefore, consider wetting the waste prior to loadout. Increasing the moisture content, however, may not be suitable for all waste streams, as water could cause an adverse

[17]Containerizing wastes provides highly effective control of PM emissions, but, due to the large volume of many industrial waste streams, containerizing waste may not always be feasible.

chemical reaction with some wastes or unacceptably increase leachate production. To reduce the need for water or suppressants, cover or confine freshly exposed material. In addition, consider increasing the moisture content of the cover material.

It can also be useful to apply water to unit surfaces after waste placement. Water is generally applied using a truck with a gravity or pressure feed. Watering may or may not be advisable depending on application intensity and frequency, the potential for tracking of contaminated material off site, and climatic conditions. PM control efficiency generally increases with application intensity and frequency but also depends on activity levels, climate, and initial surface conditions. Infrequent or low-intensity water application may provide little effective control, while too frequent or high-intensity application may increase leachate volume, straining leachate collection systems and threatening ground water and surface water. Addition of excess water to bulk waste material or to unit surfaces also can reduce the structural integrity of the landfill lifts, increase tracking of contaminated mud off site, and worsen odor. These undesirable possibilities may have long-term implications for the proper management of a unit. Before instituting a watering program, therefore, ensure that addition of water does not produce undesirable impacts on ground- and surface-water quality. Consult with your state agency with respect to these problems.

Chemical dust suppressants are an alternative to water application. The suppressants are detergent-like surfactants that increase the total number of droplets and allow particles to more easily penetrate the droplets, increasing the total surface area and contact potential. Adding a surfactant to a relatively small quantity of water and mixing vigorously produces small-bubble, high-energy foam in the 100 to 200 μm size range. The foam occupies very little liquid volume, and when applied to the surface of the bulk material, wets the fines more effectively than water. When applied to a unit, suppressants cement loose material into a more impervious surface or form a surface which attracts and retains moisture. Examples of chemical dust suppressants are provided in Appendix IV . The degree of control achieved is a function of the application intensity and frequency and the dilution ratio. Chemical dust suppressants tend to require less frequent application than water, reducing the potential for leachate generation. Their efficiency varies, depending on the same factors as water application, as well as spray nozzle parameters, but generally falls between 60 and 90 percent reduction in fugitive dust emissions. Suppressant costs, however, can be high.

At land application units, if wastes contain considerable moisture, PM can be suppressed through application of more waste rather than water or chemical suppressants. This method, however, is only viable if it would not cause an exceedence of a design waste application rate or exceed the capacity of soil and plants to assimilate waste.

At surface impoundments, the liquid nature of the waste means PM is not a major concern while the unit is operational. Inactive or closed surface impoundments, however, may emit PM during scraping or bulldozing operations to remove residual materials. The uppermost layer of the low permeability soils, such as compacted clay, which may be used to line a surface impoundment, contains the highest contaminant concentrations. Particulate emissions from this uppermost layer, therefore, are the chief contributor to contaminant emissions. When removing residuals from active units, ensure that equipment scrapes only the residuals, avoiding the liner below.

3. Wind Erosion

Wind erosion occurs when a dry surface is exposed to the atmosphere. The effect is most pronounced with bare surfaces of fine particles, such as silty soil; heavier or better anchored material, such as stones or clumps of vegetation, has limited erosion potential and requires higher wind speeds before erosion can begin.

Compacted clay and in-situ soil liners tend to form crusts as their surfaces dry. Crusted surfaces usually have little or no erosion potential. Examine the crust thickness and strength during site inspections. If the crust is more than ¼ inch thick and does not crumble easily, then the soil probably has almost no erosion potential.

Wind fences or barriers are effective means by which to control fugitive dust emissions from open dust sources. The wind fence or barrier reduces wind velocity and turbulence in an area whose length is many times the height of the fence. This allows settling of large particles and reduces emissions from the exposed surface. It can also shelter materials handling operations to reduce entrainment during loadin and loadout. Wind fences or barriers can be portable and either man-made structures or vegetative barriers, such as trees. A number of studies have attempted to determine the effectiveness of wind fences or barriers for the control of windblown dust under field conditions. Several of these studies have shown a decrease in wind velocity, however, the degree of emissions reduction varies significantly from study to study depending on test conditions.

Other wind erosion control measures include passive enclosures such as three-sided bunkers for the storage of bulk materials, storage silos for various types of aggregate material, and open-ended buildings. Such enclosures are most easily used with small, temporary waste piles. At land application units that use spray application, further wind erosion control can be achieved simply by not spraying waste on windy days.

Windblown PM emissions from a waste pile depend on how frequently the pile is disturbed, the moisture content of the waste, the proportion of aggregate fines, and the height of the pile. When fine-particle wastes are loaded onto a waste pile, the potential for dust emissions is at a maximum, as fine particles are easily disaggregated and picked up by wind. This tends to occur when material is either added to or removed from the pile or when the pile is otherwise reshaped. On the other hand, when the waste remains undisturbed for long periods and is weathered, its potential for dust emissions may be greatly reduced. This occurs when moisture from precipitation and condensation causes aggregation and cementation of fine particles to the surface of larger particles, and when vegetation grows on the pile, shielding the surface and strengthening it with roots. Finally, limiting height of the pile can reduce PM emissions, as wind velocities generally increase with distance from the ground.

B. VOC Emission Control Techniques

If air modeling indicates that VOC emissions are a concern, consider pollution prevention and treatment options to reduce risk. There are several control techniques you can use. Some are applied before the waste is placed in the unit, reducing emissions; others contain emissions that occur after waste placement; still others process the captured emissions.

1. Choosing a Site to Minimize Airborne Emission Problems

Careful site choice can reduce VOC emissions. Look for locations that are sheltered

from wind by trees or other natural features. Know the direction of prevailing winds and determine whether the unit would be upwind from existing and expected future residences, businesses, or other population centers. After a unit is sited, observe wind direction during waste placement, and plan or move work areas accordingly to reduce airborne emission impacts on neighbors.

2. Pretreatment of Waste

Pretreating waste can remove organic compounds and possibly eliminate the need for further air emission controls. Organic removal or pretreatment is feasible for a variety of wastes. These processes, which include steam or air stripping, thin-film evaporation, solvent extraction, and distillation, can sometimes remove essentially all of the highly volatile compounds from your waste. Removal of the volatiles near the point of generation may obviate the need for controls on your subsequent process units and may facilitate recycling the recovered organics back to the process.

The control efficiency of organic removal depends on many factors, such as emissions from the removal system, and the uncontrolled emissions from management units before the removal device was installed. Generally, overall organic removal efficiencies of 98 to over 99 percent can be achieved.

3. Enclosure of Units

You may be able to control VOC emissions from your landfill or waste pile by installing a flexible membrane cover, enclosing the unit in a rigid structure, or using an air-supported structure. Fans maintain positive pressure to inflate an air-supported structure. Some of the air-supported covers that have been used consist of PVC-coated polyester with a polyvinyl fluoride film backing. The efficiency of air-supported structures depends primarily on how well the structure prevents leaks and how quickly any leaks that do occur are detected. For effective control, the air vented from the structure should be sent to a control device, such as a carbon adsorber. Consider worker safety issues related to access to the interior of any flexible membrane cover or other pollutant concentration system.

Wind fences or barriers may also aid in reducing organic emissions by reducing air mixing on the leeward side of the screen. In addition, wind fences reduce soil moisture loss due to wind, which may in turn result in decreased VOC emissions.

Floating membrane covers provide control on various types of surface impoundments, including water reservoirs in the western United States. For successful control of organic compounds, the membrane must provide a seal at the edge of the impoundment and rainwater must be removed. If gas is generated under the cover, vents and a control device may also be needed. Emission control depends primarily on the type of membrane, its thickness, and the nature of the organic compounds in the waste. One study tracked a membrane cover made of 100-mil high-density polyethylene extended over a concrete ring wall that extended above grade level around the perimeter of the impoundment, and covered with backfill to anchor and seal it. Theoretical estimates based on diffusion through the membrane indicate control efficiencies of 50 to 95 percent. Again, consult with your state or local air quality agency to identify the most appropriate emission control for your impoundment.

4. Treatment of Captured VOCs

In some cases, waste will still emit some VOCs despite waste reduction or pretreatment

efforts. Enclosing the unit serves to prevent the immediate escape of these VOCs to the atmosphere. To avoid eventually releasing VOCs through an enclosure's ventilation system, a treatment system is necessary. We discuss some of the better-known treatment methods below; others also may be available.

a. Adsorption

Adsorption is the adherence of particles of one substance, in this case VOCs, to the surface of another substance, in this case a filtration or treatment matrix. The matrix can be replaced or flushed when its surface becomes saturated with the collected VOCs.

Carbon Adsorption. In carbon adsorption, organics are selectively collected on the surface of a porous solid. Activated carbon is a common adsorbent because of its high internal surface area: 1 gram of carbon can have a surface area equal to that of a football field and can typically adsorb up to half its weight in organics. For adsorption to be effective, replace, regenerate, or recharge the carbon when treatment efficiency begins to decline. In addition, any emissions from the disposal or regeneration of the carbon should be controlled. Control efficiencies of 97 to 99 percent have been demonstrated for carbon adsorbers in many applications.

Biofiltration. While covering odorous materials with soil is a longstanding odor control practice, the commercial use of biofiltration is a relatively recent development. Biofilters reproduce and improve upon the soil cover concept used in landfills. In a biofilter, gas emissions containing biodegradable VOCs pass through a bed packed with damp, porous organic particles. The biologically active filter bed then adsorbs the volatile organic compounds. Microorganisms attached to the wetted filter material aerobically degrade the adsorbed chemical compounds. Biofiltration may be a highly effective and low-cost alternative to other, more conventional, air pollution control technologies such as thermal oxidation, catalytic incineration, condensation, carbon adsorption, and absorption. Successful commercial biofilter applications include treatment of gas emissions from composting operations, rendering plants, food and tobacco processing, chemical manufacturing, foundries, and other industrial facilities.[18]

b. Condensation

Condensers work by cooling the vented vapors to their dew point and removing the organics as liquids. The efficiency of a condenser is determined by the vapor phase concentration of the specific organics and the condenser temperature. Two common types of condensers are contact condensers and surface condensers.

c. Absorption

In absorption, the organics in the vent gas dissolve in a liquid. The contact between the absorbing liquid and the vent gas is accomplished in spray towers, scrubbers, or packed or plate columns. Some common solvents that may be useful for volatile organics include water, mineral oils, or other nonvolatile petroleum oils. Absorption efficiencies of 60 to 96 percent have been reported for organics. The material removed from the absorber may present a disposal or separation problem. For example, organics must be removed from the water or nonvolatile oil without losing them as emissions during the solvent recovery or treatment process.

d. Vapor Combustion

Vapor combustion is another control technique for vented vapors. The destruction of

[18]Mycock, J.C., J.D. McKenna, and L. Theodore. 1995. *Handbook of Air Pollution Control Engineering and Technology.*

organics can be accomplished in flares; thermal oxidizers, such as incinerators, boilers, or process heaters; and in catalytic oxidizers. Flares are an open combustion process in which oxygen is supplied by the air surrounding the flame. Flares are either operated at ground level or elevated. Properly operated flares can achieve destruction efficiencies of at least 98 percent. Thermal vapor incinerators can also achieve destruction efficiencies of at least 98 percent with adequately high temperature, good mixing, sufficient oxygen, and an adequate residence time. Catalytic incinerators provide oxidation at temperatures lower than those required by thermal incinerators. Design considerations are important because the catalyst may be adversely affected by high temperatures, high concentrations of organics, fouling from particulate matter or polymers, and deactivation by halogens or certain metals.

5. Special Considerations for Land Application Units

Since spraying wastes increases contact between waste and air, promoting VOC emissions, you may want to choose another application method, such as subsurface injection, if the waste contains volatile organics. During subsurface injection, waste is supplied to the injection unit directly from a remote holding tank and injected approximately 6 inches into the soil; hence, the waste is not exposed to the atmosphere. In addition, consider pretreating the waste to remove the organics before placing it in the land application unit.

Protecting Air Quality Action Items

Consider the following issues when evaluating and controlling air emissions from nonhazardous industrial waste management units:

- ☐ Understand air pollution laws and regulations, and determine whether and how they apply to a unit.
- ☐ Evaluate waste management units to identify possible sources of volatile organic emissions.
- ☐ Work with your state agency to evaluate and implement appropriate emission control techniques, as necessary.

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Part 3
Protecting Surface Water

Chapter 6
Protecting Surface Water

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Protecting Surface Water

Protect surface waters by limiting the discharge of pollutants into the waters of the United States. Guard against inappropriate discharges of pollutants associated with process wastewaters and storm water to ensure the safety of the nation's surface waters. Reduce storm water discharges by complying with regulations, implementing available storm water controls, and identifying best management practices (BMPs) to control storm water.

Over 70 percent of the Earth's surface is water. Of all the Earth's water, 97 percent is found in the oceans and seas, while three percent is fresh water. This fresh water is found in glaciers, lakes, ground water, and rivers. Water offers many valuable uses to individuals and communities. Water is necessary for recreational needs, drinking water demands, fishing, commerce, agriculture, and the overall quality of life.

This chapter will help address the following questions:

- What are the objectives of run-on and run-off control systems?
- What should be considered in designing surface-water protection systems?
- What are the appropriate BMPs to address pollutant sources?
- What are some of the engineering and physical mechanisms available to control storm water?

With water being such a valuable commodity, the protection of our surface waters should be everyone's goal. This goal can be achieved by everyone focusing on improving the quality of our surface waters. Improvements in the quality of our surface waters can be achieved by the continued protection against the discharge of pollutants. Pollutants associated with process wastewaters and storm waters need to be controlled.

This chapter summarizes the existing federal surface-water protection programs. The majority of this chapter then discusses methods that can be used to eliminate pollutant discharges into surface waters associated with storm-water management. Controlling storm-water run-on and run-off from waste management units minimizes contamination of surface water. Use best management practices (BMPs) in conjunction with engineering and physical mechanisms to control storm water and reduce or eliminate contaminant releases to the environment.

I. Federal Surface-Water Protection Programs

The federal Clean Water Act (CWA) governs the discharge of all pollutants into waters of the United States, such as lakes, rivers, streams, wetlands, ponds, or lagoons. It does so primarily through a permitting process known as the National Pollutant Discharge Elimination System (NPDES). All entities that discharge pollutants of any kind into waters of the United States must have an NPDES permit. Permits are issued for three types of wastewaters: process wastewater, nonprocess wastewater, and storm water. Permits typically set forth specific "effluent limitations" relating to the type of discharge. For process wastewaters, the permit incorporates the more stringent of industry-specific, technology-based limitations, which can be found at 40 CFR Parts 405-471, or water quality-based effluent limits (WQBELs).[1] NPDES permits also set forth monitoring and reporting requirements. Some waste management units, such as surface impoundments, may receive an NPDES permit to discharge wastewaters directly to surface waters. Other units may need an NPDES permit only for storm-water discharges. For industrial facilities that discharge wastewaters to Publicly Owned Treatment Works (POTW) through domestic sewer lines, pretreatment of the wastewater may be required. Under the National Pretreatment Program, EPA, the state, and the local regulatory agency establish discharge limits to reduce the level of pollutants discharged by industry into municipal sewer systems. These limits control pollutant levels reaching a POTW, improving the quality of the effluent and sludges produced by the POTW. Protecting the POTW and improving effluent and sludge quality significantly increases the opportunity for beneficial reuse of these end products. A fact sheet and frequently asked questions on industrial pretreatment is included in the Appendix I for this chapter, and are available on the Office of Wastewater Management's web page at **<www.epa.gov/owm/pre.htm>**.

As mentioned previously, some units may be required to obtain an NPDES permit for storm-water discharges. EPA has defined 11 categories under the definition of "storm water associated with industrial activity" (40 CFR §122.26(b)(14)) that require an NPDES storm-water permit for discharges to navigable waters. These 11 categories consist of: (1) facilities subject to storm-water effluent limitations guidelines, new source performance standards, or toxic pollutant effluent standards under 40 CFR Part 129 (manufacturers of 6 specific pesticides); (2) "heavy" manufacturing facilities; (3) mining and oil and gas operations with "contaminated" storm-water discharges; (4) hazardous waste treatment, storage, or disposal facilities; (5) landfills, land application sites, and open dumps; (6) recycling facilities; (7) steam electric generating facilities; (8) transportation facilities; (9) sewage treatment plants; (10) construction operations disturbing five or more acres; and (11) other industrial facilities where materials are exposed to storm water. Nonhazardous waste landfills and land application units would fall under category 5.

Most surface impoundments that are addressed by this guidance are part of an industrial wastewater treatment process that results in an NPDES-permitted discharge into surface waters. The NPDES permit only sets pollution limits for the final discharge of treated wastewater. It does not establish any regulatory requirements for design or operation of surface impoundments that are part of the treatment process such as liners and ground-water monitoring. Individual state environmental agencies, under their own statutory authorities, may

[1]Facilities that discharge wastewaters to publicly-owned treatment works (POTWs) may be subject to pretreatment requirements found in 40 CFR Part 403.

impose such requirements on surface impoundment design and operation.

To provide flexibility for the regulated community in acquiring storm-water discharge permits, EPA has two NPDES permit application options: individual permits and general permits.[2] Applications for individual permits require the submission of a site drainage map, a narrative description of the site that identifies potential pollutant sources, and quantitative testing data for specific parameters. General permit applications usually involve the submission of a Notice of Intent (NOI) that includes only general information, not industry-specific or pollutant-specific BMPs, and typically do not require collection of monitoring data. NPDES general storm-water permits require the development and implementation of storm-water pollution prevention plans and BMPs to limit pollutants in storm-water discharges. EPA has issued the Multi-Sector General Permit (60 *Federal Register* 50803; September 29, 1995) which covers 29 different industry sectors. The Agency reviewed, on a sector-by-sector basis, information concerning industrial activities, BMPs, materials stored outdoors, and end-of-pipe storm-water sampling data. Based on this review, EPA identified pollutants of concern in each industry sector, sources of these pollutants, and BMPs used to control them. The Multi-Sector General Permit requires the submission of an NOI, development and implementation of a site-specific pollution prevention plan as the basic storm-water control strategy for each industry sector.

Sometimes it may be appropriate to "pretreat" the storm water before discharging it into municipal separate storm sewer systems. Using proven pollution control technologies, practices that promote reuse and recycling of material, and wastewater treatment, pollutants from storm water can be reduced or eliminated before it is discharged. NPDES permits for "storm-water discharges associated with industrial activity" (as previously defined) are issued by EPA or states with NPDES permitting authority. If located in a state with NPDES authority, contact the state directly to determine the requirements for storm water discharges. EPA's Office of Wastewater Management's web page contains a complete, updated list of the states with approved NPDES permit programs, as well as fact sheets and frequently asked questions on the NPDES permit program. These facts sheets can be found at **<www.epa.gov/owm/npdes.htm>**, and are included in the Appendix III for this chapter . If a state does not have NPDES permitting authority, follow any state requirements for storm-water discharges and contact EPA to determine applicable federal requirements for storm-water discharges.

If a waste management unit is subject to federal or state storm-water discharge requirements, use this chapter as an aid in complying with applicable storm-water

Is a permit needed?

To answer questions about whether or not a facility needs to seek permit coverage, or to determine whether a particular program is administered by EPA or a state agency, contact the state or EPA regional storm water official listed in the Appendix II. Currently, 42 states and the U.S. Virgin Islands have federally approved state NPDES permit programs. The following 8 states do not have final EPA approval: Alaska, Arizona, Idaho, Maine, Massachusetts, New Hampshire, New Mexico and Texas.

[2]Initially a group application procedure was available for facilities with similar activities to jointly submit a single application for permit coverage. A multi-sector general permit was then developed based upon information provided in the group applications. The group application option was only for use in the initial stages of the program and is no longer available.

discharge requirements and maintaining appropriate surface-water controls. If a unit is not subject to federal or state storm-water discharge requirements, use this information to proactively develop surface-water protection systems.

II. Overview of Storm-Water Protection Systems

Protecting surface water entails preventing storm-water contamination during both unit construction and the operational life of the waste management unit. The primary run-off contaminant during construction is sediment eroded from exposed soil surfaces. Temporary sediment and erosion control measures, such as silt fences around construction perimeters, straw bales around storm-water inlets, and seeding or straw covering of exposed slopes, are typically used to limit and manage erosion. States or localities often require the use of sediment and erosion controls at any construction site disturbing greater than a certain number of acres, and may have additional requirements in especially sensitive watersheds. Consult with the state and local regulatory agency to determine sediment and erosion control requirements for construction.

Once a waste management unit has been constructed, permanent run-on and run-off controls are necessary to protect surface water. Run-on controls are designed to prevent storm water from entering active areas of units. If run-on is not prevented from entering active areas, it may seep into the waste and increase the amount of leachate that must be managed. It can also deposit contaminants from nearby sites, such as pesticide from adjoining farms, further burdening treatment systems. Excessive run-on may also damage earthen containment systems, such as covers and berms. Run-on that contacts the waste may carry contaminants into receiving waters through surface-water run-off or into ground

What is "run-on"?

Run-on is a term used to refer to water from outside a waste management unit that flows toward the unit. Run-on encompasses storm water from rainfall or the melting of snow or ice that falls directly on the unit as well as the water that drains from adjoining areas.

Why are run-on controls necessary?

Run-on controls are designed to prevent (1) contamination of storm water, (2) erosion that may damage the physical structure of units, (3) the surface discharge of waste constituents, (4) the creation of leachate, and (5) already contaminated surface water from entering the unit.

What is "run-off"?

Run-off is a term used to refer to water or leachate that drains or flows over land from any part of a waste management unit. Run-off can be created by rainfall, or the melting of snow and ice.

What is the purpose of a "run-off" control system?

Run-off control systems are designed to collect and control at least the water flow resulting from a storm event of a specified duration, such as a 24-hour, 25 year storm event.

water through infiltration. The Multi-Sector General Permit does not authorize discharges of leachate, which includes storm water which contacts waste. The discharge of leachate would be regulated under either an individually drafted NPDES permit with site-specific discharge limitations, or an alternative NPDES general permit if one is available. Divert run-on by taking advantage of natural contours or by constructing ditches or berms designed to intercept and drain storm water. Run-on diversion systems should be designed to handle the peak discharge of a design storm event, such as a 25-year storm. (See Section IV for more information about design storm events.)

Run-off controls channel, divert, and convey storm water to treatment facilities, if appropriate, and to intended discharge points. Manage run-off from a waste management unit as a potentially contaminated material. Due to the potential for contamination, manage contact run-off from active areas of a landfill or waste pile as leachate. Design the leachate collection and removal systems to handle such run-off, as well as any leachate generated. Segregate noncontact run-off to reduce the volume that may need to be handled as leachate. Design surface impoundments with sufficient freeboard and adequate capacity to accommodate not only waste but also precipitation. For land application sites, run-off from the application site may adversely affect nearby surface waters.

III. Best Management Practices for Waste Management Units

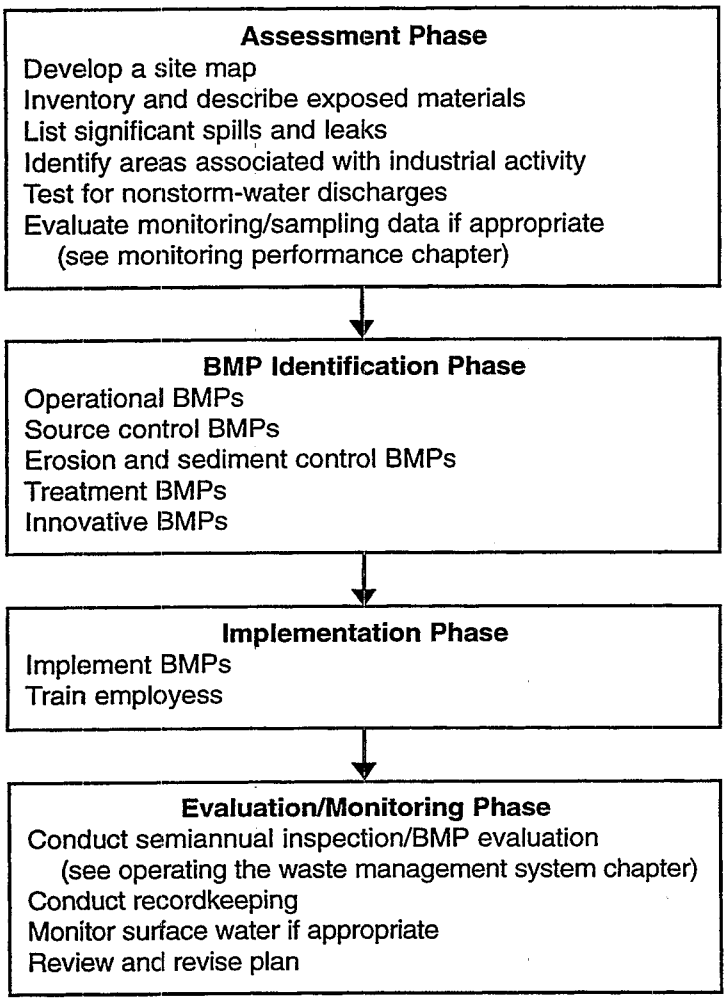
Evaluation of BMPs should be considered in both the design and operation of a waste management unit. Before identifying and implementing BMPs, assess potential sources of storm-water contamination. Two of the most common sources of contamination from waste management units are erosion and sediment discharges caused by storm events. To conduct a thorough assessment, create a map of the waste management unit area, review operating practices, and consider the design of the waste management unit. Designing a surface-water management system requires a knowledge of local precipitation patterns, surrounding topographic features, and geologic conditions. After a unit is in place, consider sampling run-off to ascertain the quantity and concentration of pollutants currently being discharged. (Refer to the chapter on monitoring performance for more information.) Collecting this information may help select the most appropriate BMPs to prevent or control pollutant discharges. Figure 1 illustrates the process of identifying and selecting the most appropriate BMPs.

After assessing the potential and existing sources of storm water contamination, the

What are BMPs?

BMPs are measures used to reduce or eliminate contaminate releases to the environment. They can take the form of a process, activity, or physical structure.

Figure 1. BMP Identification and Selection Flow Chart



Adapted from U.S. EPA. 1992. *Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices.* EPA832-R-92-006.

next step is to select appropriate BMPs to address these pollutant contamination sources. BMPs fall into three categories: baseline, activity-specific, and site-specific.

A. Baseline BMPs

These practices are, for the most part, inexpensive and relatively simple. They are geared toward preventing situations that could lead to surface-water contamination before they occur. Many industrial facilities already have these measures in place for product loss prevention, accident and fire prevention, worker health and safety, or compliance with other regulations. (See the chapter on operating the waste management system.) Baseline BMPs include the following measures.

Good housekeeping. A clean and orderly work environment is an effective first step toward preventing contamination of run-on and run-off. Inventory materials effectively and, if appropriate, store them safely in areas protected from precipitation and other water.

Preventive maintenance. Expand existing facility maintenance programs to include inspection, upkeep, and repair or replacement of surface-water protection systems.

Visual inspections. Conduct inspections of surface-water protection systems and waste management unit areas to discover potential problems and identify necessary changes. Areas to pay particularly close attention to include previous spill locations; material storage, handling, and transfer areas; and waste storage, treatment, and disposal areas. Promptly rectify any situations, such as leaks or spills, that could lead to surface-water contamination.

Spill prevention and response. Establish standard general operating practices for safety and spill prevention to reduce accidental

releases that could contaminate run-on and run-off. Devise spill response plans to prevent any accidental releases from reaching surface water.

Training employees to operate, inspect, and maintain surface-water protection measures is itself considered a BMP, as is keeping records of installation, inspection, maintenance, and performance of surface-water protection measures. For more information on employee training and record keeping, consult the chapter on operating the waste management system.

B. Activity-Specific BMPs

After planning for baseline BMPs, consider planning for activity-specific BMPs. In the BMP manual for industrial facilities, *Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices* (EPA832-R-92-006), EPA developed activity-specific BMPs for nine industrial activities, including waste management. The waste management BMPs are summarized in this section. Like baseline BMPs, these are often procedural rather than structural measures and, therefore, are often inexpensive and easy to implement.

Prevent waste leaks and dust emissions due to vehicular travel. To prevent leaks, ensure that trucks moving waste into and around a unit have baffles (if they carry liquid waste) or sealed gates, spill guards, or tarpaulin covers (if the waste is solid or semisolid). To minimize tracking dust off site where it can be picked up by storm water, wash trucks in a curbed truck wash area where wash water is captured and properly handled. For more information on these topics, consult the chapter on operating the waste management system. Please be aware that washwater from vehicle and equipment cleaning is considered to be "process wastewaters," and is not eligible for discharge under EPA's Multi-Sector General Permit for industrial storm water discharges. Such discharges would require coverage under either an individually drafted, site-specific NPDES permit, or an alternative NPDES general permit if one is available.

For land application, choose appropriate slopes. Minimize run-off by designing a site with slopes less than six percent. Moderate slopes help reduce storm-water run-off velocity, which encourages sedimentation and infiltration, and reduces erosion. Storm-water discharges from land application units are also regulated under the Multi-Sector General Permit.

C. Site-Specific BMPs

In addition to baseline and activity-specific BMPs, consider site-specific BMPs, which are more advanced measures tailored to specific pollutant sources at a particular waste management unit. These site-specific BMPs are grouped into seven areas—flow diversion, exposure minimization, sediment and erosion prevention, infiltration, mitigation, wetlands, and other prevention—for discussion below. With many of the surface-water protection techniques described in this section, it is important to design for an appropriate storm event. Generally, structures that control run-on and run-off should be designed for the discharge of a 24-hour, 25-year storm event.[3]

BMP Maintenance

Maintain these BMPs to ensure adequate surface-water protection. Maintenance is important because storms may damage surface-water protection systems, such as storage basin embarkments or spillways. Run-off may also cause sediments to settle in storage basins or ditches and carry floatables—tree branches, lumber, leaves, and litter—to the basin. Facilties may need to repair storm-water controls and periodically remove sediment and floatables.

[3]This discharge is the amount of water resulting from a 24-hour rainfall event of a magnitude with a 4 percent statistical likelihood of occurring in any given year (i.e, once every 25 years). Such an event may not occur in a given 25-year period, or may occur more than once during a single year.

When selecting and designing surface-water protection systems, consult state, regional, and local watershed management organizations. Some of these organizations maintain management plans devised at the overall watershed level that address storm-water control. They may be able to offer guidance in developing surface-water protection systems for optimal coordination with others in the watershed. As a general guide, once a BMP has been implemented, evaluate the effectiveness of the selected BMPs from time to time.

1. Flow Diversion Practices

These measures are used to protect surface water in two ways. First, they channel storm water away from waste management units to minimize contact of water with waste. Second, they carry polluted or potentially polluted materials to treatment facilities.

a. Storm-Water Conveyances (Channels, Gutters, Drains, and Sewers)

Storm-water conveyances, such as channels, gutters, drains, and sewers, may prevent storm-water run-on from entering a waste management unit or run-off from leaving a unit untreated. Some run-on and run-off conveyances collect storm water and route it around waste containment areas to prevent contact with the waste, which might otherwise contaminate storm water with pollutants. Other conveyances collect water that may have already come into contact with the waste management unit and carry it to a treatment plant (or possibly back to the unit for reapplication in the case of land application units). Conveyances should not mix the stream of storm water diverted around the unit with that of water that may have contacted waste. Remember, storm water that contacts waste is considered leachate and can only be discharged in accordance with an NPDES permit other than the Multi-Sector General Permit.

Conveyances can:

Direct storm-water flows around industrial areas, prevent temporary flooding, require little maintenance, and provide long-term control of storm-water flows.

Keep in mind:

Conveyances require routing through stabilized structures to minimize erosion. They also may increase flow rates, may be impractical if there are space limitations, and may not be economical.

Storm-water conveyances may be constructed of or lined with materials such as concrete, clay tile, asphalt, plastic, metal, riprap, compacted soil, and vegetation. The material used will vary depending on the use of the conveyance and the expected intensity of storm-water flow. Design storm-water conveyances with capacity to accept the estimated storm-water flow associated with the selected design storm event. Section IV below discusses methods for determining these flows.

b. Diversion Dikes

Diversion dikes, often made with compacted soil, direct run-on away from a waste management unit. Dikes usually are built uphill from a unit and work with a storm-water conveyance to divert the water from the unit. To minimize the potential for erosion, diversion dikes are often constructed to redirect run-off at a shallow slope to slow its velocity. A similar means of flow diversion is grading a site to keep storm water away from waste handling areas, instead of or in

Diversion dikes can:

Efectively limit storm-water flows over industrial site areas, be installed at anytime, be economical temporary structure when built from soil onsite, and be converted from temporary to permanent at any time.

Keep in mind:

Diversion dikes are not suitable for large drainage areas unless there is a gentle slope and may require maintenance after heavy rains.

addition to using diversion dikes to redirect water that would otherwise flow into these areas. In planning for the installation of dikes, consider the slope of the drainage area, the height of the dike, the size of the flow it will need to divert, and the type of conveyance that will be used with the dike.

2. Exposure Minimization Practices

These measures, like flow diversion practices, reduce contact of water with waste. They often are small structures immediately surrounding a higher risk area, while flow diversion practices may operate on the scale of an entire waste management unit.

a. Curbing and Diking

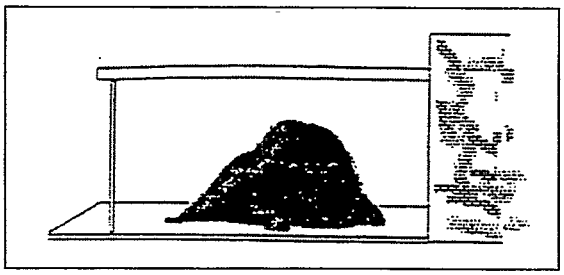
These are raised borders enclosing areas where liquid spills may occur. Such areas could include waste transfer points in land application, truck washes, and leachate management areas at landfills and waste piles. The raised dikes or curbs prevent spilled liquids from flowing to surface waters, enabling prompt cleanup of only a small area.

b. Covering

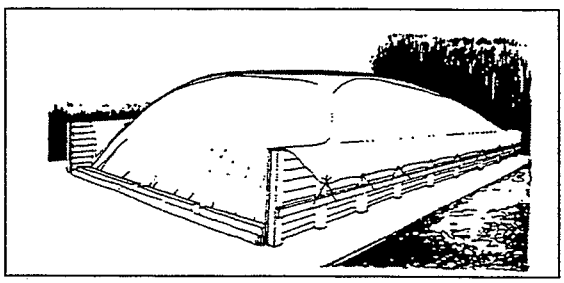
Protect surface water by erecting a roof, tarpaulin, or other permanent or temporary covering (see Figure 2) over areas where sources of surface-water contamination may be located. Such areas could include the active area of a landfill, transfer locations, and stockpiles of daily cover. Combining covering with other measures, such as curbing, can prevent precipitation from falling directly on materials and simultaneously prevent water originating elsewhere from running on to the materials.

If using temporary coverings, ensure that sufficient weight is attached to prevent wind from moving the cover, and repair or replace the cover material if holes or leaks develop.

Figure 2. Coverings



Roof, overhang, or other permanent structure



Tarp or other permanent structure

From U.S. EPA. 1992. *Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices.* EPA832-R-92-006.

3. Sediment and Erosion Prevention Practices

These practices serve to limit erosion (the weathering of soil or rock particles from the ground by wind, water, or human activity) and to prevent particles that are eroded from reaching surface waters as sediment. Erosion and sedimentation can threaten aquatic life, increase treatment costs for downstream water treatment plants, and impede recreational and navigational uses of waterways. Erosion and sedimentation are of particular concern at waste management units because the sediment may be contaminated with waste constituents and because erosion may undercut or otherwise weaken waste containment structures. The following measures can help limit erosion and sedimentation.

a. Vegetation

Reduce erosion and sedimentation by ensuring that areas where water is likely to flow are vegetated. Vegetation slows erosion and sedimentation by shielding soil surfaces from rainfall impacts, improving soil's water storage capacity, holding soil in place, slowing run-off, and enabling sediment to drop out. One means of providing vegetation is to preserve natural growth. This is achieved by managing construction of the unit to minimize disturbance of surrounding plants. If it is not possible to leave all areas surrounding a unit undisturbed, preserve strips of existing vegetation as buffer zones in strategically chosen areas of the site where erosion and sediment control is most needed, such as on steep slopes and along stream banks. If it is not possible to leave sufficient buffer zones of existing vegetation, create buffer zones by planting such areas with new vegetation.

Temporary or permanent seeding of erodible areas is another means of controlling erosion and sedimentation using vegetation. Permanent seeding, often of grass, is appropriate for establishing long-term ground cover after construction and other land-disturbing activities are complete. Temporary seeding can help prevent erosion and sedimentation in areas that are exposed but will not be disturbed again for a considerable time. These areas include soil stockpiles, temporary roadbanks, and dikes. Local regulations may require temporary seeding of areas that would otherwise remain exposed greater than a certain length of time. Consult local officials to determine whether such requirements apply. Seeding may not be feasible for quickly establishing cover in arid climates or during nongrowing seasons in other climates. Sod, although more expensive, may be more tolerant of these conditions than is seed and may establish a denser grass cover more quickly. Compost can also be used effectively to establish vegetation on slopes.

Three other practices are often considered along with vegetative measures. First, streambank stabilization is the reinforcement of stream banks with stones, concrete or asphalt, logs, or gabions— structures formed from crushed rock encased in wire mesh. Stabilization is appropriate where stream flow may be increased due to construction or other unit activities and where vegetative measures are not practical. Second, mulching, compost, matting, and netting cover surfaces that are steep, arid, or otherwise unsuitable for planting. These methods also can work in conjunction with planting to secure and protect seeds. Mattings are sheets of mulch that are more stable than loose mulch chips. Netting is a mesh of jute, wood fiber, plastic, paper, or cotton that can hold mulch on the ground or stabilize soils. These measures are sometimes used with seeding to provide insulation, protect against

birds, and hold seeds and soil in place. Third, chemical stabilization—also known as chemical mulch, soil binder, or soil palliative—involves spraying vinyl, asphalt, or rubber onto soil surfaces to hold the soil in place and protect against erosion. Erosion and sediment control is immediate upon spraying and does not depend on climate or season. Apply stabilizer according to manufacturer's instructions to ensure that water quality is not affected, and avoid coating a large area with a thick layer of stabilizer, which would create an impervious surface and speed run-off to downgradient areas.

b. Interceptor Dikes and Swales

Dikes, or ridges of compacted soil, and swales, excavated depressions in which water flows, work together to prevent entry of run-on into erodible areas. A dike is built across a slope upgradient of an area to be protected, such as a waste management unit, with a swale just above the dike. Water flows down the slope, accumulates in the swale, and is blocked from exiting it by the dike. The swale is graded to direct water slowly downhill across the slope to a stabilized outlet structure. Since flows are concentrated in the swale, it is important to vegetate the swale to prevent erosion of its channel and grade it so that predicted flows will not damage vegetation.

c. Pipe Slope Drains

Pipe slope drains are flexible pipes or hoses used to traverse a slope that is already damaged or at high risk of erosion. They are often used in conjunction with some means of blocking water flow on the slope, such as a dike. Water collects against the dike and is then channeled to one point along the dike where it enters the pipe, which conveys it downhill to a stabilized (usually riprap-lined) outlet area at the bottom of the slope. Ensure that pipes are of adequate size to accommodate the design storm event and are kept clear of clogs.

d. Silt Fences, Straw Bales, and Brush Barriers

Silt fences (see Figure 3) and straw bales (see Figure 4) are temporary measures designed to capture sediment that has already eroded and to reduce the velocity of storm water. Silt fences and straw bales should not be considered permanent measures. They could be used, for example, during construction of a waste management unit or on a final cover before permanent grass growth is established. Silt fences consist of geotextile fabric supported by wooden posts. These fences slow the flow of water and retain sediment as water filters through the geotextile fabric. If properly installed, straw bales perform a similar function. Straw bales should be placed end to end (with no gaps in between) in a shallow, excavated trench and staked into place. Silt fences and straw bales limit sediment entering

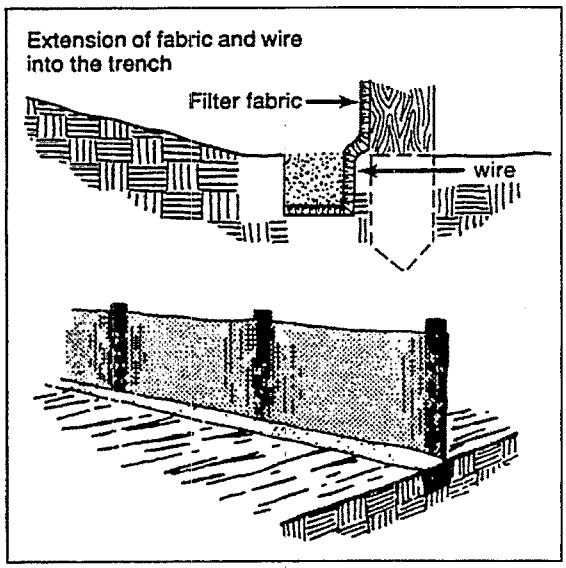
Silt fences, straw bales, and brush barriers can:

Prevent downstream damage from sediment deposits and inexpensively prevent eroded materials from reaching surface waters

Keep in mind:

These measures are not aproriate for streams or large swales and pose a risk of washouts if improperly installed.

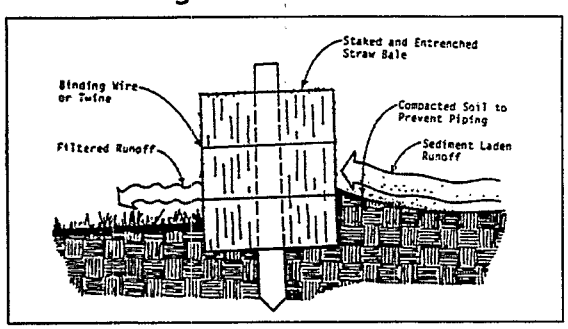
Figure 3. Silt Fence



Bottom: Perspective of silt fence. Top: Cross-section detail of base of silt fence.

From U.S. EPA. 1992. *Storm Water Management for Industrial Activitites: Developing Pollution Prevention Plans and Best Management Practices.* EPA832-R-006.

Figure 4. Straw Bale



From U.S. EPA. 1992. *Storm Water Management for Industrial Activitites: Developing Pollution Prevention Plans and Best Management Practices.* EPA832-R-006.

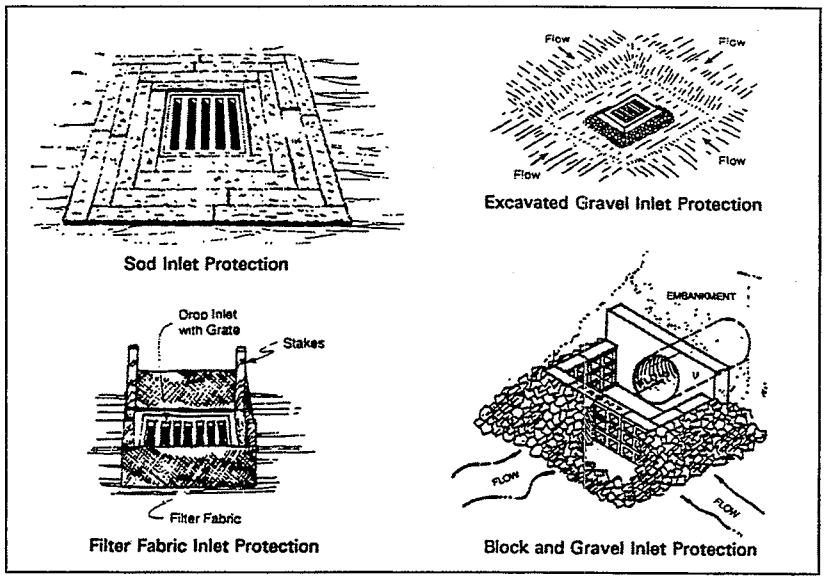
receiving waters. Both measures require frequent inspection and maintenance, including checking for channels eroded beneath the fence or bales, removing accumulated sediment, and replacing damaged or deteriorated sections.

Brush barriers work like silt fences and straw bales but are constructed of readily available materials. They consist of brush and other vegetative debris piled in a row and are often covered with filter fabric to hold them in place and increase sediment interception. Brush barriers are inexpensive due to their reuse of material that is likely available from clearing the site. New vegetation often grows in the organic material of a brush barrier, helping anchor the barrier with roots. Depending on the material used, it may be possible to leave a former brush barrier in place and allow it to biodegrade, rather than remove it.

e. *Storm Drain Inlet Protection*

Filtering measures placed around any inlet or drain to trap sediment are known as inlet protection (see Figure 5). These measures prevent sediment from entering inlets or drains and possibly making their way to the receiving waters into which the storm drainage system discharges. Keeping sediment out of drainage systems also serves to prevent clogging, loss of capacity, and other problems associated with siltation of drainage structures. Inlet protection methods include sod, excavated areas for settlement of sediment, straw bales or filter fence, and gravel or stone with wire mesh. These measures are appropriate for inlets draining small areas where soil will be disturbed. Some jurisdictions require installation of these measures before disturbance of more than a certain acreage of land begins. Clean accumulated sediment from inlet protection material frequently to ensure continued operation.

Figure 5. Storm Drain Inlet Protection



From U.S. EPA. 1992. *Storm Water Management for Industrial Activitites: Developing Pollution Prevention Plans and Best Management Practices.* EPA832-R-006.

f. *Collection and Sedimentation Basins*

A collection or sedimentation basin (see Figure 6) is an area that retains run-off long enough to allow most of the sediment to settle out and accumulate on the bottom of the basin. Since many pollutants are attached to suspended solids, some other pollutants also may settle out in the basin with the sediment. The quantity of sediment removed will depend on basin volume, inlet and outlet configuration, basin depth and shape, and retention time. Basins should be periodically dredged to remove the accumulated sediment and regularly maintained to minimize growth of aquatic plants that can reduce their effectiveness. All dredged materials, whether they are disposed of or reused, should be managed appropriately.

Basins also may present a safety hazard. Fences or other measures to prevent unwanted public access to the basins and their associated inlet and outlet structures are prudent safety precautions.

In designing collection or sedimentation basins (a form of surface impoundment), consider stormwater flow, sediment and pollutant loadings, and the characteristics of expected pollutants. In the case of certain pollutants, it may be appropriate to line the basins to protect the ground water below. Lining a basin with concrete also facilitates maintenance by allowing dredging vehicles to drive into a drained basin and remove sediment. Poor implementation of baseline and activity-specific BMPs may result in high sediment and pollutant loads, leading to unusually frequent dredging of settled materials. For this reason, when operating sedimentation basins, ensure that baseline and activity-specific BMPs are first implemented to the fullest extent practicable. Construction of these basins should be

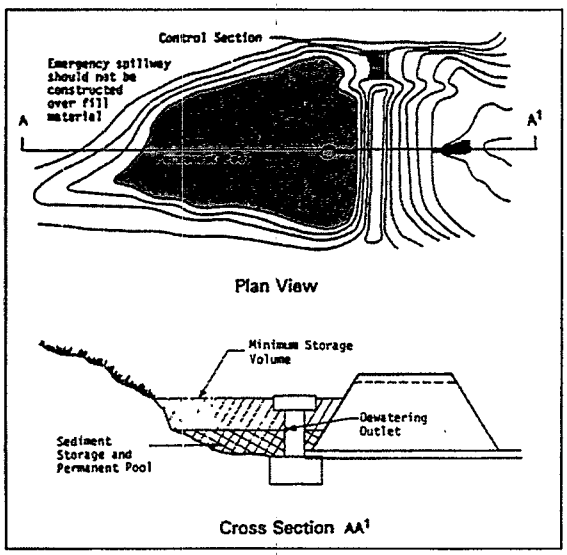
Sedimentation basins can:

Protect downstream areas against clogging or damage, and contain smaller sediment particles than sediment traps can due to their longer detention time.

Keep in mind:

Sedimentation basins are generally not suitable for large areas, require regular maintenance and cleaning, and will not remove very fine silts and clays unless used with other measures

Figure 6.
Collection and Sedimentation Basins



From U.S. EPA. 1992. *Storm Water Management for Industrial Activitites: Developing Pollution Prevention Plans and Best Management Practices.* EPA832-R-006.

supervised by a qualified engineer familiar with state, regional or watershed, and local storm-water requirements.

g. Check Dams

Small rock or log dams erected across a ditch, swale, or channel can reduce the speed of water flow in the conveyance. This reduces erosion and also allows sediment to settle out along the channel. Check dams are especially useful in steep, fast-flowing swales where vegetation cannot be established. For best results, place check dams along the swale so that the crest of each check dam is at the same elevation as the toe (lowest point) of the previous (upstream) check dam. Check dams work best in conveyances draining small areas and should be installed only in manmade conveyances. Placement of check dams in streams may require a permit and is not recommended.

h. Terraces and Benches

Terraces and benches are earthen embankments with flat tops or ridge-and-channels. Terraces and benches hold moisture and minimize sediment loadings in run-off. They may be used on land with no vegetation or where it is anticipated that erosion will be a problem. Terraces and benches reduce erosion damage by capturing surface run-off and directing it to a point where the run-off will not cause erosion or damage. For best results, this point should be a grassy waterway, vegetated area, or tiled outlet. Terraces and benches should not be constructed on sandy or rocky slopes.

What are some advantages of terraces and benches?

Terraces and benches reduce run-off speed and increase the distance of overland run-off flow. In addition, they hold moisture better than do smooth slopes and minimize sediment loading of surface run-off.

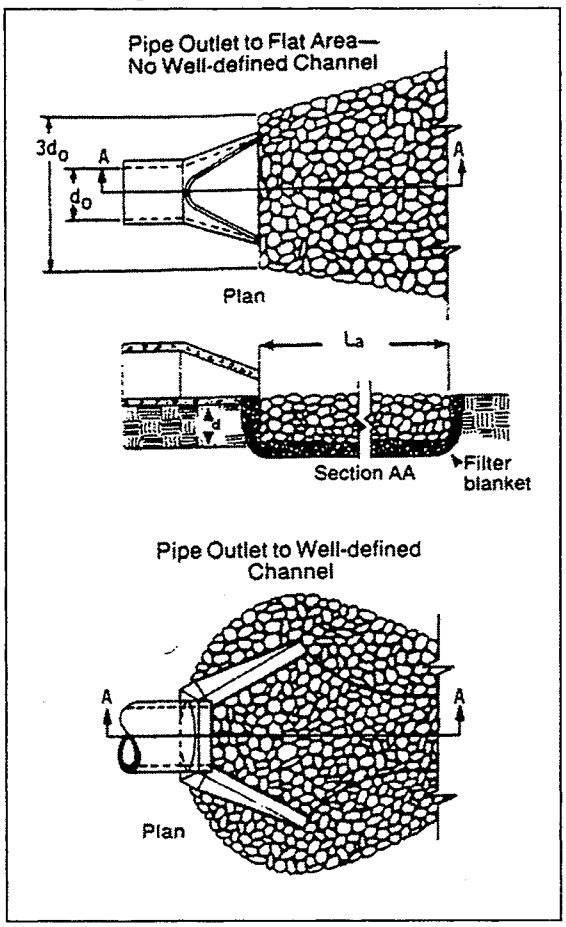
What are some disadvantages of terraces and benches?

Terraces and benches may significantly increase cut and fill costs and cause sloughing if excess water infiltrates the soil. They are also not practical for sandy, steep, or shallow soils.

i. Outlet Protection

Stone, riprap, pavement, or other stabilized surfaces placed at a storm-water conveyance outlet are known as outlet protection (see Figure 7). Outlet protection reduces the speed of concentrated storm-water flows exiting the outlet, lessening erosion and scour of

Figure 7. Outlet Protection



From U.S. EPA. 1992. *Storm Water Management for Industrial Activitites: Developing Pollution Prevention Plans and Best Management Practices.* EPA832-R-006.

channels downstream. It also removes sediment by acting as a filter medium. Consider installing outlet protection wherever predicted outflow velocities may cause erosion.

4. Infiltration Practices

These measures encourage quick infiltration of storm-water run-off by preserving or providing porous surfaces. Infiltration not only reduces run-off velocity but also provides some treatment of run-off, preserves natural stream flow, and recharges ground water. In many cases, these added functions are beneficial, but they may make infiltration practices inappropriate on unstable slopes, in cases where run-off may be contaminated, or where wells, foundations, or septic fields are nearby.

a. Vegetated Filter Strips and Grassed Swales

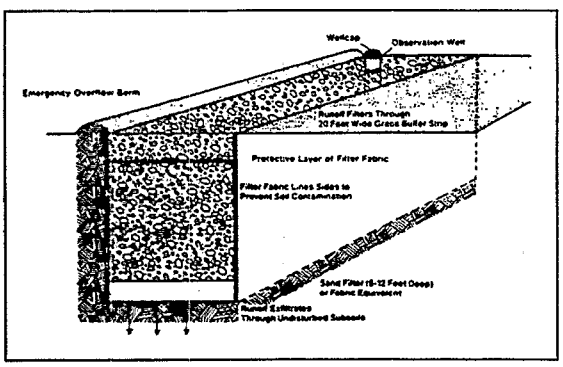
Vegetated filter strips are gently sloped areas of natural or planted vegetation. They allow water to pass over them in sheetflow (run-off that flows in a thin, even layer), infiltrate the land, and drop sediment. Vegetated filter strips are appropriate where soils are well drained and the ground-water table is well below the surface. They will not work well on slopes of 15 percent or more due to high run-off velocity. Strips should be at least 20 feet wide and 50 to 75 feet long in general, and longer on steeper slopes. If possible, plan to leave existing natural vegetation in place as filter strips, rather than planting new vegetation, which will not function as well until it becomes established.

Grassed swales function similarly to nonvegetated swales (see Sediment and Erosion Control Practices above) except that grass planted along the swale bottom and sides will slow water flow and filter out sediment. Permeable soil in which the swale is cut encourages reduction of water volume through infiltration. Check dams (see Sediment and Erosion Control Practices above) are sometimes provided in grassed swales to further slow run-off velocity, increasing the rate of infiltration. To optimize swale performance, use a soil which is permeable but not excessively so; very sandy soils may not hold vegetation well or may not form a stable channel structure. Additionally, grade the swale to a very gentle slope to maximize infiltration.

b. Infiltration Trenches

An infiltration trench (see Figure 8) is a long, narrow excavation ranging from 3 to 12 feet deep. It is filled with stone to allow for temporary storage of storm water in the open spaces between the stones. The water eventually infiltrates surrounding soil or is collected by perforated pipes in the bottom of the trench and conveyed to an outflow point. Such trenches can remove fine sediments and soluble pollutants. They should not be built in relatively impervious soils, such as clay, that would prevent water from draining from the bottom of the trench; less than 3 feet above the water table; in soil that is subject to deep frost penetration; or at the foot of slopes steeper than 5 percent. Infiltration trenches should not be used to handle contaminated run-off. Run-off can be pretreated using a grass buffer/filter strip or treated in the trench with filter fabric.

Figure 8. Infiltration Trench



From U.S. EPA. 1992. Storm Water Management for Industrial Activitites: Developing Pollution Prevention Plans and Best Management Practices. EPA832-R-006.

5. Other Prevention Practices

Prevention of surface-water contamination can be accomplished by means other than flow diversion, exposure minimization, sediment and erosion control, or infiltration. Many of these practices are simple and inexpensive to implement.

a. Preventive Monitoring

This includes automatic monitoring and control systems, monitoring of operations by unit personnel, and testing of equipment. These processes ensure that equipment functions as designed and is in good repair, so that spills and leaks, which could contaminate surface water, are minimized and do not go undetected when they do occur. Some automatic monitoring equipment, such as pressure gauges coupled with pressure relief devices, can correct problems without human intervention, preventing leaks or spills that could contaminate surface water if allowed to occur. Other monitoring equipment may provide early warning of problems so that personnel can intervene before leaks or spills occur. Systems that could contaminate surface water if they failed and that could benefit from automatic monitoring or early warning devices include leachate pumping and treatment systems, liquid waste distribution and storage systems at land application units, and contaminated run-off conveyances.

b. Dust Control

In addition to being an airborne pollutant itself, dust can be deposited as sediment in run-off, threatening downstream surface waters. Several methods of dust control are available to prevent this. These include irrigation, chemical treatments, minimization of exposed soil areas, wind breaks, tillage, and sweeping. For further information on dust control, consult the chapter on operating the waste management system.

c. Vehicle Washing

Materials that accumulate on tires and other vehicle surfaces and then disperse across a facility are an important source of surface-water contamination. Vehicle washing removes materials such as dust and waste. Washing stations can be located near waste transfer areas or near the site exit. Pressurized water spray is usually sufficient to remove dust. Waste water from vehicle washing operations should be contained and handled appropriately. Discharge of such waste water requires an NPDES permit other than the Multi-Sector General Permit.

6. Mitigation Practices

These practices contain, clean up, or recover spilled, leaked, or loose material before it can reach surface water and cause contamination. Other BMPs should be considered and implemented to avoid releases, but procedures for mitigation should be devised so that unit personnel can react quickly and effectively to any releases that do occur. Mitigation practices include simply sweeping or shoveling loose waste into appropriate areas of the unit, vacuuming or pumping spilled materials into appropriate treatment or handling systems, cleaning up liquid waste or leachate using sorbents such as sawdust, or applying gelling agents to prevent spilled liquid from flowing towards surface water.

a. Discharges to Wetlands

Other methods of storm-water control are available, such as discharge to constructed wetlands. These methods are less frequently used and may involve more complicated designs. The discharge of storm water into natural wetlands, or the modification of such wetlands to improve their treatment capacity, may damage a wetland ecosystem and, therefore, is subject to federal, state, and local regulations.

Constructed wetlands can:

Provide aesthetic as well as water quality benefits and areas for wildlife habitat.

Keep in mind:

This method may be subject to multiple federal, state and local regulations. In addition, constructed wetlands may not be feasible if land is not available and may not be effective until time has been allowed for substantial plant growth.

Constructed wetlands provide an alternative to natural wetlands. In this method, a specially designed pond or basin, which is lined in some cases, is stocked with wetland plants that can manage pollutants through biological uptake, microbial action, and other mechanisms, as well as sedimentation. This process often results in better pollutant removal than would be expected from sedimentation alone. When designing constructed wetlands, consider that maintenance may include dredging, similar to that required for sedimentation basins; provisions for a dry-weather flow to maintain the wetlands; measures to limit mosquito breeding; structures to prevent escape of floating wetland plants (such as water hyacinths) into downstream areas where they are undesirable; and a program of harvesting and replacing plants.

IV. Methods of Calculating Run-on and Run-off Rates

The design and operation of surface-water protection systems will be driven by storm-water flow. Calculate run-on and run-off

flows for the chosen design storm event in order to properly size controls and minimize storm-water impacts. Controls based on too small a design storm event, or sized without calculating flows, may release contaminated storm water. Similarly, systems can also be designed for too large a flow, resulting in unnecessary controls and excessive costs.

The usual approach for sizing surface-water protection systems relies on the use of standardized "design storms." A design storm is, in theory, representative of many recorded storms and reflects the intensity, volume, and duration of a storm predicted to recur once in a given number of years. In general, surface-water protection structures should be designed to handle the discharge from a 24-hour, 25-year storm event—a rainfall event of 24 hours duration and of such a magnitude that it has a 4 percent statistical likelihood of occurring in any given year.

The Hydrometeorological Design Studies Center (HDSC) at the National Weather Service has prepared *Technical Paper 40, Rainfall Frequency Atlas of the United States for Durations From 30 Minutes to 24 Hours and Return Periods From 1 to 100 Years.* This document, published in 1961, contains rainfall intensity information for the entire United States. Another HDSC document, *NOAA Atlas 2, Precipitation Frequency Atlas of the Western United States* comes in 11 volumes, one for the 11 westernmost of the contiguous 48 states. It was published in 1973. Precipitation frequency maps for the eleven western most states are available on the Western Regional Climate Center's web page at **< www.wrcc.sage.dri.edu/pcpnfreq.html >**, and are included in Appendix IV. HDSC is currently assembling more recent data for some areas. The state or local regulatory agency may be able to provide data for the area.

Several methods are available to help calculate storm-water flows. The Rational Method (see sidebar) may be used for calculating run-off for areas of less than 200 acres. Another potentially helpful tool for estimating storm flows is the Natural Resource Conservation Service's TR-55 software.[4] TR-55 estimates run-off volume from accumulated rainfall and then applies the run-off volume to a simplified hydrograph for peak discharge total run-off estimations.

Rational Method for Calculating Storm-Water Run-off Flow

$Q = cia$

where

Q = peak flow rate (run-off), in cubic feet per second (cfs)*

c = run-off coefficient, unitless. The coefficient c is not directly calculable, so average values based on experience are used. Values of c range from 0 (all infiltration, no run-off) to 1 (all run-off, no infiltration). For example, flat lawns with sandy soil have c of 0.05 to 0.10, while concrete streets have c of 0.80 to 095.

i = average rainfall intensity, in inches per hour, for the time of concentration, t_c, which is a calculable flowtime from the most distant point in the drainage area to the point at which Q is being calculated. Once t_c is calculated and a design storm event frequency selected, i can be read from a graph such as that shown in Figure 9.

a = drainage area, in acres. The drainage area is the expanse in which all run-off flows to the point at which Q is being calculated.

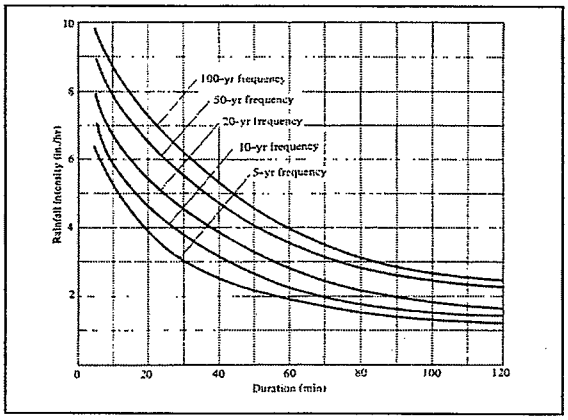
* Examining the units of i and *a* would indicate that *Q* should be in units of ac-in/hr. Since1 ac-in/hr = 1.008 cfs, however, the units are interchangeable with a negligible loss of accuracy, and units of cfs are usually desired for subsequent calculations.

[4]TR-55, Urban Hydrology for Small Watersheds Technical Release 55, presents simplified procedures to calculate storm run-off volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. These procedures are applicable in small and especially urbanizing watersheds. TR-55 can be downloaded from NRCS at **<www.ncg.nrcs.usda.gov/tech_tools.html>**.

Computer models are available to aid in the design of run-on and run-off control (see sidebar). EPA's Storm Water Management Model (SWMM) is a comprehensive model capable of simulating the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage treatment units, and finally to receiving water bodies. Using SWMM, it may be possible to perform both single-event and continuous simulation on catchments having storm sewers and natural drainage, for prediction of flows, stages, and pollutant concentrations.

Some models, including SWMM, were developed for purposes of urban storm-water control system design, so it is necessary to ensure that their methodology is applicable to design for industrial units. As with all computer models, these should be used as part of the array of design tools, rather than as a substitute for careful consideration of the unit's design by qualified professionals.

Figure 9. Typical Intensity-Duration-Frequency Curves



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BASINS: A Powerful Tool for Managing Watersheds. A multi-purpose environmental analysis system that integrates a geographical information system (GIS), national watershed data, and state-of-the-art environmental assessment and modeling tools into one convenient package.

Storm Water Management Model (SWMM). Simulates the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage treatment units, and receiving waters.

The Source Loading and Management Model (SLAMM). Explores relationships between sources of urban run-off pollutants and run-off quality. It now includes a wide variety of source area and outfall control practices. SLAMM is strongly based on actual field observations, with minimal reliance on theoretical processes that have not been adequately documented or confirmed in the field. SLAMM is mostly used as a planning tool, to better understand sources of urban run-off pollutants and their control.

Simulation for Water Resources in Rural basins (SWRRB). Simulates hydrologic, sedimentation, and nutrient and pesticide transport in large, complex rural watersheds. It can predict the effect of management decisions on water, sediment, and pesticide yield with seasonable accuracy for ungauged rural basins throughout the United States.

Pollutant Routing Model (P-ROUTE). Estimates aqueous pollutant concentrations on a reach by reach flow basis, using 7Q10 or mean flow.

Enhanced Strem Water Quality Model (QUAL2E). Simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration and their effects on the dissolved oxygen balance. It is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality charactersitics of nonpoint sources

Action Items for Protecting Surface Water

Conduct the following activities when designing or operating a units surface-water protection systems.

- ☐ Comply with applicable National Pollutant Discharge Elimination System (NPDES) and state permitting requirements.
- ☐ Assess operating practices, potential pollutant sources, and surface-water flows to determine the need for and type of storm-water controls.
- ☐ Implement baseline and activity-specific best management practices (BMPs), such as good housekeeping practices and spill prevention and response plans.
- ☐ Choose a design storm event, such as the 24-hour, 25-year event, and obtain precipitation intensity data for that event to size storm-water control devices.
- ☐ Select and implement site-specific BMPs, such as diversion dikes, sedimentation basins, and outlet protection.
- ☐ Devise a system for inspecting and maintaining the chosen controls, possibly as part of the operating plan.

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Part IV
Protecting Ground Water

Chapter 7: Section A
Assessing Risk Section

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Assessing Risk

Protect ground water by assessing risk associated with the waste management practices and tailoring management controls accordingly. Use the three-tiered evaluation approach to determine recommended liner systems and whether land application is appropriate. Follow guidance on liner design and land application practices.

Ground water is the water found in the soil and rock that make up the Earth's surface. Although it comprises only about 0.69 percent of the Earth's water resources, ground water is of great importance. It represents about 25 percent of fresh water resources, and, when the largely inaccessible fresh water in ice caps and glaciers is discounted, ground water is the Earth's largest fresh water resource, far surpassing lakes and rivers (see Table 1).[1] Statistics about use of ground water as a drinking water source underscore the importance of the resource. Ground water is a source of drinking water for more than half of the people in the United States.[2] In rural areas, 97 percent of households rely on ground water as their primary source of drinking water.

Table 1.
Earth's Water Resources

Resource	Percent of Total	Percent of Nonoceanic
Oceans	97.25	—
Ice caps and glaciers	2.05	74.65
Ground water and soil moisture	0.685	24.94
Lakes and Rivers	0.0101	0.37
Atmosphere	0.001	0.036
Biosphere	0.00004	0.0015

Adapted from Berner, E.K. and R. Berner. 1987. The Global Water Cycle: Geochemistry and Environment

In addition to its importance for domestic water supplies, ground water is heavily used by industry and agriculture. It provides approximately 37 percent of irrigation water and about 18 percent of the water used by industry.[3] Ground water has other important environmental functions as well, such as providing recharge to lakes, rivers, wetlands, and estuaries.

Water beneath the ground surface occurs in an upper unsaturated or vadose zone and a deeper saturated zone. The unsaturated zone is the area above the water table where the soil pores are not filled with water, although some

[1] Berner, E. K. and R. Berner. 1987. *The Global Water Cycle: Geochemistry and Environment.*

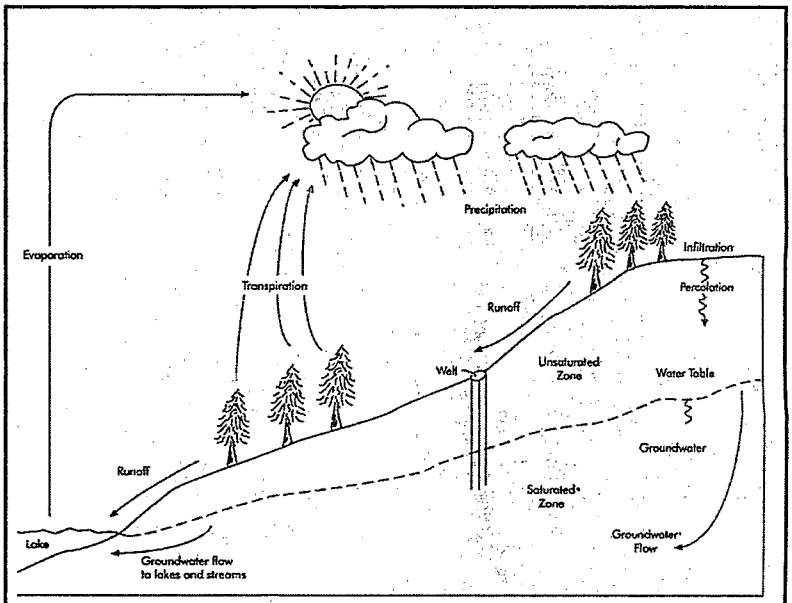
[2] Surface water, in the form of lakes and rivers, is the other major drinking water source. Speidel, D., L. Ruedisili, and A. Agnew. 1988. *Perspectives on Water: Uses and Abuses.*

[3] Excludes cooling water for steam-electric power plants. U.S. Geological Survey. 1998. *Estimated Use of Water in the United States in 1995.* **<www.usgs.gov/watuse>**.

water may be present.[4] The subsurface area below the water table where the pores and cracks are filled with water is called the saturated zone. This chapter focuses on ground water in the saturated zone, from which most ground-water withdrawals are made.

Because ground water is a major source of water for drinking, irrigation, and process water, the public, industry, and federal, state, and local governments are all concerned about ground-water contamination. There are many threats to the quality of ground water, such as infiltration of fertilizers and pesticides, contamination from faulty or overloaded septic fields, and releases from industrial facilities, including waste management units.

Because ground water flows beneath the surface of the earth, and moves very slowly in many aquifers, years may elapse before contamination is discovered and its sources identified. Once ground water has been contaminated, remedial action and monitoring can be costly, can require years of effort, or in some circumstances, might be technically infeasible. For these reasons, it is extremely important to prevent ground-water contamination if possible or minimize impacts by implementing controls tailored to the risks associated with the waste. Natural subsurface processes, such as biodegradation, sorption, and precipitation, can attenuate compounds in the ground water before they reach receptors.



Ground Water in the Hydrologic Cycle

The hydrologic cycle involves the continuous movement of water between the atmosphere, surface water, and the ground. Ground water must be understood in relation to both surface water and atmospheric moisture. Most additions (recharge) to ground water come from the atmosphere in the form of precipitation, but surface water in streams, rivers, and lakes will move into the ground-water system wherever the hydraulic head of the water surface is higher than the water table. Most water entering the ground as precipitation returns to the atmosphere by evapotranspiration. Most water that reaches the saturated zone eventually returns to the surface by flowing to points of discharge, such as rivers, lakes, or springs. Soil, geology, and climate will determine the amounts and rates of flow among the atmospheric, surface, and ground-water systems.

[4] U.S. EPA. 1989. *Glossary of Environmental Terms and Acronym List.*

I. An Overview of the Approach in the Guide

The guidance recommends tailoring protective liner systems to the wastes that are managed in a unit and evaluating whether land application of a waste is appropriate using a three-tiered approach to ground-water modeling and risk assessment. The type of assessment you choose depends, in part, on the complexity of a site and the characteristics of the waste. All three tiers rely on ground-water modeling to evaluate the potential for ground-water contamination. Each successive tier incorporates more site-specific data to tailor recommendations to your circumstances.

The modeling tool for Tiers 1 and 2 is the EPA Industrial Waste Evaluation Model (IWEM) incorporated into the CD ROM version of this guidance. This is a stand-alone, simple-to-use model that does not require previous modeling experience. Tier 1 National Evaluation lookup tables can be found in Appendix I.

Tier 1 - National Evaluation: Once you know the concentrations of constituents in a waste, generic tables provide design recommendations (liner system or waste application concentrations). If the waste contains several constituents, choose the most protective design indicated for any of the constituents. This tier of analysis is the most conservative and will generally recommend more stringent controls. It is designed to be more conservative because it captures a wide range of site conditions across the country.

Tier 2 - Location-Adjusted Evaluation: You can enter data for up to seven of the most sensitive waste and site-specific variables to assess whether an alternative design will be protective. This tier is generally less conservative because it incorporates an intermediate level of specificity in the data.

Tier 3 - Comprehensive Risk Assessment: This tier relies on a comprehensive analysis of site characteristics to determine a design that will be protective. Tier 3 uses substantial amounts of site-specific data.

A. Assessing Risk

IWEM analyzes three liner scenarios over a 10,000 year time frame. The Tier 1 and 2 risk evaluations work as follows. IWEM incorporates 191 constituents with toxicity reference levels that are either drinking water maximum contaminant levels (MCLs) set under the Safe Drinking Water Act or health-based numbers (HBNs) derived from several sources. First, we have identified a benchmark concentration (MCL or HBN) for each constituent in a monitoring well associated with a waste management unit. The goal is not to exceed the benchmark concentrations in the monitoring well. The model starts from this benchmark concentration in the monitoring well and back calculates the effects of dilution and attenuation and release rate from a unit to determine the leachate constituent concentrations for wastes that can be protectively managed in a particular unit design. For land application, the model recommends whether wastes can be protectively land applied, based on leachate constituent concentrations. Finally, the model caps leachate concentrations from an industrial solid waste management unit at a level no higher than 1000 mg/l for any single constituent, because higher leachate concentrations are not expected from these waste management units. The 39 hazardous waste toxicity characteristic constituents (TC) are capped at their TC lev-

els because concentrations above those levels are hazardous waste.

The technical background document accompanying the model thoroughly explains the model, including the parameters that have the greatest effect on modeling results. The sensitive parameters that a user can input at Tier 2, in addition to waste characteristics, are:

- Leakage rate,
- Surface area of the waste management unit,
- Depth to water table,
- Distance to the well,
- Thickness of the aquifer,
- KOC (retardation rate for organic constituents), and adjusted Kd for metals,
- λ (coefficient defining hydrolysis or biodegradation rate).

One of the most sensitive parameters is the leakage rate or the rate at which leachate is released from a unit and moves into subsurface soils. The leakage rate is influenced by a number of factors. Some key factors are the amount of precipitation, the level of liquid in the unit (head), and the hydraulic conductivity of the liner material. Hydraulic conductivity refers to the capacity to transmit fluid. Low hydraulic conductivity slows leachate migration out of a unit. For synthetic liners, the occurrence of tears, rips or holes also influences leakage rate.

Units that rely only on natural soils underlying the unit, including units for direct land application of waste, generally have higher leakage rates. A single clay or synthetic liner can reduce the leakage rate to some extent. However, composite and double liners that combine two or more layers of liner material with leachate collection and leak detection (for double liners) significantly increase the effectiveness of the containment system in minimizing leakage to the subsurface during the period when the leachate collection system is actively managed.

For a landfill that no longer receives waste and for surface impoundments and waste piles where waste remains in place at closure, the cap that is placed over the unit becomes an important component of the final containment system. One key purpose of the final cap is to minimize infiltration of precipitation which generates leachate that may eventually leak into subsurface soils and migrate to ground water. The liner system in the short term, and the cap and the liner system together in the long term, to a large extent determine the leakage rate from the unit. The leakage rate that is associated with various unit designs is one of the most sensitive variables in ground-water risk modeling to evaluate which liner system is protective for managing particular wastes in a unit.

1. The Approach to Liner Performance and Liner Assumptions in the Guide

The guide recommends a comprehensive approach to design, construction, operation and long term care of a waste management unit to minimize the potential for many of these problems. This includes:

- Recommending liner design based on characteristics of waste managed in the unit.
- Strong emphasis on construction quality assurance and control.
- Emphasis on compatibility between the liner and the waste .
- Continuing operation and maintenance practices to protect liner performance.

- Ground-water monitoring as an integral component of a protective management system, to assess liner performance.
- Corrective action to clean up releases.
- Closure with a cap that meets or exceeds the design of the liner (infiltration through the cap equal to or less than leakage through the liner).
- Post closure care and monitoring to maintain the cap for the time period necessary to ensure the waste no longer poses a risk to human health.

In addition, assumptions concerning liner performance have a significant impact on the modeling results. A brief summary of the basis for leakage rate in the modeling scenario for each liner type follows (these performance levels remain constant for the 10,000 year time frame of the model):

No liner: In Tier 1, monte carlo analysis of a range of leakage rates, based on water balance and native soil type for nearest meteorological station. In Tier 2, the model can provide a regional infiltration rate, based on user-specified location.

Single liner: consisting of three feet of compacted clay with a hydraulic conductivity of 10^{-7} cm/s. In Tier 1, monte carlo analysis of a range of infiltration rates, based on water balance for nearest meteorological station. In Tier 2, the model can provide users with a regional infiltration rate, based on user-specified location.

Composite liner: the engineered system includes leachate collection. Landfills are assumed to have a constant hydraulic head of no more than 12 inches. The leakage rate, in Tier 1, is a single value calculated using an equation developed by Bonaparte et al[5], assuming one .005 in.^{2} hole per acre. For landfills, the leakage rate is 0.1 g/a/d and for surface impoundments, 0.9 g/a/d This represents a well designed and installed liner.

2. What We Know About Liners and Caps

In general, we have learned much over the past 20 years about the performance of liner systems and caps, and there have been many improvements in construction, installation, and quality assurance and control procedures. However, we recognize that there is still uncertainty associated with liner performance, in the near term as well as in the long term. While some studies indicate that engineering properties of liners may last for hundreds of years, there are a variety of factors that may influence longevity and performance, such as poor construction, installation or facility operation, or geologic movement below the liner that can cause holes, tears or larger failures. Some defects are likely to have little to moderate effect on the leakage rate. Other defects may have a significant effect and even necessitate corrective action.

We have conducted some preliminary sensitivity analyses to compare leakage rates from a variety of theoretical composite liner scenarios. Scenarios varied the size of holes and tears and the number per acre; contact between the synthetic and the clay layer; the conductivity of the underlying clay layer; and the head of liquid on top of the synthetic liner. Results of these preliminary analyses provided a range of leakage rates ranging from 1.5E-08 m/year to an unrealistically high 353 m/year. As a comparison, the leakage rate used in our composite liner scenario is 3.3E-05 m/yr (landfills). These results indicate several key areas to pursue further analyses. 1) What empirical data are available concerning liner defects at the time of installation; and what data are available concerning actual leakage rates at operating industrial

[5] Bonaparte, R., Giraud, J.P., and Gross, B.A. 1989. "Rates of Leakage Through Landfill Liners," *Proceedings of Geosynthetic '89 Conference, Volume 1.*

waste units to serve as a basis for identifying reasonable performance scenarios? 2) We calculate the leakage rate for our modeling scenario using the equation cited above (and discussed in the *IWEM Technical Background Document*). We are looking for information on the validity of the equation over a wide range of conditions. 3) If we were to model a range of infiltration rates for composite liners, what is a reasonable range to include in the analysis? (A more thorough discussion of the sensitivity analyses is in the *IWEM Technical Background Document*, contained on the CD ROM and available in the docket.)

Another area of uncertainty is the fate of constituents within a unit. Over time, a number of degradation processes may be under way that reduce the hazards associated with some constituents. On the other hand, a landfill with an intact cover may be reasonably dry and thus degradation may be quite slow (also reducing leachate generation). Other toxic constituents, such as heavy metals, will not degrade.

Covers present continuing engineering challenges over time, because they are more susceptible to factors such as freezing and thawing, wetting and drying, temperature fluctuations, root infiltration, and subsidence. Covers are, however, not subject to chemical attack from waste constituents, nor are they subject to the same stresses from waste placement as a bottom liner. Also, final covers are simpler to repair, which would help control the risk of infiltration into the landfill, assuming there is an active program to monitor or periodically replace the cover. Unless the final cover is regularly repaired or replaced, the bottom liner could outlast the cover. While covers containing a synthetic membrane are likely to prevent precipitation from entering a closed unit while they are performing as designed and there are no failures, uncorrected failure of a cover would allow precipitation to enter the unit. After leachate removal is discontinued, this could lead to a "bathtub effect" where the unit has increasing leachate volumes and hydraulic head that could lead to increased leakage rates or overflow.

B. Request For Comments

We invite comments on all aspects of the model, the values, and data sources used for specific parameters, and the modeling scenarios for liner performance, including the following:

- Is the cap of 1000 mg/l concentration for most constituents in leachate from an industrial solid waste management unit, realistic? If not, provide data on which waste units generate leachate at higher concentration levels and what those levels are likely to be.
- What approaches are reasonable to address the question of the changing effectiveness of liners and caps over time?
- Provide data on the occurrence of defects in liners at the time of installation and on changes in leakage rate or other data or indicators of possible changes in liner defects over time.
- The hazardous waste program deals with liner/cap uncertainties by requiring treatment prior to disposal. How should such uncertainties be dealt with for non-hazardous industrial wastes? One possibility is to rely on quality assurance and control, long-term monitoring and corrective action to address non-hazardous waste. Where uncertainties are too great, we could rely on the hazardous waste program to list such wastes as hazardous and require treatment. A second approach could be to rely on treatment of certain non-hazardous wastes. What other approaches are available?
- Should the composite liner scenario, in Tier 1, use a different leakage rate, or monte carlo analysis to reflect a range of

performance levels, rather than a single value? What values should be used, and what is the basis for them?

We are also obtaining peer review of the ground-water model by a group of technical experts who have been commissioned to provide an independent analysis of the model and the way it is used in the guidance. The results of the peer review will be published in the *Federal Register*, so that interested parties may obtain copies of the review and take it into account as they prepare their own comments on the ground-water protection components of the guide.

Construction and installation quality assurance and quality control are critical to ensuring liner performance. The guidance is intended to reflect the most up-to-date installation practices and techniques and the most appropriate materials and techniques for installing a final cap on a unit.

- Are there additional practices and techniques that should be reflected in the guidance?
- For those with experience installing liners and caps and operating lined units, how do you measure liner performance and what are your experiences over time monitoring liner and cap performance?

II. Identification of Contaminants

The guidance addresses constituents with toxicity reference levels (TRLs) (i.e., MCLs and HBNs). These constituents have been included because they have human health concentration levels for exposure through drinking water. MCLs are drinking water standards, set in the Safe Drinking Water Act, which establish the maximum permissible level of a contaminant allowed in drinking water. A list of constituents with MCLs used in this guidance's ground-water risk modeling can be found in Table 2. A HBN is a level which is derived from reference doses or reference concentrations which estimate daily exposure to a constituent that is likely to be without appreciable risk of deleterious effects during a human lifetime. For further information on TRLs, see the *User's Guide and Background Document for the Industrial Waste Management Evaluation Model.*

This guidance addresses both MCLs and HBNs, to the extent available, for each constituent. The constituents specifically addressed by this guidance include both organic and inorganic chemicals. Organic chemicals are chemical compounds containing carbon.[6] Inorganic chemicals include chemical substances of mineral origin, such as cadmium and chromium. For the 191 constituents included in the guidance, 51 have an MCL, 189 have an HBN value, and 41 have both. TRLs may vary from state to state. States can impose more stringent drinking water standards than federal MCLs.[7] To keep the software developed for this guidance up to date and to accommodate concerns at levels different from the current TRLs, the TRL values can be modified by the user of the software.

A first step in determining the most appropriate waste management unit design is to identify the constituents in the waste and expected leachate concentrations from the waste. For information on determining leachate concentrations, see the characterizing waste chapter.

[6]Some regulatory definitions include carbon monoxide, carbon dioxide, etc. as organic compounds, some definitions exclude them as organic compounds. Lee, C. 1992. *Environmental Engineering Dictionary*, 2d. Ed.

[7]For example, a state can make secondary MCLs, which are not federally enforceable standards, mandatory, or a state may use different exposure assumptions which result in a different HBN.

Table 2.
List Of Constituents with maximum Contaminant Levels (MCLs)

Organics with an MCL	mg/l		mg/l
Benzene	0.005	HCH (Lindane) gamma-	0.0002
Benzo[a]pyrene	0.0002	Heptachlor	0.0004
Bis(2-ethylhexyl)phthalate	0.006	Heptachlor epoxide	0.0002
Bromodichloromethane*	0.10	Hexachlorobenzene	0.001
Butyl-4,6-dinitrophenol,2-sec-(Dinoseb)	0.007	Hexachlorocyclopentadiene	0.05
Carbon tetrachloride	0.005	Methoxychlor	0.04
Chlordane	0.002	Methylene chloride (Dichloromethane)	0.005
Chlorobenzene	0.1	Pentachlorophenol	0.001
Chlorodibromomethane*	0.10	Polychlorinated biphenyls (Aroclors)	0.0005
Chloroform*	0.10	Styrene	0.1
Dibromo-3-chloropropane 1,2-	0.0002	TCD Dioxin 2,3,7,8-	0.00000003
Dichlorobenzene 1,2-	0.6	Tetrachloroethylene	0.005
Dichlorobenzene 1,4-	0.075	Toluene	1
Dichloroethane 1,2-	0.005	Toxaphene (chlorinated camphenes)	0.003
Dichloroethylene cis-1,2-	0.07	Tribromomethane (Bromoform)*	0.10
Dichloroethylene trans-1,2-	0.1	Trichlorobenzene 1,2,4-	0.07
Dichloroethylene 1,1-(Vinylidene chloride)	0.007	Trichloroethane 1,1,1-	0.2
Dichloropropane 1,2-	0.005	Trichloroethane 1,1,2-	0.005
Endrin	0.002	Trichloroethylene (1,1,2-Trichloroethylene)	0.005
Ethylbenzene	0.7	Vinyl chloride	0.002
Ethylene dibromide (1,2-Dibromoethane)	0.00005	Xylenes	10
Inorganics with an MCL			
Antimony	0.006	Chromium	0.1
Arsenic	0.05	Mercury	0.002
Barium	2.0	Selenium	0.05
Berylium	0.004	Silver**	0.10
Cadmium	0.005	Thallium	0.002

<www.epa.gov/OGWDW/wot/appa.html>.

* Listed as Total Trihalomethanes (TTHMs), constituents do not have individually listed MCLs.

** Silver is a secondary MCL. Secondary MCLs (SMCLs) are non-enforceable guidelines regulating contaminants that may cause cosmetic effects, such as skin or tooth discoloration, or aesthetic effects, such as taste, odor, or color, in drinking water.

A. Exposure Assessment: Understanding Fate and Transport

A source of ground-water contamination from a waste management unit is the release of leachate. Residents who live close to a waste management unit and who use wells for water supply can be directly exposed to waste constituents by drinking or bathing in contaminated ground water. Residents also can be exposed by inhaling volatile organic compounds (VOCs) released during use of ground water such as during showering, when volatile compounds can be released to the air.

Releases from a waste management unit and subsequent transport of constituents to ground water are affected by three types of factors: waste characteristics, site characteristics, and liner system design (as the primary containment system to minimize release of constituents of concern out of a unit).

First, the physical, chemical, and biological properties of the waste/constituents affect the potential for constituents to leach or otherwise be released into the environment. For example, waste characteristics influence how a liner system prevents or mitigates the migration of leachate. Wastes that are highly acidic or alkaline can dissolve soil minerals and thus increase the hydraulic conductivity or permeability of a compacted clay liner. Waste constituent characteristics affect the movement or transport of constituents through soil and ground water. For example, wastes with a density lower than ground water tend to concentrate in the upper portions of an aquifer, while those with a higher density concentrate in the lower portions. The viscosity (tendency to resist internal flow) of specific contaminants affects their rate of migration through soil and within an aquifer. Solubility (which affects the mobile concentration), chemical structure, and many other waste constituent properties can affect contaminant migration.

Second, site characteristics, including geologic setting and hydrology, may inhibit or facilitate movement of constituents. Natural subsurface processes, such as biodegradation, sorption, and precipitation, can attenuate compounds in the ground water before they reach receptors. Alternatively, fractures in rocks can act as conduits and water can move through them quickly carrying contaminants.

Finally, engineered liners have a variety of properties that contain constituents to varying degrees. Compacted clays, geomembranes, and composite liners act as hydraulic barriers to minimize release of leachate.[8] Compacted clay liners also can reduce the concentration of constituent levels through attenuation. In addition to liners, final covers placed on waste management units after the final receipt of waste minimize infiltration of water into a waste management unit and thereby further reduce leachate generation and potential release.[9]

How do contaminants move from waste management units to ground water?

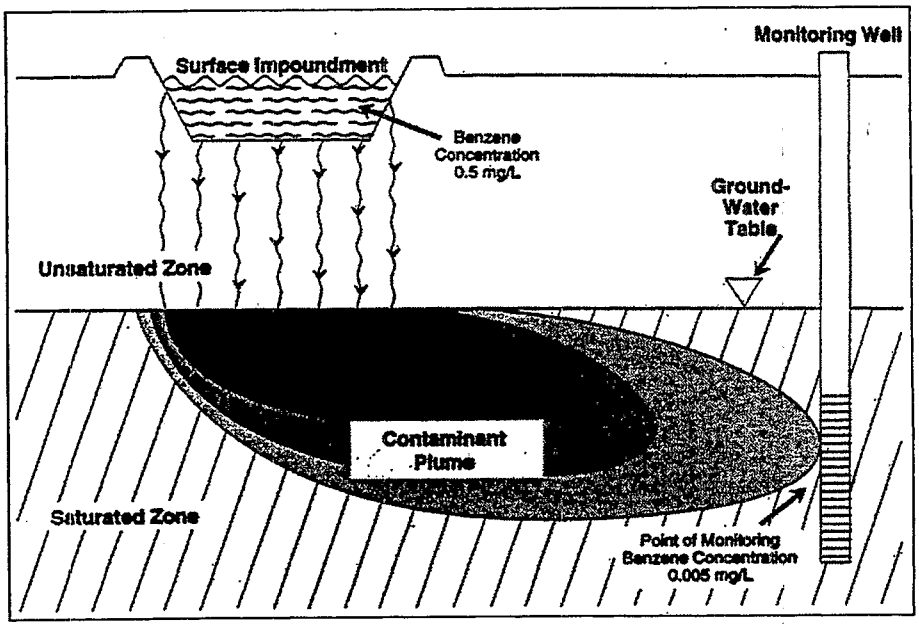
Figure 1 illustrates the concept of aqueous phase waste constituent movement from a waste management unit to a monitoring well. As can be seen in the figure, contaminant concentrations are typically highest near the source.

Waste constituents from a waste management unit migrate through the unsaturated and saturated zones where physical, chemical, and biological processes act upon them. The type of geological material below the unit also affects the rate of movement because of differences in hydraulic conductivity. More

[8]For further information on liners, see the section on designing and installing liners.

[9]For further information on covers and impact on infiltration, see the chapter on performing closure and post-closure care.

Figure 1. Representation of Fate and Transport Analysis



rapid movement of waste constituents can be expected through coarse-textured materials such as sand and gravel than through fine-textured materials such as silt and clay (see textbox on examples of soil permeability). The physical and chemical composition of the geologic material is equally important. Fine-textured material with a high clay content tends to impede contaminant migration both by having a low hydraulic conductivity and through the effects of ion exchange and physical adsorption.[10]

Contaminant movement through unsaturated zone

As waste constituents migrate, geological materials and biological processes interact with waste constituents. These interactions, which are called attenuation, lead to immobilization of potential ground-water contaminants. Attenuation processes are dependent upon pH, temperature, vapor pressure, and other compounds in the subsurface environment. Attenuation processes include sorption of cations and anions on soil mineral surfaces, such as clays, and direct precipitation of molecules from solution.[11] Sorption is the process by which leachate molecules adhere to the surface of individual clay, soil, or sediment particles. Sorption causes a decrease in the total dissolved solids in the leachate. Clays are good sorbants for two reasons: surface charge and high surface area.

Examples of Permeability of Common Natural Soil Formations

Formation	Coefficient of Permeability (cm/sec)
Mississippi river deposits	0.02 to 0.12
Dune sand	0.1 to 0.3
Loess	0.001
Clay	< 0.0000001

Sharma, H., and S. Lewis. 1994. *Waste Containment Systems, Waste Stabilization, and Landfills.*

[10]Boulding, R. 1995. *Soil, Vadose Zone, and Ground-Water Contamination: Assessment, Prevention, and Remediation.*

[11]These attenuation processes can occur in both the vadose and saturated zones.

Examples of Attenuation Processes

Attenuation processes are dependent upon pH, temperature, pressure, and other compounds in the subsurface environment.

Biological degradation: decomposition of a substance into more elementary compounds by action of microorganisms such as bacteria. Sullivan. 1993. *Environmental Regulatory Glossary*, 6th Ed. Government Institutes.

Bio-uptake: the uptake and, at least temporary, storage of a chemical by an exposed animal. The chemical can be retained in its original form and/or modified by enzymatic and non-enzymatic reactions in the body. Typically, the concentrations of the substance in the organism exceed the concentrations in the environment since the organism will store the substance and not excrete it. Sullivan. 1993. *Environmental Regulatory Glossary*, 6th Ed. Government Institutes.

Filtration: physical process whereby solid particles and large dissolved molecules suspended in a fluid are entrapped or removed by the pore spaces of the soil and aquifer media. Boulding, R. 1995. *Soil, Vadose Zone, and Ground-Water Contamination: Assessment, Prevention, and Remediation.*

Hydrolysis: a chemical process of decomposition in which the elements of water react with another substance to yield one or more entirely new substances. This transformation process changes the chemical structure of the substance. Sullivan. 1993. *Environmental Regulatory Glossary*, 6th Ed. Government Institutes.

Oxidation/Reduction (Redox) reactions: involve a transfer of electrons and, therefore, a change in the oxidation state of elements. The chemical properties for elements can change substantially with changes in the oxidation state. U.S. EPA. 1991. *Site Characterization for Subsurface Remediation.*

Precipitation: chemical or physical change whereby a contaminant moves from a dissolved form in a solution to a solid or insoluble form. It reduces the mobility of constituents, such as metals. Unlike sorption, precipitation is not generally reversible. Boulding, R. 1995. *Soil, Vadose Zone, and Ground-Water Contamination: Assessment, Prevention, and Remediation.*

Sorption: the ability of a chemical to partition between the liquid and solid phase by determining its affinity for adhering to other solids in the system such as soils or sediments. The amount of chemical that "sorbs" to solids and does not move through the environment is dependent upon the characteristics of the chemical, the characteristics of the surrounding soils and sediments, and the quantity of the chemical. Sorption generally is reversible. Sorption often includes both adsorption and ion exchange.

In addition, microorganisms frequently are the catalysts or promoters of reactions in the subsurface. Microorganisms can break down wastes, produce various organic acids, and use up available oxygen supplies creating anaerobic environments. Whether soil conditions are oxidizing (aerobic) or reducing (anaerobic) will strongly affect the types of microbial activity and contaminant degradation processes that may occur. For more information on specific attenuation processes, see the text box on the previous page.

Contaminant movement through the saturated zone

Eventually, the waste constituents can reach the saturated zone where dilution or dispersion can occur. Dilution reduces the concentration of constituents but does not alter their chemical structure. Dilution is directly related to ground-water velocity and the size of the leachate plume tends to increase with more rapid ground-water flow.

Attenuation also occurs in the saturated zone. Attenuation processes can remove or degrade waste constituents through filtration, sorption, precipitation, and hydrolysis. For example, filtration is the entrapment of solid particles and large dissolved molecules in the pore spaces of the soil and aquifer.

If contamination reaches a monitoring well, corrective action may need to be initiated to protect human health and the environment. The overall goal of any corrective action should be to perform a technically and economically feasible risk-reduction, designed to achieve a cleanup standard at a specified point on the facility property. Using the ground-water pathway as an example, corrective action for new units should have as a goal a reduction of constituent concentration levels to the ground-water protection standards, that is the TRL (e.g., a MCL or HBN) at the monitoring point. For more information on corrective action, see the chapter on taking corrective action.

Examples of Attenuation Mechanisms for Specific Contaminants

Contaminants	Attenuation mechanisms
Arsenic	Adsorption, precipitation
Barium	Adsorption, precipitation
Beryllium	Precipitation
Cadmium	Adsorption, precipitation
Chromium	Adsorption, precipitation
Mercury	Adsorption, precipitation, redox reactions
Nickel	Precipitation, sorption
Selenium	Adsorption, anion exchange
Zinc	Adsorption, precipitation
Volatile organic compounds (VOCs)	Biological uptake

Bagchi, A. 1994. *Design, Construction, and Monitoring of Landfills.*

B. Risk Characterization: The 3-Tiered Approach

The three assessment tiers and the IWEM, the ground-water model included in this guidance for Tiers 1 and 2, can be used to help select protective practices to manage waste constituents. First determine state requirements for liners and waste limits for land application and comply with those requirements. IWEM and the three-tiered assessment recommended here can help choose management controls where there is flexibility for site-specific determinations in state regulations.

It is important to understand how Tier 1 and 2 incorporate risk assessment. The goal in choosing a liner design or waste application rate is to prevent, to the extent possible, or to minimize ground-water contamination. Defining a monitoring well (rather than a drinking water well) as the point to measure benchmark concentrations is a way to asses performance of the liner system and potential migration of contaminants from the unit. The human health benchmark values serve as a flag for additional action to characterize a release, correct problems with the liner, and cleanup contamination.

At Tier 1, the model analyzes a monitoring well set at 150 meters from the unit boundary to accommodate states that have adopted a non-degradation policy to protect ground water for current and future users. At Tier 2, IWEM allows a user to set an alternative distance to the monitoring well. This approach recognizes that, on a site-specific basis, an alternative distance to monitoring wells may be appropriate, as long as the distance is agreed to in consultation with all the interested parties. EPA's Composite Model for Leachate Migration with Transformation Products is the basis for the Tier 1 and 2 analyses.

EPA's Composite Model for Leachate Migration with Transformation Products

The Tier 1 and Tier 2 modeling tools are based on EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP).[12] EPACMTP simulates subsurface fate and transport of contaminants leaching from the bottom of a waste management unit and predicts concentrations of those contaminants in a downgradient well. In making these predictions, the model accounts for many complex processes[13] that occur as waste constituents and their transformation products move to and through ground water. As leachate carrying waste constituents migrates through the unsaturated zone to the water table, attenuation processes such as adsorption and degradation reduce constituent concentrations. Ground-water transport in the saturated zone further reduces leachate concentrations through dilution and attenuation. The concentration of constituents arriving at a receptor well, therefore, is generally lower than that in the leachate released from a waste management unit.

EPACMTP can determine the effect of fate and transport through the unsaturated and saturated zone on leachate constituent concentrations. In the unsaturated zone, it simulates one-dimensional vertical migration with steady infiltration of constituents from the waste management unit. In the saturated zone, it simulates three-dimensional ground-water flow (horizontal as well as vertical spreading of a contaminant plume to incorporate infiltration from waste management units).[14] EPACMTP is a refined version of earlier EPA fate and transport models. With these improvements, the model considers not only the subsurface fate and transport of constituents but also the formation and the fate and transport of transformation (daughter and granddaughter) products. The model also can simulate fate and transport of metals, taking into account geochemical influences on the mobility of metals. EPACMTP has been favorably reviewed by EPA's Science Advisory Board (SAB) which stated that it "represents the state of the art for such analyses."[15]

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[12]For more detailed information on EPACMTP, consult the EPA's Industrial Waste Management Evaluation Model (EPAIWEM) background materials.

[13]The processes addressed by the model include transport through the unsaturated zone, advection due to ambient ground-water flow, hydrodynamic dispersion, first-order decay, linear and non-linear equilibrium sorption of chemicals, decay reactions and transport of daughter and granddaughter products, effects of water table mounding, and the duration of leachate release.

[14]This effect is called ground-water mounding underneath a waste unit.

[15]60 FR 66344, 66367 (December 21, 1995).

Another unique feature of EPACMTP is that it can calculate the reduction in leachate concentration expressed by a dilution/attenuation factor (DAF). A DAF is defined as the ratio of the expected leachate concentration to the monitoring well concentration. The DAF is then determined from the relationship:

$$DAF = \frac{C_L}{C_{MW}}$$

where: C_L is the leachate concentration (mg/L)

C_{MW} is the monitoring well concentration (mg/L).

The magnitude of a DAF reflects the capabilities of the unsaturated and saturated zone to retard or slow the transport of constituents to a monitoring well. The lowest possible value of DAF is one; a value of DAF=1 means that there is no dilution or attenuation at all; the concentration at a monitoring point is the same as that in the waste. High values of DAF on the other hand correspond to a high degree of dilution and attenuation. For any specific site, the DAF depends on the interaction of waste constituent characteristics (e.g., whether or not the constituent degrades or sorbs), site-specific factors (e.g., geology), and physical and chemical processes in the subsurface environment.

EPACMTP was developed for regulatory purposes. The analyses done with it are based upon simplifying assumptions, and data may not apply or may be inappropriate for evaluating a specific waste management unit. EPACMTP does not account for heterogeneities in the flow system, such as fractures. It does not handle colloidal and immiscible (NAPL) transport. EPACMTP does not account for multi-phase (vapor) flow; nor does it account for reactive transport other than sorption and decay. Thus the results of the Tier 1 and Tier 2 modeling with EPAIWEM do not reflect these characteristics of a particular waste management unit or location. Waste management unit systems which exhibit unique heterogeneities or have several phases, such as colloids, and NAPLs should be evaluated with a tool that is more appropriate to the particular characteristics of the facility. The assumptions used and potential limitations of EPACMTP are discussed in the *Industrial Waste Management Evaluation Model Background Document*; *EPACMTP Background Document*. U.S. EPA. 1996; and *EPACMTP Background Document for the Finite Source Methodology*. U.S. EPA. 1996.

Leachate Concentration Threshold Values (LCTVs)

The Tier 1 and Tier 2 assessment tools recommend liner system designs or the appropriateness of land application based on calculated protective leachate thresholds for all wastes in a unit. These LCTVs are the maximum leachate concentrations for which water in a monitoring well is not likely to exceed the given TRL. The LCTV accounts for waste releases through a liner and dilution and attenuation in the unsaturated and saturated zone prior to reaching a monitoring well.

The LCTV for a specific constituent is the product of the TRL and the dilution and attenuation factor (DAF):

$$LCTV = DAF * MCL$$

or $$LCTV = DAF * HBN$$

The adequacy of a liner system design is evaluated by comparing the estimated waste constituent leachate concentrations to the LCTV. The Tier 1 National Evaluation Model is the most conservative and calculates LCTVs using data collected on waste management units throughout the United States.[16] LCTVs are generated for all unit types (i.e., landfills, waste piles, surface impoundments,

[16]For additional information on the nationwide data used in the modeling, see the *IWEM Background Document*.

and land application units). LCTVs are also generated according to the type of liner design (i.e., no-liner, single liner, or composite liner).[17] At Tier 2, a user can input site-specific data for 6 to 7 parameters depending on the type of waste management unit.

1. Tier I: National Evaluation

The Tier 1 National Evaluation lookup tables (see Appendix I) identify whether a proposed liner design or land application is appropriate based on the constituent concentrations present in the leachate from a waste management unit. It allows you to compare the expected waste constituent concentrations to the calculated LCTVs in the lookup tables to help make this determination. The LCTVs are the maximum leachate concentration which does not result in a ground-water concentration at a downgradient well which exceeds a given TRL. The lookup tables do not require site-specific data, only waste constituent concentrations, and are simple and easy to use. Alternatively, the EPAIWEM software contains a database with the Tier 1 lookup tables.

The lookup tables were developed from EPACMTP modeling results. Using input parameters from national waste and management unit characteristics,[18] EPACMTP simulated four waste management unit types — landfills, surface impoundments, waste piles, and land application units — and determined DAFs for 175 organic chemicals and 16 metals species. In developing the DAF values, EPACMTP performed simulations on a nationwide basis that reflect expected variations in site and hydrogeological conditions. To account for this variability, the EPACMTP fate and transport model is linked to a monte carlo module which generates model input parameter values from the probability distribution of each parameter. The monte carlo method involves the repeated generation of values for the uncertain input variables (drawn from the known distribution) and the application of the fate and transport model to generate a series of model responses (downgradient well concentrations). The generation of random parameter values and fate and transport simulation is repeated many times to determine the probability distribution of the downgradient well concentrations. The DAF value is developed from this probability distribution.

The LCTVs in the lookup table were determined by multiplying the EPACMTP 90th percentile DAF values with constituent-specific TRLs. DAF values are determined by selecting the monitoring well concentration for which 90 percent of the peak concentrations (or peak 30-year average concentration for carcinogens) analyzed in a particular scenario are less than the toxicity benchmark at the monitoring well. In addition, several EPACMTP parameters were fixed at conservative values. Specifically, the monitoring well is assumed to be located on the contaminant plume centerline. This ensures that the highest constituent concentrations in the plume would reach the monitoring well. Similarly, the national evaluation modeling limited the potential distance to the monitoring well to 150 meters in order to monitor

Information Needed to Use Tier 1 Lookup Tables

Waste management unit types:	Landfill, surface impoundment, waste pile, or land application unit.
Waste constituent names:	Constituents expected in leachate.
Leachate concentrations:	Expected leachate concentration of each constituent or concentration in surface impoundments or waste to be applied.

[17]LCTVs are influenced by liner designs because of different infiltration rates.

[18]See the *EPAIWEM Background Document* for detailed information on parameter input values.

the performance of the liner system and to avoid ground-water degradation, not because of the presence of human receptors at that distance. For these reasons, the National Evaluation LCTVs are relatively conservative.

How do I use the Tier 1 lookup tables?

As the first step in any ground-water risk assessment, characterize the waste going into a unit and determine the expected waste constituent leachate concentrations. Estimate leachate concentrations using knowledge of waste generation processes and/or an analytical leaching test appropriate to the circumstances, such as the Toxicity Characteristic Leaching Procedure (TCLP). For more information on estimating a waste constituent concentrations and appropriate leaching tests, refer to the chapter on characterizing waste.

A comparison of the expected leachate concentrations to the LCTVs in the Tier 1 lookup tables can help evaluate the type of liner needed for the proposed waste management unit or whether waste should be land applied. The only input needed for this tool is the expected waste constituent leachate concentration. Tier 1 lookup tables are available for each waste management unit type. See Appendix I. Alternatively, EPAIWEM has a database with the lookup tables that can be used.

Tier 1 National Evaluation Example

The following example illustrates the Tier 1 process for evaluating a proposed liner design for an industrial landfill. The example assumes the expected leachate concentration for toluene is 1.6 mg/L and styrene is 0.5 mg/L. In the Tier 1 process, the user would compare the estimated constituent leachate concentrations to the LCTVs in the National Evaluation lookup tables summarized in Table 3.

Table 4 shows the results of comparing estimated constituent concentrations to the LCTVs in the lookup tables. To determine whether a proposed liner design is appropriate, the example relied on LCTVs based on MCLs. The lookup tables also allow comparisons to LCTVs based on HBNs.

Because EPA does not expect leachate concentrations from waste management units covered by this guidance to exceed 1,000 mg/L for a single constituent, the waste constituent input values and all Tier 1 and Tier 2 LCTVs have been capped at a maximum value of 1,000 mg/L. For any waste constituent covered by the Toxicity Characteristic

Table 3
Example National Evaluation Lookup Table for Landfills

Waste	MCL (mg/L)	HBN (mg/L)	LCTVs (mg/L)					
			No Liner/In-Situ Soil*		Single Liner*		Composite Liner*	
			based on MCL	based on HBN	based on MCL	based on HBN	based on MCL	based on HBN
Toluene	1.0	7.0	2.2	15	4.6	32	1000	1000
Styrene	0.1	7.0	0.22	15	0.46	32	1000	1000

* Section B of this chapter describes designing and installing liners of different types.

Table 4
Example National Evaluation Lookup Table Comparison Results

Waste Constituent	Expected Concentration in Leachate (mg/L)	Finding and Recommendation
Toluene	1.6	Does not exceed no-liner/in-situ soil LCTV. **No-liner/in-situ soil recommended**
Styrene	0.5	Exceeds no-liner/in-situ-soil and single liner LCTVs. **Composite liner recommended**

(TC) Rule (40 CFR Part 261), the LCTV is capped at the TC Rule regulatory level. Leachate concentrations above this level are considered to be characteristic hazardous waste. If any waste constituent concentrations exceed the toxicity characteristic maximum concentrations, the waste is considered RCRA hazardous and outside the scope of this guidance.

What do the results mean and how should I interpret them?

If the expected leachate concentrations for all constituents are lower than the no-liner LCTVs, the proposed landfill does not need a liner to contain this waste. If any constituent concentration is higher than the no-liner LCTV, then a single compacted clay liner or composite liner would be recommended for containment of the waste. If any concentration is higher than the single-liner LCTV, then the recommendation is at least a composite liner. If any concentration is higher than the composite liner, consider pollution prevention, treatment, or additional controls. For waste streams with multiple constituents, select the most protective liner that is specified for any one constituent.

Continuing with the example above, the recommendation is a composite liner because the styrene concentrations exceed the single liner threshold even though toluene did not. Interpretation for land application is similar. If all the waste leachate concentrations are below the threshold values in the Tier 1 lookup tables, land-applying waste may be appropriate for the site. It is still important, however, to evaluate other land application factors outlined in Section C of this chapter. These will still influence whether land application is appropriate and at what rate. If the waste had several constituents whose concentrations were less than the land application threshold and one constituent exceeding the land application threshold, the recommendation is that land application is not appropriate.

After conducting the Tier 1 National Evaluation, consider the following steps.

- **Consider waste reduction/pollution prevention, recycling, or treatment.** If the waste has one or very few "problem" constituents that call for a more stringent and costly liner system (or which make land application inappropriate), evaluate pollution prevention, recycling, and treatment efforts for those constituents. Waste reduction, recycling, or treatment options that before may have appeared economically infeasible, may be worthwhile if they can reduce the problem constituent concentration to levels which result in a different liner recommendation or make land application

appropriate. After implementing these measures, repeat the Tier 1 evaluation. Based on the above example, pollution prevention, recycling, or treatment measures could be used to reduce the styrene concentrations below 0.46 mg/L so that a single liner is recommended for the unit. Consult the chapter on integrating pollution prevention, recycling, and treatment for ideas and tools.

- **Implement recommendations.** This option is the most straightforward. Design the unit based on the liner recommendations of the Tier 1 lookup tables. In the case of land application, develop a land application system (after evaluating other factors) if the design lookup tables found land application to be appropriate for all constituents. In either case, consult the state to ensure compliance with state regulations, which could require more protective measures than the Tier 1 lookup tables recommend.
- **Conduct additional evaluations.** Conduct either a Tier 2 Location Adjusted Evaluation or a Tier 3 site-specific ground-water fate and transport analysis as discussed below.

Figure 2 illustrates the basic steps for using the Tier 1 lookup tables to determine whether a liner design or land application is appropriate.

2. Tier 2: Location-Adjusted Evaluation

The Tier 2 Location-Adjusted Evaluation is a method in which a limited number of site-specific parameters are used to determine the effect on the DAFs and the resulting LCTVs. To facilitate this evaluation, EPA has developed a set of artificial neural networks (one for each waste management unit type) that utilizes information concerning the waste management unit and the hydrogeological conditions of the site to determine the appropriate liner type for containment of the wastes. When calculating LCTVs, a user can take into account a limited-number of site-specific considerations without having to run the EPACMTP or another ground-water fate and transport model. As with any ground-water assessment, discuss the results of the Tier 2 evaluation with the state and public before selecting a liner design or land-applying waste.

What are the basic principles and components of the model?

The Tier 2 artificial neural network program that has been incorporated into a stand-alone executable computer program requires no specialized training in EPACMTP, neural networks, or statistics. The Tier 2 tool

What are neural networks?

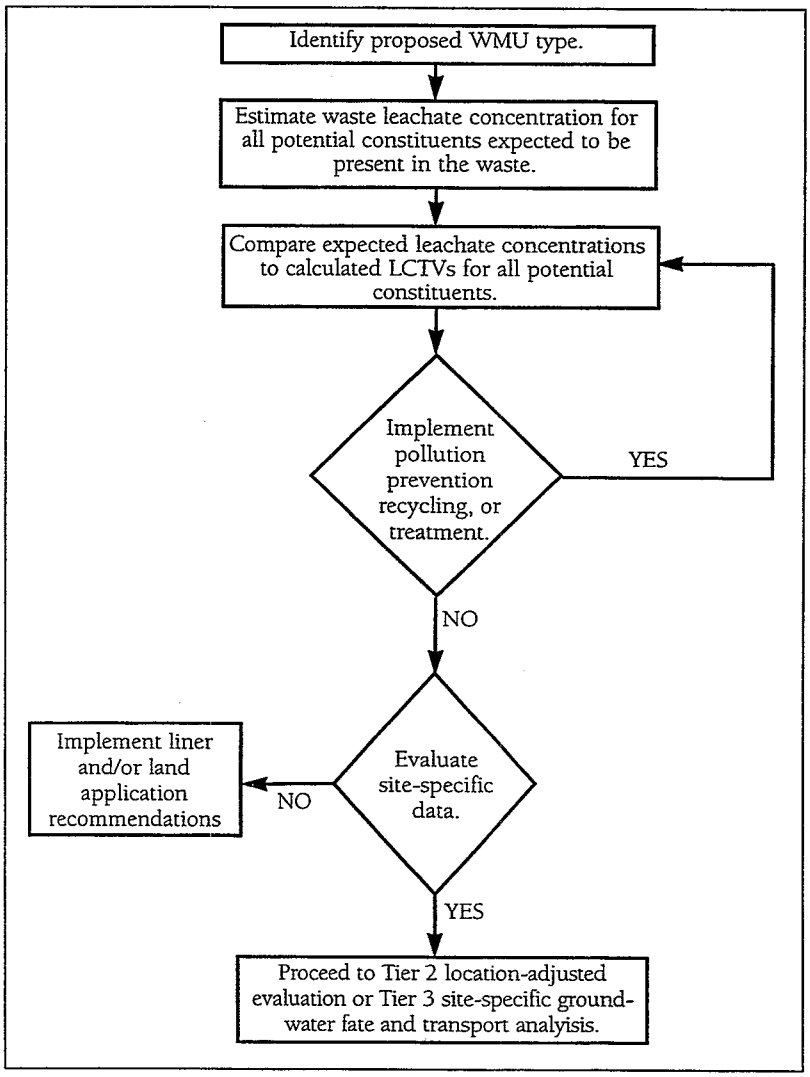
Neural networks are an information processing method. The revolutionary aspect of neural networks is their ability to learn complex patterns and/or be trained to adjust to new data. Neural networks apply knowledge from past experience to new problems. Neural networks acquire this knowledge by training on a specified set of combinations of input data. After the network has been trained and validated, the model may use data it has not seen previously for prediction, classification, time series analysis or data segmentation. Unlike traditional statistical methods, neural networks do not require assumptions about the form or distribution of the data to analyze it.

Additional information on neural networks is available in the *Industrial Waste Management Facility Design Evaluation Model Background Document* and on the Internet at **<www.spss.com/software/Neuro/nnbckgrnd.html>.**

uses a multi-layer perception (MLP) computing model and software package as the neural network for this model. Using hundreds of thousands of actual EPACMTP realizations, the neural network was trained to estimate the DAFs that EPACMTP generated based on changes in specific combinations of input parameters.[19] The neural network closely matches the results that EPACMTP generated.

Using the neural-network-estimated DAFs, the software calculates corresponding LCTVs by multiplying the DAFs for each constituent by its appropriate TRL. The model will then compare the expected leachate concentrations to these LCTVs and identify a recommended liner for landfills, surface impoundments, and waste piles. The model can evaluate in-situ soil, compacted clay liners, and other liner designs for which the resulting infiltration rate is known.

Figure 2. Process Diagram: Use of National Evaluation Lookup Tables



In developing and training the neural networks, problems were encountered when the extremes of the distributions were used as input to the training. Training of the neural networks was then limited to parameter values between the 10th and 90th percentile. The composite liner infiltration rate assumed in Tier 1 (3×10^{-3} for landfills) was outside the 10th to 90th percentile range (0.024 to 0.45 m/yr for landfills), and thus the neural networks were not trained using this value. Because the use of infiltration rates outside the range over which the neural networks were trained will result in significant error, the Tier 2 Location-Adjusted Evaluation does not explicitly address the composite liner scenario.

The proposed guidance still allows for assessment of the composite liner scenario through the Tier 1 and Tier 3 evaluations. EPA is seeking comment on how to address inclusion of the composite liner scenario in the Tier 2 Location-Adjusted Evaluation. Options

[19]The *Background Document* and *User's Guide* discuss training the neutral network.

currently under consideration include: development of multiple networks—one for low infiltration rates and one for high infiltration rates; and use of a Windows version of EPACMTP (currently under development).

What input parameters most strongly influence Tier 2 results?

EPA conducted numerous analyses to identify the input parameters that had the greatest influence on the LCTVs generated by the model. These "sensitive parameters" are those that have the most significant effect on model results given a relatively small change in input values.

- **Waste management unit area.** Area covered by the waste management unit in square meters.
- **Infiltration rate.** Rate at which leachate flows from the bottom of a waste management unit (including any liner) into the unsaturated zone beneath the waste management unit. An area's rainfall intensity affects infiltration rates as does the performance of the liner system. Users can either input infiltration rates directly or allow the Tier 2 program to estimate values for the no—and single—liner scenarios based on the unit's geographic location (or impoundment characteristics for surface impoundments).[20]
- **Depth to the water table.** The depth in meters of the zone between the land surface and the water table.
- **Aquifer thickness.** The thickness of an aquifer measured in meters.
- **Radial distance to monitoring well.** Distance in meters from the waste management unit to a monitoring well.
- **Organic carbon distribution coefficient (KOC).** A function of the nature of a sorbent (the soil and its organic carbon content) and the properties of a chemical (the leachate constituent). It is equal to the ratio of the solid and dissolved phase concentrations. The higher the value of the distribution coefficient, the higher the adsorbed-phase concentration, meaning the constituent would be less mobile. For metals, include Kd, but if Kd is not known, software can estimate if given the ground-water pH.
- **Decay rate.** The rate at which constituents degrade or decay within an aquifer due to chemical hydrolysis or biodegradation. Measured in liters per year. The default decay rate represents degradation from chemical hydrolysis only, since biodegradation rates are often strongly influenced by site-specific factors.

Because site-specific data for all of the sensitive parameters may not be available to a user of the software, the model contains "default" values for these parameters. The default values were derived from a number of sources, including a survey of industrial waste management units, a hydrogeologic database, water-balance modeling, and values reported in the scientific literature. The selection of default values is explained in the *IWEM Technical Background Document.* Use all site-specific data available, as the estimated leachate concentration values generated using primarily default data will tend to be conservative and may not accurately represent the conditions at the site.[21]

How do I use the model?

The CD-ROM contains the Tier 2 model. *The User's Guide for the Industrial Waste Management Evaluation Model* provides complete installation instructions. The software will prompt a user to enter information on

[20]The software can estimate infiltration rates for surface impoundments if impoundment characteristics such as ponding depth, thickness of sediment layer, and conductivity of sediment layer are input.

[21]A Tier 2 evaluation is not always less conservative than a Tier 1. For example, if a site has a very large area, a very shallow water table, and/or the aquifer thickness is well below the national average, then the Tier 2 evaluation results can be more stringent than the Tier 1 analysis results.

waste management unit type, waste constituents, and expected leachate concentrations. In addition, it will prompt a user to enter site-specific values for known selected parameters—those that were identified as being the most sensitive—replacing the default values developed from the EPACMTP input data. Figure 3 is an example of some of the Tier 2 software screens. When conducting a Tier 2 evaluation, use documented and realistic data for the site. When changing default values, provide justifications of the data sources and values as necessary. Default values can be used if representative of site-specific conditions. State agencies and the public can review a location-adjusted evaluation and may question any unsupported assumptions.

Table 5.
Example Site-Specific Parameters

Parameters	Site-Specific Data
Infiltration rate*	Local climate: Madison, WI Soil Type: fine-grained soil
Waste management unit area	15,000 m^2
Depth to the water table	10 m
Aquifier thickness	25 m
Distance from receptor well	150 m

*The Tier 2 model can calculate an infiltration rate for the liner scenarios based on local climate and soil data.

Tier 2 Location-Adjusted Evaluation Example

Continuing the example from Tier 1 for toluene and styrene disposal in a proposed landfill, consider the location-adjusted data for the following sensitive parameters.

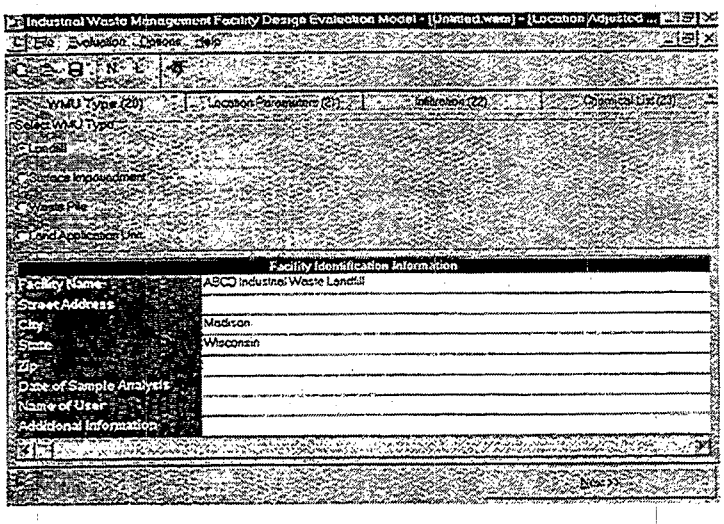
The Tier 2 evaluation will develop LCTVs based on the location-adjusted data and compare expected leachate concentrations to the calculated LCTVs to determine a recommended liner system. The results recommend a single liner system to dispose of toluene and styrene under the location-adjusted conditions. The Tier 2 evaluation also provides a detailed presentation of results which includes a summary of inputs and accompanying narrative, leachate concentrations, DAF values, toxicity benchmarks (MCLs/HBNs), chemical-specific parameters (KOC and decay rate), and LCTVs. This allows a user to understand how the LCTV values were calculated and how the liner design recommendations were developed. Because the detailed results give the chemical-specific DAF value for each liner scenario evaluated, a user can calculate different LCTV values using different TRLs, such as 0.1 times the MCL value or 10 times the HBN value.

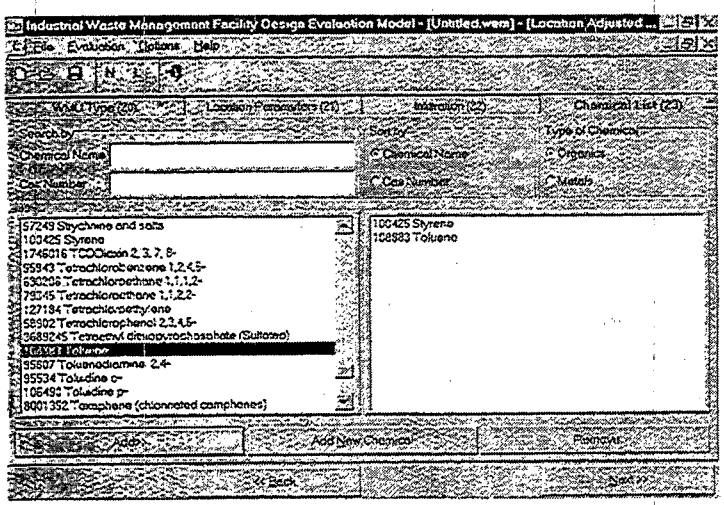
What do the results mean and how should I interpret them?

As in the Tier 1 analysis, if the expected leachate concentration is lower than the no-liner LCTV, then the waste management unit does not require a liner other than the native soil. If the expected leachate concentration is higher than the no-liner LCTV, then the recommendation is at least a single compacted clay liner. If the expected leachate concentration is higher than the single-liner LCTV, then the recommendation is to consider pollution prevention, treatment, or additional controls. For waste streams with multiple constituents, the recommendation is the most conservative liner design identified for any one constituent.

As in the Tier 1 evaluation, consider integrating pollution prevention, recycling, and treatment practices. If you choose to follow

Figure 3. Example Input Screens for Tier 2 Model





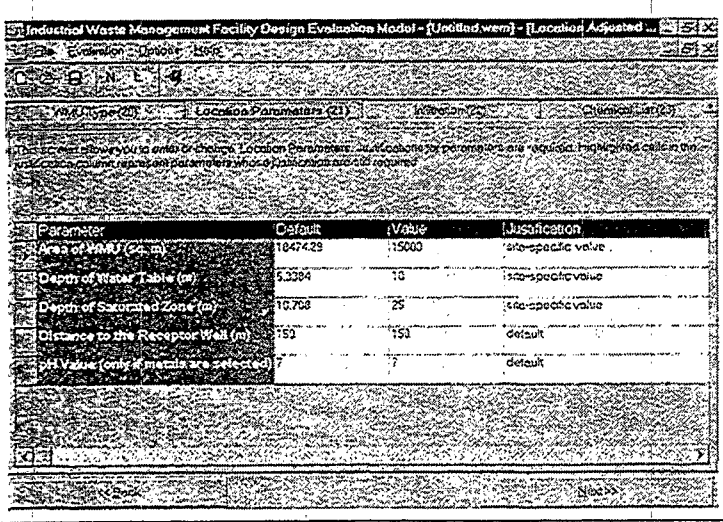
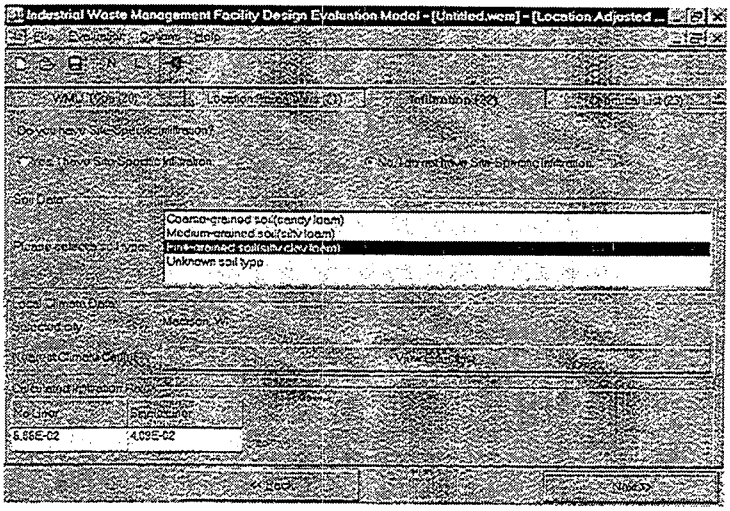
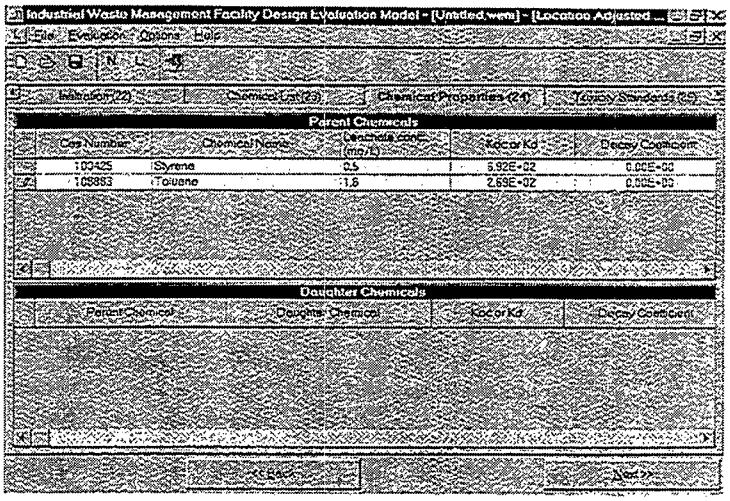
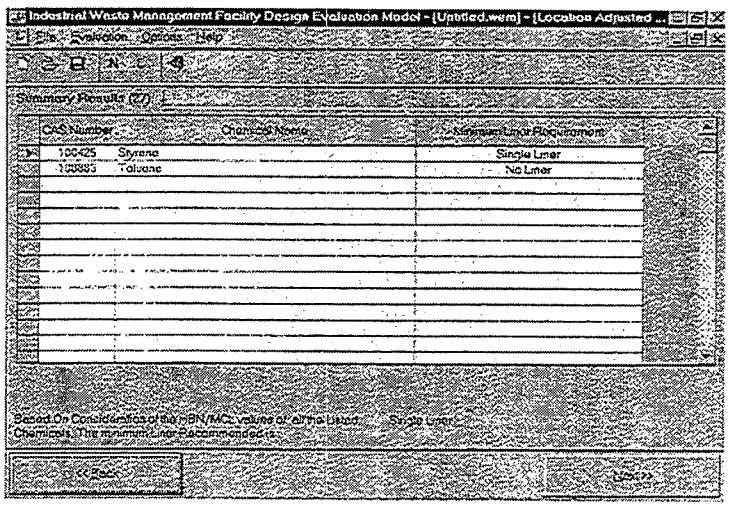


Figure 3. Example Input Screens for Tier 2 Model (cont.)







the Tier 2 recommendations, consult with the state to develop a more detailed design plan for the waste management unit. Alternatively you can undertake a comprehensive assessment to more accurately reflect site-specific conditions. See Tier 3: Site-Specific Ground-Water Fate and Transport Analysis, for further information.

In addition to the Tier 2: Location-Adjusted Evaluation model, other fate and transport models have been developed that incorporate location-specific considerations, such as the American Petroleum Institute's (API's) *Graphical Approach for Determining Site-Specific Dilution-Attenuation Factors.*[22] API developed its approach to calculate facility-specific DAFs quickly using graphs rather than computer models. Graphs visually indicate the sensitivity to various parameters. This approach can be used for impacted soils located above or within an aquifer. This approach accounts for attenuation with distance and time due to advective/dispersive processes. API's approach has a preliminary level of analysis that uses a small data set containing only measures of the constituent plume's geometry. The user can read other necessary factors off graphs provided as part of the approach. This approach also has a second level of analysis in which the user can expand the data set to include site-specific measures, such as duration of constituent leaching, biodegradation of constituents, or site-specific dispersivity values. At either level of analysis, the calculation results in a DAF. This approach is not appropriate for all situations; it should not be used to estimate chemical concentrations in active ground-water supply wells or to model very complex hydrogeologic settings, such as fractured rock. Consult with the state to discuss the applicability of the API approach or any other location-adjusted model prior to use.

Why is it important to use a qualified professional?

- Fate and transport modeling can be extremely complex.
- Incorrect fate and transport modeling can result in a liner system that is not sufficiently protective or an inappropriate land application rate.
- To avoid incorrect analyses, check to see if the professional has sufficient training and experience at analyzing ground-water flow and contaminant fate and transport.

3. Tier 3: Site-Specific Ground-Water Fate and Transport Analysis

Site-specific ground-water fate and transport analysis is the most detailed method for estimating potential risk to ground water and evaluating alternative liner designs or application rates. If the Tier 1 and Tier 2 modeling do not adequately simulate conditions at a proposed site because the hydrogeology of the site is complex, consider a site-specific risk assessment.[23] Consult with the state and use a qualified professional experienced in ground-water modeling if appropriate. Talk to state officials and/or appropriate trade associations to solicit recommendations for a good consultant to perform the analysis.

How to select a site-specific ground-water fate and transport model?

Estimating exposure concentrations in ground water using models can be a complex task due to the many physical and chemical

[22]A copy of API's user manual can be found on the CD-ROM. *The Technical Background Document and User Manual* (API Publication 4659) can be obtained from the American Petroleum Institute, 1220 L Street, NW., Washington, DC 20005, 202 682-8375.

[23]For example, if the depth to ground water at the site is over 250 feet, use of the Tier 2 Location-adjusted Evaluation tool may not be appropriate because the model is based on data from units with shallower depths to ground water.

processes that affect transport and transformation of constituents in ground water. Hundreds of different models have been developed to simulate the fate and transport of constituents in ground water. Proper selection and application of ground-water models requires a thorough understanding of the waste and the physical, chemical, and hydrogeologic characteristics of the site.

In addition to evaluating whether a model will adequately address site characteristics, ask the following questions to ensure that the model will provide accurate, meaningful results.

- What is the source of the model and how easy is it to obtain? Is it a proprietary model?
- Are documentation and user's manuals available for the model and, if so, are they well-written and easy to use?
- Has the model been verified against analytical solutions and other models and, if so, are the test cases available so that your consultant can test the model on his/her computer system?
- Has the model been validated using field data?

As with all modeling, consult with the state before investing significant resources in a site-specific analysis. The state may have a list of preferred models and may be able to help plan the fate and transport analysis.

EPA's report *Selection Criteria for Mathematical Models Used in Exposure Assessments: Ground-Water Models* lists a number of criteria to evaluate before selecting a ground-water fate and transport model. It also provides a primer on ground-water flow. This document is available through the National Technical Information Service, Springfield, Virginia, 22161, phone: 800 553-6847, Internet: **<www.ntis.gov/home.htm>**. The American Society for Testing and Materials (ASTM) also provides guidance for conducting modeling and a listing of guidance material can be found in the sidebar.

Examples of questions to answer before selecting a model are provided below.

- Does a confined aquifer, an unconfined aquifer, or both need to be simulated?
- Does the ground water flow through porous media, fractures, or a combination of both?
- Is it necessary to simulate three-dimensional flow or can the dimensionality be reduced without significantly reducing accuracy?
- Is there a single or are there multiple hydrogeologic layers to be simulated?
- Is (are) the hydrogeologic layer(s) of constant or variable thickness spatially?
- Does the model simulate dispersion?
- Does the model simulate sorption?
- Does the model simulate first, second-order, or other-order decay?
- Does the model simulate density effects related to changes in temperature and concentration?

What do the results of a site-specific fate and transport analysis mean?

A site-specific analysis should, at a minimum, provide estimated leachate concentrations at specified downgradient points for a proposed liner design. For landfills, surface impoundments, and waste piles, compare these concentrations to appropriate MCLs, health-based standards, and/or state standards. For land application units, if a waste leachate concentration is below the values specified by the state, land application may be appropriate. Conversely, if a leachate concen-

tration is above state-specified values, land application may not be protective of the ground water.

A well-executed, site-specific analysis can be a useful instrument to anticipate and avoid potential risks. A poorly-executed, site-specific analysis, however, could over-or under-emphasize risks, possibly leading to adverse human health and environmental effects, or costly cleanup liability, or could overemphasize risks, possibly leading to the unnecessary expenditure of limited resources. Share the model, if possible, and the results of the final analyses, including input and output parameters and key assumptions, with key stakeholders. The chapter on building partnerships provides a more detailed description of activities to keep the public informed and involved.

What are some useful resources for selecting a ground-water fate and transport model?

The following list of EPA resources can help select an appropriate model.

- *Ground Water Modeling Compendium*, Second Edition (EPA 1994)
- *Assessment Framework for Ground-Water Modeling Applications* (EPA 1994)
- *Selection Criteria for Mathematical Models Used in Exposure Assessments: Ground-Water Models* (EPA 1988c).
- *Superfund Exposure Assessment Manual* (SEAM—EPA 1988b).
- *Exposure Assessment Methods Handbook* (EPA 1989f).
- EPA's Center for Exposure Assessment Modeling (CEAM—Environmental Research Laboratory; Athens, Georgia).
- EPA regional offices.

Table 6 provides a brief description of five ground-water fate and transport models. These descriptions are included in EPA's *Ground-Water Modeling Compendium* (see Resources at the end of this chapter for a complete citation).

ASTM Ground-Water Modeling Standards

The American Society for Testing and Materials (ASTM), Section D-18.21.10 concerns subsurface fluid-flow (ground-water) modeling. The ASTM ground-water modeling section is one of several task groups funded under a cooperative agreement between USGS and EPA to develop consensus standards for the environmental industry and keep the modeling community informed as to the progress being made in development of modeling standards.

The standards being developed by D-18.21.10 are "guides" in ASTM terminology, which means that the content is analogous to that of EPA guidance documents. The ASTM modeling guides are intended to document the state-of-the-science related to various topics in subsurface modeling.

The following standards have been developed by D-18.21.10 and passed by ASTM. They can be purchased from ASTM by calling 610 832-9585. See the ASTM web site <www.astm.org> to order or browse for publications.

D-5447 Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem

D-5490 Guide for Comparing Ground-Water Flow Model Simulations to Site- Specific Information

D-5609 Guide for Defining Boundary Conditions in Ground-Water Flow Modeling

D-5610 Guide for Defining Initial Conditions in Ground-Water Flow Modeling

D-5611 Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application

D-5718 Guide for Documenting a Ground-Water Flow Model Application

D-5719 Guide to Simulation of Subsurface Air Flow Using Ground-Water Flow Modeling Codes

D-5880 Guide for Subsurface Flow and Transport Modeling

D-5981 Guide for Calibrating a Ground-Water Flow Model Application

A compilation of most of the current modeling and aquifer testing standards also can be purchased. The title of the publication is *ASTM Standards on Analysis of Hydrologic Parameters and Ground Water Modeling*, publication number 03-418096-38. For more information by e-mail, contact **service@astm.org**.

Table 6.
Example Site-Specific, Ground-Water Fate and Transport Models

Model Name	Description
AT123D	AT123D is a generalized analytical transient, one- two-, and/or three-dimensional computer code developed for estimating the transport of chemicals in a confined aquifer system with uniform flow. The model handles various source configurations (including point source, line source, and areal source) and release characteristics. The transport mechanisms include advection, longitudinal as well as horizontal and vertical trans verse hydro-dynamic dispersion, diffusion, linear adsorption, and first-order decay/degeneration and chemical losses to the atmosphere. The model calculates concentration distribution in space and time using Green's function. The model was developed by Oak Ridge National Laboratory. For more information and/or to obtain a copy of this model, contact: International Ground Water Modeling Center (IGWMC) Colorado School of Mines Golden, Colorado 80401-1887 Phone: 303 273-3103 (General Questions, Sales) Phone: 303 273-3105 (Technical Support) Internet: **<www.mines.edu/igwmc>** igwmc@mines.edu (General Questions, Sales) gwtech@mines.edu (Technical Support)
MOC	MOC is a ground-water flow and mass transport model. It provides capabilities for two dimensional simulation of non-conservative solute transport in aquifers. It computes changes in time in the spatial concentration distribution caused by convective transport, hydrodynamic, dispersions, mixing or dilution from recharge, and chemical reactions. The chemical reactions include first-order sorption irreversible rate reaction (e.g., radioactive decay), equilibrium-controlled sorption with linear, Freundlich or Langmuir isotherms, and monovalent and/or divalent ion-exchange reactions. It uses the method of characteristics followed by an explicit procedure to solve the transport equation. MOC uses a subgrid of the flow grid for simulation of containment transport. The model was developed by the U.S. Geological Survey. For more information and/or to obtain a copy of this model, contact IGWMC using the information described above.

Table 6.
Example Site-Specific, Ground-Water Fate and Transport Models (cont.)

Model Name	Description
MODFLOW	MODFLOW is a model for steady state and transient simulation of two-dimensional, quasi three-dimensional, and fully three-dimensional saturated flow problems in confined and unconfined aquifers. It calculates flow rates and water balances. The model includes flow towards wells, through riverbeds, and into drains. For more information and/or to obtain a copy of this model, contact IGWMC using the information described above.
MT3D	MT3D is a three-dimensional contaminant transport model using a hybrid method of characteristics. Two numerical techniques are provided for the solution of the advective-dispersive reactive solute transport equation: the method of characteristics (MOC) and the modified method of characteristics (MMOC). The MMOC method overcomes many of the traditional problems with MOC, especially in 3D simulations, by directly tracking nodal points backwards in time and by using interpolation techniques. MT3D selectively uses the MOC or the MMOC technique dependent on the problem at hand. The transport model is so structured that it can be used in conjunction with any block-centered finite difference flow model such as the USGS MODFLOW model. The model was developed by S.S. Papadopulos & Associates, Inc. For more information and/or to obtain a copy of this model, contact: Center for Subsurface Modeling Support R.S. Kerr Environmental Research Laboratory U.S. EPA P.O. Box 1198 Ada, OK 74820 Phone: 405 332-8800
RANDOM WALK	RANDOM WALK/TRANS is a numerical model to simulate two-dimensional steady or transient flow and transport problems in aquifers under water table and/or confined or leaky confined conditions. The flow is solved using a finite difference approach and the iterative alternating direction implicit method. The advective transport is solved with a particle-in-cell method, while the dispersion is analyzed with the random walk method. This model was developed by Illinois State Water Survey. For more information and/or to obtain a copy of this model, contact IGWMC using the information described above.

Action Items for Assessing Risks to Ground Water

- ☐ Review the risk characterization tools recommended by this chapter.
- ☐ Characterize the waste in accordance with the recommendations of the chapter on characterizing waste. Obtain leachate concentrations for all relevant waste constituents.
- ☐ Understand and use the Tier 1: National Evaluation lookup tables, if appropriate.
- ☐ If appropriate, understand and use the Tier 2: Location-adjusted Evaluation.
- ☐ If appropriate, understand and use a site-specific ground-water fate and transport model.

Resources

American Petroleum Institute. Graphical Approach for Determining Site-Specific Dilution-Attenuation Factors: Technical Background Document and User Manual. API Publication 4659.

ASTM. 1996. ASTM Standards on Analysis of Hydrologic Parameters and Ground Water Modeling, Publication Number 03-418096-38.

ASTM. 1993. D-5447 Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem.

ASTM. 1993. D-5490 Guide for Comparing Ground-Water Flow Model Simulations to Site- Specific Information.

ASTM. 1994. D-5609 Guide for Defining Boundary Conditions in Ground-Water Flow Modeling.

ASTM. 1994. D-5610 Guide for Defining Initial Conditions in Ground-Water Flow Modeling.

ASTM. 1994. D-5611 Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application.

ASTM. 1994. D-5718 Guide for Documenting a Ground-Water Flow Model Application.

ASTM. 1994. D-5719 Guide to Simulation of Subsurface Air Flow Using Ground-Water Flow Modeling Codes.

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Sharma, H., and S. Lewis. 1994. Waste Containment Systems, Waste Stabilization, and Landfills.

Speidel, D., L. Ruedisili, and A. Agnew. 1988. Perspectives on Water: Uses and Abuses.

U.S. EPA. 1998. Industrial Waste Management Evaluation Model Technical Background Document.

U.S. EPA. 1998. The User's Guide for the Industrial Waste Management Evaluation Model.

U.S. EPA. 1996. Composite Model for Leachate Migration with Transformation Products.

U.S. EPA. 1996. EPACMTP Background Document.

U.S. EPA. 1996. EPACMTP Background Document for the Finite Source Methodology.

U.S. EPA. 1994. Assessment Framework for Ground-Water Modeling Applications. EPA500-B-94-003.

U.S. EPA 1994. Ground Water Modeling Compendium, Second Edition. EPA500-B-94-003.

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U.S. EPA. 1991. Seminar Publication: Site Characterization for Subsurface Remediation. EPA625-4-91-026.

U.S. EPA. 1989. Exposure Assessment Methods Handbook.

U.S. EPA. 1988. Selection Criteria For Mathematical Models Used In Exposure Assessments: Ground-water Models. EPA600-8-88-075.

U.S. EPA. 1988. Superfund Exposure Assessment Manual.

Part IV
Protecting Ground Water

Chapter 7: Section B
Designing and Installing Liners
Technical Considerations for Surface Impoundments, Landfills, and Waste Piles

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Designing and Installing Liners—Technical Considerations for Surface Impoundments, Landfills, and Waste Piles

Employ liner systems where needed to protect ground water from contamination. Select from clay liners, synthetic liners, composite liners, leachate collection systems, and leak detection systems as appropriate. Consider technical issues carefully to ensure that the liner system will function as designed.

Once risk has been characterized and the most appropriate liner system chosen, unit design can proceed. A critical part of this design for landfills, waste piles, and surface impoundments is the liner system. The liner system recommendations in this guidance do not apply to land application units, since such operations generally do not include a liner system as part of their design. (For design of land application units, refer to the discussion in designing a land application program section of this chapter.) During liner system design, work with state agencies to ensure consideration of any applicable liner system requirements, recommendations, or standard practices the state may have. In this part of the chapter, sections I though IV discuss four liner options—no liner/in-situ soils, single liner, composite liner, and double liner. Section V covers leachate collection and leak detection systems, and section VI discusses construction quality assurance and quality control.

I. In-Situ Soil Liners

For the purpose of this guidance, in-situ soil liners refer to simple, excavated areas or impoundments, without any additional engineering controls. The ability of natural soils to reduce the concentration of constituent levels through dilution and attenuation may provide sufficient protection when the initial constituent levels in the waste stream are very low, when the wastes are inert, or when the hydrogeologic setting affords sufficient protection.

What are the recommendations for in-situ soils?

The soil below and adjacent to a waste management unit should be suitable for construction. It should provide a firm foundation for the waste. Due to the low risk associated with wastes being managed in these units, no liner may be necessary; however, it is still helpful to review the recommended location considerations and operating practices for the unit.

What technical issues should be considered with the use of in-situ soils?

In units using in-situ natural soils, construction and design of an engineered liner will not be necessary; however, there are still technical concerns to consider. These include the following:

- The stability of foundation soils;
- The compatibility of the waste with native soils;
- The location where the unit will be sited; and
- The potential to recompact existing soils.

Potential instability can occur in the foundation soil, if its load-bearing capacity and resistance to movement or consolidation are insufficient to support the waste. The ground-water table or a weak soil layer also may influence the stability of the unit. Take measures, such as designing maximum slopes, to avoid slope failure during construction and operation of the waste management unit. Most soil slopes are stable at a 3:1 horizontal to vertical inclination. Follow common sense operating practices and ensure that any wastes to be managed on in-situ soils will not inappropriately interact with the soils. When using in-situ soils, refer to the chapter on considering the site. Selecting an appropriate location will be of increased importance, since the added barrier of an engineered liner will not present. Because in-situ soil may have non-homogeneous material, root holes, and cracks, its performance can be improved by scarifying and compacting the top portion of the in-situ natural soils.

II. Single Liners

If the risk evaluation recommended the use of a single liner, determine the type of single liner system most appropriate for the site. The discussion below addresses three types of single liner systems: compacted clay liners, geomembrane liners, and geosynthetic clay liners. Determine which material, or combination of materials, protects human health and the environment based on the cost of these materials for the unit.[1]

A. Compacted Clay Liners

A compacted clay liner can serve as a single liner or as part of a composite or double liner system. Compacted clay liners are composed of natural mineral materials (natural soils), bentonite-soil blends, and other materials placed and compacted in layers called lifts. If natural soils at the site contain a significant quantity of clay, then liner materials may be excavated from onsite locations known as borrow pits. Alternatively, if on-site soils do not contain sufficient clay, clay materials can be hauled from off-site sources, often referred to as commercial pits.

Compacted clay liners can be designed to work effectively as hydraulic barriers. To ensure that compacted clay liners are well constructed and perform as they are designed, implement effective quality control methods emphasizing soil investigations and construction practices. Three objectives of quality assurance and quality control for compacted soil liners are to ensure that (1) selected liner materials are suitable, (2) liner materials are properly placed and compacted, and (3) the completed liner is properly protected before, during, and after construction. Quality assurance and quality control are discussed in greater detail in section VI.

[1]Many industry and trade periodicals, such as *Waste Age, MSW Management, Solid Waste Technologies,* and *World Wastes,* have articles on liner types and their corresponding costs, as well as advertisements and lists of vendors.

What are the thickness and hydraulic conductivity recommendations for compacted clay liners?

Compacted clay liners should be at least 2 feet thick and have a maximum hydraulic conductivity of 1×10^{-7} cm/sec (4×10^{-8} in/sec). Hydraulic conductivity refers to the degree of ease with which a fluid can flow through a material. A low hydraulic conductivity will help minimize leachate migration out of a unit. Designing a compacted clay liner with a thickness ranging from 2 to 5 feet will help ensure that the liner meets desired hydraulic conductivity standards and will also minimize leachate migration as a result of any cracks or imperfections present in the liner. Thicker compacted clay liners provide additional time to minimize leachate migration prior to the clay becoming saturated.

What issues should be considered in the design of a compacted clay liner?

The first step in designing a compacted clay liner is selecting the clay material. The quality and properties of the material will influence the performance of the liner. The most common type of compacted soil is one that is constructed from naturally occurring soils that contain a significant quantity of clay. Such soils are usually classified as CL, CH, or SC in the Unified Soil Classification System (USCS). Some of the factors to consider in choosing a soil include soil properties, interaction with wastes, and test results for potentially available materials.

Soil Properties

Minimizing hydraulic conductivity is the primary goal in constructing a soil liner. Consider water content, plasticity characteristics, percent fines, and percent gravel, as these properties affect the soil's ability to achieve a specified hydraulic conductivity.

Hydraulic Conductivity. Select compacted clay liner materials so that remolding and compacting of the materials will produce a low hydraulic conductivity. Factors influencing the hydraulic conductivity at a particular site include: the degree of compaction, compaction method, type of clay material used, soil moisture content, and density of the soil during liner construction. The hydraulic conductivity of a soil also depends on the viscosity and density of the fluid flowing through it. Consider measuring hydraulic conductivity using methods such as American Society of Testing and Materials (ASTM) D-5084.[2]

Water Content. Water content refers to the amount of liquid, or free water, contained in a given amount of material. Measuring water content can help determine whether a clay material needs preprocessing, such as moisture adjustment or soil amendments, to yield a specified density or hydraulic conductivity. Compaction curves can be used to depict moisture and density relationships, using either ASTM D-698 or ASTM D-1557, the standard or modified Proctor test methods, depending on the compaction equipment used and the degree of firmness in the foundation materials.[3] The critical relationship between clay soil moisture content and density is explained thoroughly in Chapter 2 of EPA's 1993 technical guidance document *Quality Assurance and Quality Control for Waste Containment Facilities* (EPA600-R-93-182).

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[2]ASTM D-5084, *Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.*

[3]ASTM D-698, *Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft3 (600 kN-m/m3)).*

Plasticity Characteristics. Plasticity characteristics describe a material's ability to behave as a plastic or moldable material. Soils containing clay are generally categorized as plastic. Soils that do not contain clay are non-plastic and typically considered unsuitable materials for compacted clay liners, unless soil amendments such as bentonite clay are introduced.

Plasticity characteristics are quantified by three parameters: liquid limit, plastic limit, and plasticity index. The liquid limit is defined as the minimum moisture content (in percent of oven-dried weight) at which a soil-water mixture can flow. The plastic limit is the minimum moisture content at which a soil can be molded. The plasticity index is defined as the liquid limit minus the plastic limit and defines the range of moisture content over which a soil exhibits plastic behavior. When soils with high plastic limits are too dry during placement, they tend to form clods, or hardened clumps, that are difficult to break down during compaction. As a result, preferential pathways may form around these clumps allowing leachate to flow through the material at a higher rate. Soil plasticity indices typically range from 10 percent to 30 percent. Soils with a plasticity index greater than 30 percent are cohesive, sticky, and difficult to work with in the field. Common testing methods for plasticity characteristics include the methods specified in ASTM D-4318, also known as Atterberg limits tests.[4]

Percent Fines and Percent Gravel. Typical soil liner materials contain at least 30 percent fines and may contain up to 50 percent gravel, by weight. Common testing methods for percent fines and percent gravel are specified in ASTM D-422, also referred to as grain size distribution tests.[5] Fines refer to silt and clay-sized particles. Soils with less than 30 percent fines may be worked to obtain hydraulic conductivities below 1×10^{-7} cm/sec (4×10^{-8} in./sec), but use of these soils requires more careful construction practices.

Gravel is defined as particles unable to pass through the openings of a Number 4 sieve, which has an opening size equal to 4.76 mm (0.2 in.). Although gravel itself has a high hydraulic conductivity, relatively large amounts of gravel, up to 50 percent by weight, can be uniformly mixed with clay materials without significantly increasing the hydraulic conductivity of the material. Clay materials fill voids created between gravel particles, thereby creating a gravel-clay mixture with a low hydraulic conductivity. Creating a uniform mixture of clay and gravel, where clay can fill in gaps, is more critical than the actual gravel content of the mixture, as long as the percent gravel in a compacted clay mixture remains below 50 percent.

Pay close attention to the percent gravel in cases where a compacted clay liner functions as a bottom layer to a geosynthetic, as gravel can cause puncturing in geosynthetic materials. Controlling the maximum particle size and angularity of the gravel should help prevent puncturing, as well as prevent gravel from creating preferential flow paths. Similar to gravel, soil particles or rock fragments also can create preferential flow paths. To help prevent the development of preferential pathways and an increased hydraulic conductivity, use soil liner materials where the soil particles and rock fragments are less than 3/4 inch in diameter.

[4]ASTM D-4318, *Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.*

[5]ASTM D-422, *Standard Test Method for Particle-Size Analysis of Soils.*

Interactions With Waste

Waste placed in a unit may interact with compacted clay liner materials, thereby influencing soil properties such as hydraulic conductivity and permeability. Two ways that waste materials can influence the hydraulic conductivity of the liner materials are through dissolution of soil minerals and changes in clay structure. Soil minerals can be dissolved, or reduced to liquid form, as a result of interaction with acids and bases. For example, aluminum and iron in the soil may be dissolved by acids, and silica may be dissolved by bases. While some plugging of soil pores by dissolved minerals may lower hydraulic conductivity in the short term, the creation of piping and channels over time may lead to an increased hydraulic conductivity in the long term. The interaction of waste and clay materials may also cause the creation of positive ions, or cations. The presence of cations such as sodium, potassium, calcium, and magnesium may change the clay structure, thereby influencing the hydraulic conductivity of the liner. Depending on the cation type and the clay mineral, an increased presence of such cations can cause the clay minerals to form clusters and increase the permeability of the clay. Therefore, before selecting a compacted clay liner material, develop a good understanding of the composition of the waste that will be placed in the waste management unit. EPA's Method 9100, in publication SW-846, measures the hydraulic conductivity of soil samples before and after exposure to permeants.[6]

Locating and Testing Material

Although the selection process for compacted clay liner construction materials may vary from project to project, some common material selection steps include locating and testing materials at a potential borrow or commercial pit before construction, and observing and testing material performance throughout construction. First, investigate a potential borrow or commercial pit to determine the volume of materials available. In addition, test a representative sample of soil to determine material properties such as plasticity characteristics, percent gravel, and percent fines. To confirm the suitability of the materials once construction begins, consider requesting that representative samples from the materials in the borrow or commercial pit be tested periodically after work has started.

Material selection steps will vary, depending on the origin of the materials for the project. For example, if a commercial pit provides the materials, locating an appropriate on-site borrow pit is no longer necessary. In addition to the tests performed on the material, a qualified inspector should make visual observations throughout the construction process to ensure that harmful materials, such as stones or other large matter, are not present in the liner material.

What issues should be considered in the construction of a liner and the operation of a unit?

Develop test pads to demonstrate construction techniques and material performance on a small scale. During unit construction and operation, some additional factors influencing the performance of the liner include: preprocessing, subgrade preparation, method of compaction, and protection against desiccation and cracking. Repeat all the steps, from preprocessing through protection against desiccation and cracking, for each lift, or layer of soil.

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[6]SW-846, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods.*

Test Pads

Preparing a test pad for the compacted clay liner helps verify that the materials and methods proposed will yield a liner that meets the desired hydraulic conductivity. A test pad also provides an opportunity to demonstrate the performance of alternative materials or methods of construction. A test pad should be constructed with the soil liner materials proposed for a particular project, using the same preprocessing procedures, compaction equipment, and construction practices proposed for the actual liner. A complete discussion of test pads (covering dimensions, materials, and construction) can be found in Chapter 2 of EPA's 1993 technical guidance document *Quality Assurance and Quality Control for Waste Containment Facilities* (EPA600-R-93-182). A discussion of commonly used methods to measure in-situ hydraulic conductivity is also contained in that chapter.

Preprocessing

Although some liner materials may be ready for use in construction immediately after they are excavated, many materials will require some degree of preprocessing. Preprocessing methods include: water content adjustment, removal of oversized particles, pulverization of any clumps, homogenization of the soils, and introduction of additives, such as bentonite.

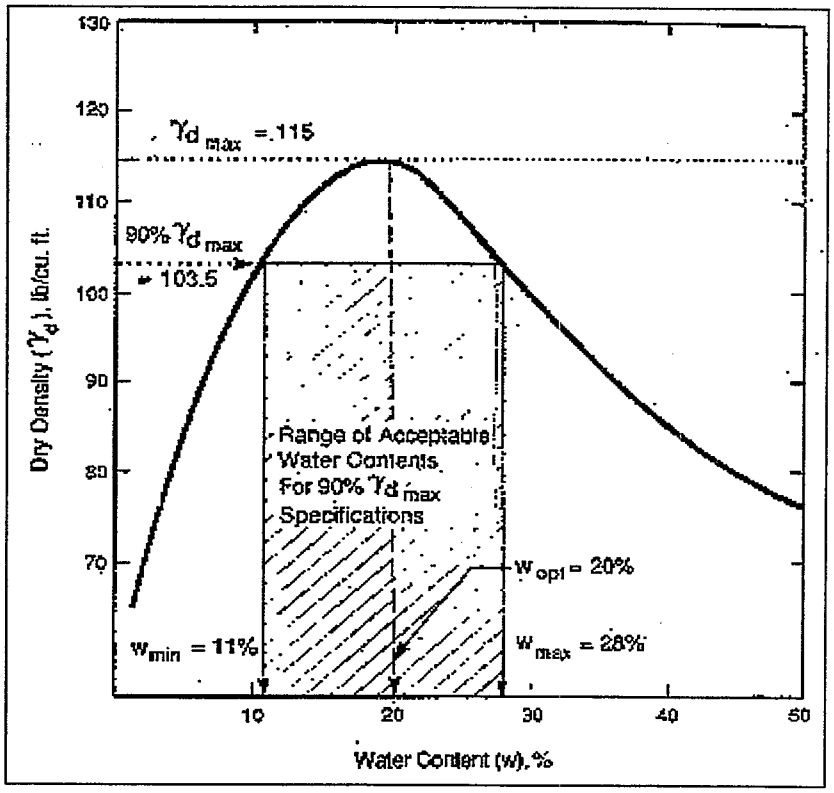
Water Content Adjustment. For natural soils, the degree of saturation of the soil liner at the time of compaction, known as molding water content, influences the engineering properties of the compacted material. Soils compacted at water contents less than optimum tend to have a relatively high hydraulic conductivity. Soils compacted at water contents greater than optimum tend to have low hydraulic conductivity and low strength.

Proper soil water content revolves around achieving a minimum dry density, which is expressed as a percentage of the soil's maximum dry density. The minimum dry density typically falls in the range of 90-95 percent of the soil's maximum dry density value. From the minimum dry density range, the required water content range can be calculated, as shown in Figure 1. In this example the soil has a maximum dry density of 115 lb/cu ft. Based upon a required minimum dry density value of 90 percent of maximum dry density, which is equal to 103.5 lb/cu ft., the required water content ranges from 10 to 28 percent.

It is less problematic to compact clay soil at the lower end of the required water content range because it is easier to add water to the clay soil than to remove it. Thus, if precipitation occurs during construction of a site which is being placed at the lower end of the required water content range, the additional water may not result in a soil water content greater than the required range. Conversely, if the site is being placed at the upper end of the range, for example at 25 percent, any additional moisture will be excessive, resulting in water content over 28 percent and making the 90 percent maximum dry density unattainable. Under such conditions construction should halt while the soil is aerated and excess moisture is allowed to evaporate.

Removal of Oversized Particles. Preprocessing clay materials, to remove cobbles or large stones that exceed the maximum allowable particle size, can improve the soil's compactibility and protect any adjacent geomembrane from puncture. A recommended maximum allowable particle size is less than 3/4 inch for compaction considerations. If a geomembrane will be placed over the compacted clay,

Figure 1.
Water Content for Achieving a Specific Density



Source: U.S. EPA. 1988. Lining of Waste Containment and Other Impoundment Facilities. EPA600-2-88-052.

only the upper lift of clay needs to address concerns regarding puncture resistance. Observation by quality assurance and quality control personnel is the most effective method to identify areas where oversized particles need to be removed. Cobbles and stones are not the only materials that can interfere with compactive efforts. Chunks of dry, hard clay, also known as clods, often need to be broken into smaller pieces to be properly hydrated, remolded, and compacted. In wet clay, clods are less of a concern since wet clods can often be remolded with a reasonable compactive effort.

Soil Amendments. If the soils at a unit do not have a sufficient percentage of clay, a common practice is to blend bentonite with them to reduce the hydraulic conductivity. Bentonite is a clay mineral that expands when it comes into contact with water. Relatively small amounts of bentonite, on the order of 5 to 10 percent, can be added to sand or other noncohesive soils to increase the cohesion of the material and reduce hydraulic conductivity.

Sodium bentonite is a common additive used to amend soils. However, this additive is vulnerable to degradation as a result of contact with certain chemicals and waste leachates. Calcium bentonite, a more permeable material than sodium bentonite, is another common additive used to amend soils. Approximately twice as much calcium bentonite is needed to achieve a hydraulic conductivity comparable to that of sodium bentonite. Amended soil mixtures generally require mixing in a pug mill, cement mixer, or other mixing equipment that allows water to be added during the mixing process. Throughout the mixing and placement processes, water content, bentonite content, and particle distribution need to be controlled. Other materials that can be used as soil additives include lime cement and other clay minerals, such as atapulgite. It may be difficult to mix

additives thoroughly with cohesive soils, or clays; the resultant mixture may not achieve the desired level of hydraulic conductivity throughout the entire liner.

Subgrade Preparation

Ensure that the subgrade on which a compacted clay liner will be constructed is properly prepared. When a compacted clay liner is the lowest component of a liner system, the subgrade consists of native soil or rock. Subgrade preparation for these systems involves compacting the native soil to remove any soft spots and adding water to or removing water from the native soil to obtain a specified firmness. Alternatively, in some cases, the compacted clay liner can be placed on top of a geosynthetic material, such as a geotextile. In such cases, subgrade preparation involves ensuring the smoothness of the geosynthetic on which the clay liner will be placed and the conformity of the geosynthetic material to the underlying material.

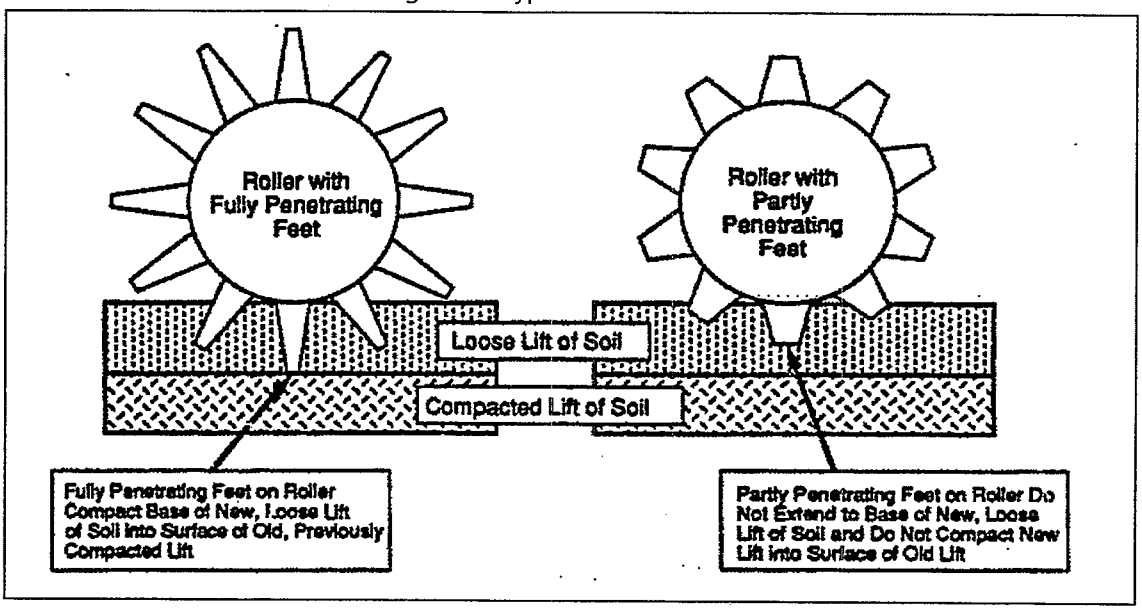
Compaction

The main purpose of compaction is to densify the clay materials by breaking and remolding clods of material into a uniform mass. Since amended soils usually do not develop clumps, the primary objective of compaction for such materials is to increase the material's density. Proper compaction of liner materials is essential to ensure that a compacted clay liner meets specified hydraulic conductivity standards. Factors influencing the effectiveness of compaction efforts include: the type of equipment selected, the number of passes made over the materials by such equipment, the lift thickness, and the bonding between the lifts. Molding water content, described earlier under preprocessing, is another factor influencing the effectiveness of compaction.

Type of Equipment. Factors to consider when selecting compaction equipment include: the type and weight of the compactor, the characteristics of any feet on the drum, and the weight of the roller per unit length of drummed surface. Heavy compactors, weighing more than 50,000 pounds, with feet long enough to penetrate a loose lift of soil, are often the best types of compactor for clay liners. For bentonite-soil mixtures, a footed roller may not be appropriate. For these mixtures, where densification of the material is more important than kneading or remolding it to meet low hydraulic conductivity specifications, a smooth-drum roller or a rubber-tired roller may produce better results. Figure 2 depicts two types of footed rollers, a fully penetrating footed roller and a partially-penetrating footed roller.

For placement of liners on side slopes, consider the angle and length of the slope. Placing continuous lifts on a gradually inclined slope will provide better continuity between the bottom and sidewalls of the liner. Since continuous lifts may be impossible to construct on steeper slopes due to the difficulties of operating heavy compaction equipment on these slopes, materials may need to be placed and compacted in horizontal lifts. When sidewalls are compacted horizontally, it is important to avoid creating seepage planes, by securely connecting the edges of the horizontal lift with the bottom of the liner. Because the lift needs to be wide enough to accommodate compaction equipment, the thickness of the horizontal lift is often greater than the thickness specified in the design. In such cases, consider trimming soil material from the constructed side slopes and sealing the trimmed surface using a sealed drum roller.

Figure 2. Types of Footer Rollers



Source: U.S. EPA. 1993. Technical Guidance Document: Quality Assurance and Quality Control For Waste Containment Facilities. EPA600-R-93-182.

It is common for contractors to use several different types of compaction equipment during liner construction. Initial lifts may need the use of a footed roller to fully penetrate a loose lift. Final lifts also may need the use of a footed roller for compaction, however, they may be formed better by using a smooth roller after the lift has been compacted to smooth the surface of the lift in preparation for placement of an overlying geomembrane.

Number of Passes. The number of passes made by a compactor over clay materials can influence the overall hydraulic conductivity of the liner. The minimum number of passes that is reasonable depends on a variety of site-specific factors and cannot be generalized. In some cases, where a minimum coverage is specified, it may be possible to calculate the minimum number of passes to meet such a specification. At least 5 to 15 passes with a compactor over a given point are usually necessary to remold and compact clay liner materials thoroughly.

An equipment pass may be defined as one pass of the compaction equipment or as one pass of a drum over a given area of soil. Clearly define what is meant by a pass in any quality assurance or quality control plans. It does not matter which definition is agreed upon, as long as the definition is used consistently throughout the project.

Lift Thickness. Determine the appropriate thickness (as measured before compaction) of each of the several lifts that will make up the clay liner. The initial thickness of a loose lift will affect the compactive effort needed to reach the lower portions of the lift. Thinner lifts allow compactive efforts to reach the bottom of a lift and provide greater assurance that compaction will be sufficient to allow homogenous bonding between subsequent lifts. Loose lift thicknesses typically range between 13 and 25

cm (5 and 10 in.). Factors influencing lift thickness are: soil characteristics, compaction equipment, firmness of the foundation materials, and the anticipated compaction necessary to meet hydraulic conductivity requirements.

Bonding Between Lifts. Since it is inevitable that some zones of higher and lower hydraulic conductivity, also known as preferential pathways, will be present within each lift, lifts should be joined or bonded in a way that minimizes extending these zones or pathways between lifts. If good bonding is achieved, the preferential pathways will be truncated by the bonded zone between the lifts. At least two recommended methods exist for preparing proper bonds. The first method involves kneading, or blending the new lift with the previously compacted lift using a footed roller. Using a roller with feet long enough to fully penetrate through the top lift and knead the previous lift improves the quality of the bond. A second method involves using a disc harrow or similar equipment to scarify, or roughen, and wet the top inch of the recently placed lift, prior to placing the next lift.

Protection Against Desiccation and Cracking

Consider how to protect compacted clay liners against desiccation and freezing during and after construction. Protection against desiccation is important, because clay soil shrinks as it dries. Depending on the extent of shrinkage, it may crack. Deep cracks, extending through more than one lift, may cause problems. Measure water content to determine whether desiccation is occurring.

There are several ways to protect compacted clay liners from desiccation. One preventive measure is to smooth roll the surface with a steel drummed roller to produce a thin, dense skin of soil; this layer can help minimize the movement of water into or out of the compacted material. Another option is to wet the clay periodically in a uniform manner; however, make sure to avoid creating areas of excessive wetness. A third measure involves covering compacted clay liner materials with a sheet of white or clear plastic or tarp to help prevent against desiccation and cracking. The cover should be weighted down with sandbags or other material to minimize exposure of the underlying materials to air. Using a light-colored plastic will help prevent overheating, which can dry out the clay materials. If the clay liner will not be covered with a geosynthetic, another method to prevent desiccation involves covering the clay with a layer of protective cover soil approximately one foot in thickness.

Protection against freezing is another important consideration, because freezing may increase the hydraulic conductivity of a liner. Avoid construction during freezing weather. If freezing does occur and the damage affects only a shallow depth, the liner may be repaired by rerolling the surface. If deeper freezing occurs, the repairs may be more complicated. For a general guide to frost depths, see Figure 1 of the chapter on performing closure and post-closure care.

B. Geomembranes or Flexible Membrane Liners

Geomembranes or flexible membrane liners are used to contain or prevent waste constituents and leachate from escaping a waste management unit. Geomembranes are made by combining one or more plastic polymers with ingredients such as carbon black, pigments, fillers, plasticizers, processing aids, crosslinking chemicals, anti-degradants, and

biocides. A wide range of plastic resins are used for geomembranes, including polyvinyl chloride (PVC), high density polyethylene (HDPE), linear low density polyethylene (LLDPE), and chlorosulfonated polyethylene (CSPE). Most manufacturers produce geomembranes through extrusion or calendering. In the extrusion process, a molten polymer is stretched into a nonreinforced sheet; extruded geomembranes are usually made of HDPE and LLDPE. During the calendering process, a heated polymeric compound is passed through a series of rollers. In this process, a geomembrane may be reinforced with a woven fabric or fibers. Calendered geomembranes are made of PVC and CSPE.

What are the thickness recommendations for geomembrane liners?

Geomembranes range in thicknesses from 20 to 120 mil (1 mil = 0.001 in.). A good design should include a minimum thickness of 30 mil, except for HDPE liners, which should have a minimum thickness of 60 mil. These minimum thicknesses ensure that the liner material will withstand the stress of construction and the weight load of the waste, and allow adequate seaming to bind separate geomembrane panels. Reducing the potential for tearing or puncture, through proper construction and quality control, is essential for a geomembrane to perform effectively.

What issues should be considered in the design of a geomembrane liner?

Several factors to address in the design include: determining appropriate material properties and testing to ensure these properties are met, understanding how the liner will interact with the intended waste stream, accounting for all stresses imposed by the design, and ensuring adequate friction.

Material Properties and Selection

When designing a geomembrane liner, examine several properties of the geomembrane material in addition to thickness, including: tensile behavior, tear resistance, puncture resistance, susceptibility to environmental stress cracks, ultraviolet resistance, and carbon black content.

Tensile Behavior. Tensile behavior refers to the tensile strength of a material and its ability to elongate under strain. Tensile strength is the ability of a material to resist pulling stresses without tearing. The tensile properties of a geomembrane must be sufficient to satisfy the stresses anticipated during its service life. These stresses include the self-weight of the geomembrane and any down drag caused by waste settlement on side slope liners.

Puncture and Tear Resistance. Geomembrane liners may be subject to tearing during installation due to high winds or handling. Puncture resistance is also important to consider since geomembranes are often placed above or below materials that may have jagged or angular edges. For example, geomembranes may be installed above a granular drainage system that includes gravel.

Susceptibility to Environmental Stress Cracks. Environmental factors may cause cracks or failures before a liner is stressed to its manufactured strength. These imperfections, referred to as environmental stress cracks, often occur in areas where a liner has been scratched or stressed by fatigue. These cracks can also result in areas where excess surface wetting agents have been applied. In surface impoundments, where

the geomembrane liner has greater exposure to the atmosphere and temperature changes, such exposure may increase the potential for environmental stress cracking.

Ultraviolet Resistance. Ultraviolet resistance is another factor to consider in the design of geomembrane liners, especially in cases where the liner may be exposed to ultraviolet radiation for prolonged periods of time. In such cases, which often occur in surface impoundments, ultraviolet radiation may cause degradation and cracking in the geomembrane. Adding carbon black or other additives during the manufacturing process may increase a geomembrane's ultraviolet resistance.

Interactions With Waste

Since the main purpose of a geomembrane is to provide a barrier and prevent contaminants from penetrating through the geomembrane, chemical resistance is a critical consideration. Testing for chemical resistance may be warranted depending on the type, volumes, and characteristics of waste managed at a particular unit. An established method for testing the chemical resistance of geomembranes, EPA Method 9090, can be found in SW-846. ASTM has also adopted standards for testing the chemical compatibility of various geosynthetics, including geomembranes, with leachates from waste management units. ASTM D-5747 provides a standard for testing the chemical compatibility of geomembranes.[7]

Stresses Imposed by Liner Design

A liner design should take into account the stresses imposed on the liner by the design configuration. These stresses include: the differential settlement in foundation soil, strain requirements at the anchor trench, strain requirements over long, steep side slopes, stresses resulting from compaction, and seismic stresses. Often an anchor trench designed to secure the geomembrane during construction is prepared along the perimeter of a unit cell. This action can help prevent the geomembrane from slipping down the interior side slopes. Trench designs should include a depth of burial sufficient to hold the specified length of liner. If forces larger than the tensile strength of the liner are inadvertently developed, then the liner could tear. For this reason, the geomembrane liner should be allowed to slip or give in the trench after construction to prevent such tearing. To help reduce unnecessary stresses in the liner design, avoid using horizontal seams. For more information on design stresses, consult U.S. EPA *Geosynthetic Guidance for Hazardous Waste Landfill Cells and Surface Impoundments* (EPA600-2-87-097).

Designing for Adequate Friction

Adequate friction between the geomembrane liner and the soil subgrade, as well as between any geosynthetic components, is necessary to prevent extensive slippage or sloughing on the slopes of a unit. Design equations for such components should evaluate: (1) the ability of a liner to support its own weight on side slopes, (2) the ability of a liner to withstand down-dragging during and after waste placement, (3) the best anchorage configuration for the liner, (4) the stability of soil cover on top of a liner, and (5) the stability of other geosynthetic components, such as geotextiles or geonets, on top of a liner. An evaluation of these issues may affect the choice of geomembrane material, polymer type, fabric reinforcement, thickness, and texture necessary to achieve the design requirements.

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[7]ASTM D-5747, *Practice for Tests to Evaluate the Chemical Resistance of Geomembranes to Liquids.*

What issues should be considered in the construction of a geomembrane liner?

When preparing to construct a geomembrane liner, plan appropriate shipment and handling procedures, perform testing prior to construction, prepare the subgrade, consider temperature effects, and account for wind effects. In addition, select a seaming process, determine a material for and method of backfilling, and plan for testing during construction.

Shipment, Handling, and Site Storage

Follow quality assurance and quality control procedures to ensure proper handling of geomembranes. Different types of geomembrane liners require different types of packaging for shipment and storage. Typically a geomembrane manufacturer will provide specific instructions outlining the handling, storage, and construction specifications for a product. In general, HDPE and LLDPE geomembrane liners are packaged in a roll form, while PVC and CSPE-R liners (CSPE-R refers to a CSPE geomembrane liner reinforced with a fabric layer) are packaged in panels, accordion-folded in two directions, and placed onto pallets. Whether the liner is shipped in rolls or panels, ensure proper storage. The rolls and panels should be packaged so that fork lifts or other equipment can safely transport them. For rolls, this involves preparing the roll to have a sufficient inside diameter so that a fork lift with a long rod, known as a stinger, may be used for lifting and moving. For accordion panels, proper packaging involves using a structurally-sound pallet, wrapping panels in treated cardboard or plastic wrapping to protect against ultraviolet exposure, and using banding straps with appropriate cushioning. Once the liners have been transported to the site, the rolls or panels may be stored until the subgrade or subbase (either natural soils or another geosynthetic) is prepared.

Subgrade Preparation

Before a geomembrane liner is installed, prepare the subgrade or subbase. The subgrade material should meet specified grading, moisture content, and density requirements. In the case of a soil subgrade, ensure that construction equipment used to place the liner does not deform the underlying materials. If the underlying materials are geosynthetics, such as geonets or geotextiles, remove all folds and wrinkles before the liner is placed. For further information on geomembrane placement, see Chapter 3 of EPA's 1993 technical guidance document *Quality Assurance and Quality Control for Waste Containment Facilities* (EPA600-R-93-182).

Testing Prior to Construction

Before any construction begins, test both the geomembrane materials from the manufacturer and the installation procedures. Acceptance and conformance testing is used to evaluate the performance of the manufactured geomembranes. Constructing test strips may help evaluate how well the intended construction process and quality control procedures will work.

Acceptance and Conformance Testing. Perform acceptance and conformance testing on the geomembrane liner received from the manufacturer to determine whether the materials meet the specifications requested. While the specific ASTM test methods vary depending on geomembrane type, recommended acceptance and conformance testing for geomembranes includes evaluations of thickness, tensile strength and elongation, and puncture and tear resistance testing, as appropriate. For most geomembrane liner types, the

recommended ASTM method for testing thickness is ASTM D-5199.[8] For tensile strength and elongation, ASTM D-638 is recommended for the HDPE and LLDPE sheets, while ASTM D-882 and ASTM D-751 are recommended for PVC and CSPE geomembranes, respectively.[9] Puncture resistance testing is typically recommended for HDPE and LLDPE geomembranes using Federal Test Method (FTM) Standard 101C. To evaluate tear resistance for HDPE, LLDPE, and PVC geomembrane liners, the recommended testing method is ASTM D-1004, Die C.[11] For CSPE-R geomembranes, ply adhesion is more of a concern than tear or puncture resistance and can be evaluated using ASTM D-413, Machine Method, Type A.[12]

Test Strips. In preparation for liner placement and field seaming, develop test strips and trial seams as part of the construction process. Construction of such samples should be performed in a manner that reproduces all aspects of field production. Providing an opportunity to test seaming methods and workmanship helps ensure that the quality of the seams remains constant and meets specifications throughout the entire seaming process.

Temperature Effects

Liner material properties may be altered by extreme temperatures. High temperatures may cause geomembrane liner surfaces to stick together, a process commonly referred to as blocking. On the other hand, low temperature may cause the liner to crack when unrolled or unfolded. Recommended maximum and minimum allowable sheet temperatures for unrolling or unfolding geomembrane liners are 50 °C (122 °F) and 0 °C (32 °F), respectively. In addition to sticking and cracking, extreme temperatures may cause geomembranes to contract or expand. Polyethylene geomembranes expand when heated and contract when cooled. Other geomembranes may contract slightly when heated. Those responsible for placing the liner need to take temperature effects into account as they place, seam, and backfill in the field.

Wind Effects

Take measures to protect geomembrane liners from wind damage. Windy conditions may increase the potential for tearing as a result of uplift. If wind uplift is a potential problem, panels may be weighted down with sand bags.

Seaming Processes

Once panels or rolls have been placed, another critical step involves field-seaming the separate panels or rolls together. The selected seaming process, such as thermal or chemical seaming, will depend on the chemical composition of the liner. To ensure the integrity of the seam, use the seaming method recommended by the manufacturer. Thermal seaming uses heat to bond together the geomembrane panels. Examples of thermal seaming processes include extrusion welding and thermal fusion (or melt bonding). Chemical seaming may involve the use of solvents, cement, or an adhesive. Chemical seaming processes include chemical fusion and adhesive seaming. For more information on seaming methods, the EPA document,

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[8] ASTM D-5199, *Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.*

[9] ASTM D-638, *Standard Test Method for Tensile Properties of Plastics.*
ASTM D-882, *Standard Test Methods for Tensile Properties of Thin Plastic Sheeting.*
ASTM D-751, *Standard Test Methods for Coated Fabrics.*

[10] FTM *Standard 101C, Puncture Resistance and Elongation Test (1/8 Inch Radius Probe Method).*

[11] ASTM D-1004, *Standard Test Method for Initial Tear Resistance of Plastic Film and Sheeting.*

[12] ASTM D-413, *Standard Test Methods for Rubber Property-Adhesion to Flexible Substrate.*

Technical Guidance Document: Inspection Techniques for the Fabrication of Geomembrane Field Seams (EPA530-SW-91-051), contains a full chapter on each of the traditional seaming methods and additional discussion of emerging techniques, such as ultrasonic, electrical conduction, and magnetic energy source methods.

Consistent quality in fabricating field seams is paramount to liner performance. Conditions that could affect seaming should be monitored and controlled during installation. Factors influencing seam construction and performance include: ambient temperature, relative humidity, wind uplift, changes in geomembrane temperature, subsurface water content, type of supporting surface used, skill of the seaming crew, quality and consistency of chemical or welding materials, preparation of liner surfaces to be joined, moisture at the seam interface, and cleanliness of the seam interface.

To help control some of these factors, no more than the amount of sheeting that can be used during a shift or a work day should be deployed at one time. To prevent erosion of the underlying soil surface or washout of the geomembrane, proper storm water control measures should be employed. Ambient temperature may become a concern, if the geomembrane liner has a high percentage of carbon black. Although the carbon black will help to prevent damage resulting from ultraviolet radiation, because its dark color absorbs heat, it may increase the ambient temperature of the geomembrane, making installation more complicated. To avoid surface moisture or high subsurface water content, geomembranes should not be deployed when the subgrade is wet.

Regardless of how well a geomembrane liner is designed, its ability to meet performance standards depends on proper quality assurance and quality control during installation. Geomembrane sheets and seams are subject to tearing and puncture during installation; punctures or tears can result from contact with jagged edges or underlying materials or by applying stresses greater than the geomembrane sheet can handle. Proper quality assurance and quality control can help minimize the occurrence of pinhole or seam leaks. For example, properly preparing the underlying layer and ensuring that the gravel is of an acceptable size reduces the potential for punctures.

Protection and Backfilling

Geomembrane liners that can be damaged by exposure to weather or work activities should be covered with a layer of soil or a geosynthetic as soon as possible after quality assurance activities associated with geomembrane testing are completed. If the backfill layer is a soil material, it will typically be a drainage material like sand or gravel. If the cover layer is a geosynthetic, it will typically be a geonet or geocomposite drain placed directly over the geomembrane. Careful placement of backfill materials is critical to avoid puncturing or tearing the geomembrane material.

For soil covers, three considerations determine the amount of slack to be placed in the underlying geomembrane. These considerations include selecting the appropriate type of soil, using the proper type of equipment, and establishing a placement procedure for the soil. When selecting a soil for backfilling, characteristics to consider include particle size, hardness, and angularity, as each of these may affect the potential for tearing or puncturing the liner. To prevent wrinkling, soil covers should be placed over the geomembrane in such a way that construction vehicles do not drive directly on the liner. Care should be taken not to push heavy loads of soil over the geomembrane in a continuous manner.

Forward pushing can cause localized wrinkles to develop and overturn in the direction of movement. Overturned wrinkles create sharp creases and localized stress in the liner and may lead to premature failure. A recommended method for placing soil involves continually placing small amounts of soil or drainage material and working outward over the toe of the previously placed material.

Another recommended method involves placing soil over the liner with a large backhoe and spreading it with a bulldozer or similar equipment. If a predetermined amount of slack is to be placed in the geomembrane, the temperature of the liner becomes an important factor, as it will effect the ability of the liner to contract and expand. Although the recommended methods for covering geomembrane liners with soil may take more time than backfilling with larger amounts of soil, these methods are designed to prevent damage caused by covering the liner with too much soil too quickly. In the long run, preventing premature liner failure can be faster and more cost-effective than having to repair a damaged liner.

The types of geosynthetics that are often used as protective covering include geotextiles and geonets. Geogrids and drainage geocomposites may be used for cover soil reinforcement on slopes. Consult Appendix VIII for additional information on geosynthetic materials. For geosynthetic protective covers, as with soil backfilling, to prevent tearing or puncturing, construction vehicles should not be permitted to move directly on the geomembrane. Seaming-related equipment may be allowed on the geomembrane liner, as long as it does not damage the liner. Geosynthetic materials are placed directly on the liner and are not bonded to it.

Testing During Construction

Testing during construction enables assessment of the integrity of the seams connecting the geomembrane panels. Tests performed on the geomembrane seams are categorized as either destructive or nondestructive.

Destructive Testing. Destructive testing refers to removing a sample from the liner seam or sheet and performing tests on the sample. For liner seams, destructive testing includes shear testing and peel testing; for liner sheets, it involves tensile testing. While quality control procedures often require destructive testing prior to construction, in order to ensure that the installed seams and sheets meet performance standards, destructive testing should be performed during construction also. For increased quality assurance, peel and shear tests on samples from the installed geomembrane should be performed by an independent laboratory. Testing methods for shear testing, peel testing, and tensile testing vary for different geomembrane liner types.

Determining the number of samples to take is a difficult step. Taking too few samples results in a poor statistical representation of the geomembrane quality. On the other hand, taking too many samples requires additional costs and increases the potential for defects. Defects can result from the repair patches used to cover the areas from which samples were taken.

A common sampling strategy is "fixed increment sampling" where samples are taken at a fixed increment along the length of the geomembrane. Increments range from 80 to 230 m (250 to 750 ft), with a commonly specified value of 150 m (500 ft). The type of welding, such as extrusion or fusion welding, used to connect the

seams and the type of geomembrane liner may also help determine the appropriate sampling interval. For example, extrusion seams on HDPE require grinding prior to welding and if extensive grinding occurs, the strength of the HDPE may decrease. In such cases, sampling at closer intervals, such as 90 to 120 m (300 to 400 ft), may provide a more accurate description of material properties. If the seam is a dual hot edge seam, both the inner and outer seams may need to be sampled and tested.

If test results for the seam or sheet samples do not meet the acceptance criteria for the destructive tests, continue testing the area surrounding the rejected sample to determine the limits of the low quality seam. Once the area of low quality has been identified, then corrective measures, such as seaming a cap over the length of the seam or reseaming the affected area, may be necessary.

Nondestructive Testing. Unlike destructive tests, which examine samples taken from the geomembrane liner, nondestructive tests are designed to evaluate the integrity of larger portions of geomembrane seams without removing pieces of the geomembrane for testing. Common nondestructive testing methods include: the probe test, air lance, vacuum box, ultrasonic methods (pulse echo, shadow, and impedance planes), electrical spark test, pressurized dual seam, and electrical resistivity. Select the test method most appropriate for the material and seaming method. If sections of a seam fail to meet the acceptable criteria of the appropriate nondestructive test, then those sections need to be delineated and patched, reseamed, or retested. If repairing such sections results in large patches or areas of reseaming, then destructive test methods should be used to verify the integrity of such pieces.

C. Geosynthetic Clay Liners

If a risk evaluation recommended the use of a single liner, another option to consider is a geosynthetic clay liner (GCL). GCLs are factory-manufactured, hydraulic barriers typically consisting of bentonite clay (or other very low permeability materials), supported by geotextiles and/or geomembranes held together by needling, stitching, or chemical adhesives. GCLs can be used to augment or replace compacted clay liners or geomembranes, or they can be used in a composite manner to augment the more traditional compacted clay or geomembrane materials. GCLs are typically used in areas where clay is not readily available or where conserving air space is an important factor. As GCLs do not have the level of long-term field performance data that geomembranes or compacted clay liners do, states may require demonstration that performance of the GCL design will be comparable to that of compacted clay or geomembrane liners.

What are the mass per unit area and hydraulic conductivity recommendations for geosynthetic clay liners?

Geosynthetic clay liners are often designed to perform the same function as compacted clay and geomembrane liner components. For geosynthetic clay liners, design for a minimum of 4 kg/m^2 (0.8 lb/ft^2) dry weight (oven dried at 105 °C) of bentonite clay with a hydrated hydraulic conductivity of no more than 5 x 10^{-9} cm/sec (2 x 10^{-9} in/sec). Follow manufacturer specifications for proper GCL installation.

What issues should be considered in the design of a geosynthetic clay liner?

Factors to consider in GCL design are the specific material properties needed for the liner and the chemical interaction or compatibility of the waste with the GCL. When considering material properties, keep in mind that bentonite has a low shear strength when it is hydrated. Manufacturers have developed products designed to increase shear strength.

Materials Selection and Properties

For an effective GCL design, material properties need to be clearly defined in the specifications used during both manufacture and construction. Properties that need to be specified include: type of bonds, thickness, moisture content, mass per unit area, shear strength, and tensile strength. Each of these properties is described below.

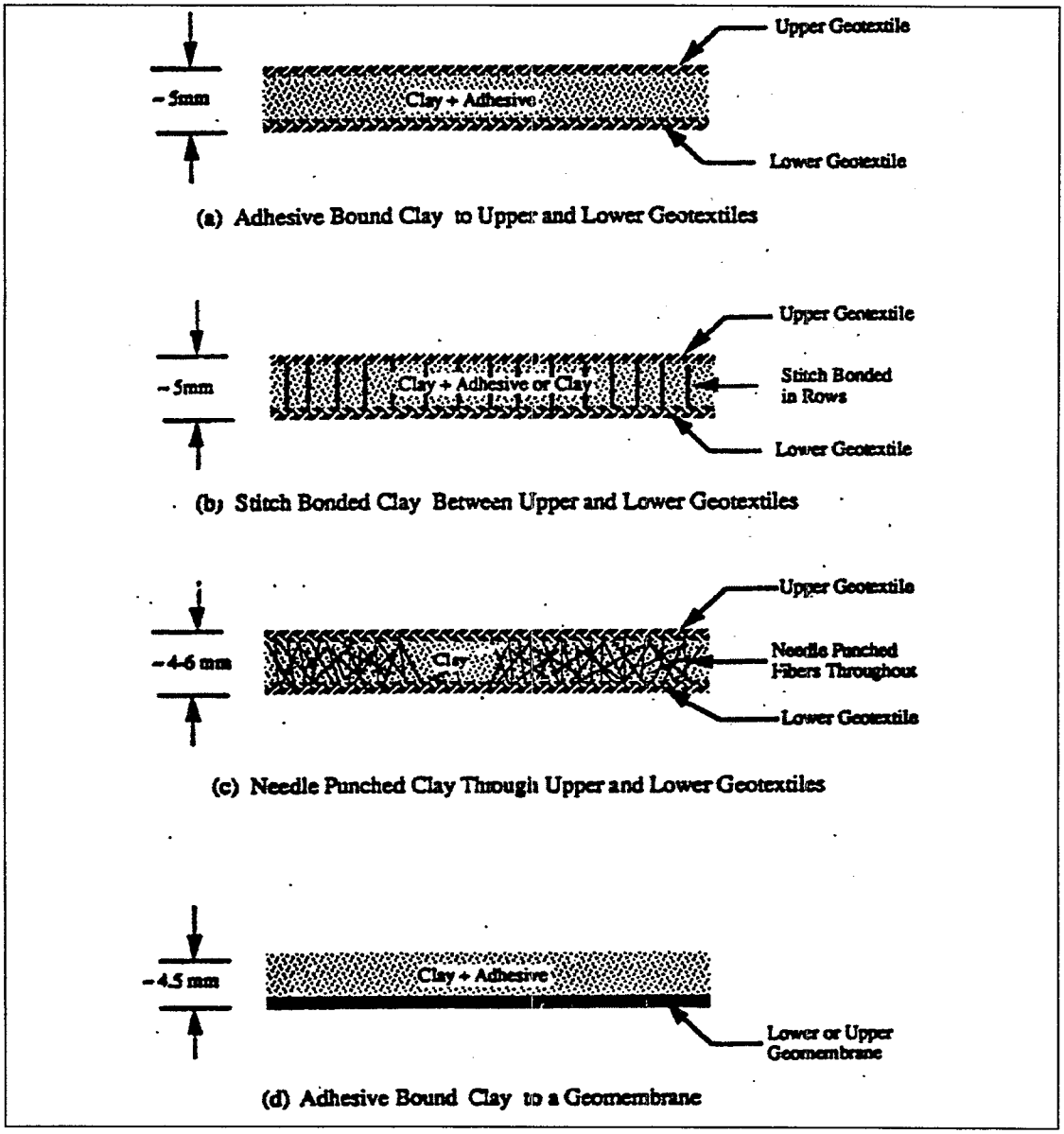
Type of bonds. Geosynthetic clay liners are available with a variety of bonding designs, which include a combination of clay, adhesives, and geomembranes or geotextiles. The type of adhesives, geotextiles, and geomembranes used as components of GCLs varies widely. One type of available GCL design uses a bentonite clay mixed with an adhesive bound on each side by geotextiles. A variation on this design involves stitching the upper and lower geotextiles together through the clay layer. Alternatively, another option is to use a GCL where geotextiles on each side of adhesive or nonadhesive bentonite clay are connected by needle punching. A fourth variation uses a clay mixed with an adhesive bound to a geomembrane on one side; the geomembrane can be either the lower or the upper surface. Figure 3 displays cross section sketches of the four variations of GCL bonds. While these options describe GCLs available at the time of this guidance, emerging technologies in GCL designs should also be reviewed and considered.

Thickness. The thickness of the various available GCL products ranges from 4 to 6 mm (160 to 320 mil). Thickness measurements are product dependent. Some GCLs can be quality controlled for thickness while others cannot.

Moisture Content. GCLs are delivered to the job site at moisture contents ranging from 5 to 23 percent; this may be referred to as the "dry" state. GCLs are delivered dry to prevent premature hydration, which can cause unwanted variations in the thickness of the clay component as a result of uneven swelling.

Stability and Shear Strength. GCLs should be manufactured and selected to meet the shear strength requirements specified in design plans. In this context, shear strength is the ability of two layers to resist forces moving them in opposite directions. Since hydrated bentonite clay has low shear strength, bentonite clay may be placed between geotextiles and stitch bonded or needle-punched to provide additional stability. For example, a GCL with geotextiles supported by stitch bonding has greater internal resistance to shear in the clay layer than a GCL without any stitching. Needle-punched GCLs tend to provide greater resistance than stitch-bonded GCLs and can also provide increased friction resistance against an adjoining layer, because they require the use of nonwoven geotextiles. Increased friction is an important consideration on side slopes.

Figure 3.
Four variations of GCL Bonding Methods



Source: U.S. EPA. 1993. Technical Guidance Document: Quality Assurance and Quality Control For Waste Containment Facilities. EPA600-R-93-182.

Interaction With Waste

During the selection process for a GCL liner, evaluate the chemical compatibility of the liner materials with the types of waste that are expected to be placed in the unit. Certain chemicals, such as calcium, can have an adverse effect on GCLs, resulting in a loss of liner integrity. Specific information on GCL compatibilities should be available from the manufacturer.

What issues should be considered in the construction of a geosynthetic clay liner?

Prior to and during construction, a qualified professional should prepare construction specifications for the GCL. In these specifications, procedures for shipping and storing materials, as well as performing acceptance testing on delivered materials, should be identified. The specifications should also address methods for subgrade preparation, joining panels, repairing sections, and protective backfilling.

Shipment, Handling, and Site Storage

GCLs are manufactured in widths of approximately 2 to 5 m (7 to 17 ft) and lengths of 30 to 60 m (100 to 200 ft). Directly after manufacturing, GCLs are rolled around a core and covered with a thin plastic protective covering. This waterproof covering serves to protect the material from premature hydration. GCLs should be stored at the factory with these protective coverings. Typical storage lengths range from a few days to 6 months. To ensure protection of the plastic covering and the rolls themselves during loading and unloading, qualified professionals should specify the equipment needed at the site to lift and deploy the rolls properly.

To reduce the potential for accidental damage or for GCLs to absorb moisture at the site, try to arrange for "just-in-time-delivery" for GCLs transported from the factory to the field. Even with "just-in-time-delivery," it may be necessary to store GCLs for short periods of time at the site. Often the rolls can be delivered in trailers, which can then serve as temporary storage. To help protect the GCLs prior to deployment, use wooden pallets to keep the rolls off the ground, placing heavy, waterproof tarps over the GCL rolls to protect them from precipitation, and using sandbags to help keep the tarps in place.

Manufacturer specifications should also indicate how high rolls of GCLs can be stacked horizontally during storage. Overstacking can cause compression of the core around which the GCL is wrapped. A damaged core makes deployment more difficult and can lead to other problems. For example, rolls are sometimes handled by a fork lift with a stinger attached. The stinger is a long tapered rod that fits inside the core. If the core is crushed, the stinger may damage the liner during deployment.

Acceptance and Conformance Testing

Perform acceptance and conformance testing either upon delivery of the GCL rolls or at the manufacturer's facility prior to delivery. Conformance test samples are used to ensure that the GCL meets the project plans and specifications. GCLs should be rewrapped and replaced in dry storage areas immediately after test samples are removed. Liner specifications should prescribe sampling frequencies based on either total area or on number of rolls. Conformance testing may include the following.

Mass Per Unit Area Test. The purpose of evaluating mass per unit area is to ensure an even distribution of bentonite throughout the GCL panel. Although mass per unit area varies from manufacturer to manufacturer, a typical minimum value for oven dry weight is 4 kg/m² (0.8 lb/ft²). Mass per unit area should be tested using ASTM D-5993.[13] This test measures the mass of bentonite per unit area of GCL. Sampling frequencies should be determined using ASTM D-4354.[14]

Free Swell Test. Free swell refers to the ability of the clay to absorb liquid. Either ASTM D-5890 or GRI-GCL1, a test method developed by the Geosynthetic Research Institute, can be used to evaluate the free swell of the material.[15]

Direct Shear Test. Shear strength of the GCLs can be evaluated using ASTM D-5321.[16] The sampling frequency for this performance-oriented test is often based on area, such as one test per 10,000 m² (100,000 ft²).

Hydraulic Conductivity Test. Either ASTM D-5084 (modified) or GRI-GCL2 will measure the ease with which liquids can move through the GCL.[17]

Other Tests. Testing of any geotextiles or geomembranes should be made on the original rolls of the geotextiles or geomembranes and before they are fabricated into the GCL product. Once these materials have been made part of the GCL product, their properties may change as a result of any needling, stitching, or gluing. Additionally, any peel tests performed on needle punched or stitch bonded GCLs should use the modified ASTM D-413 with a recommended sampling frequency of one test per 2,000 m² (20,000 ft²).[18]

Subgrade Preparation

Because the GCL layer is relatively thin, the first foot of soil underlying the GCL should have a hydraulic conductivity of 1 x 10^{-5} cm/sec or less. Proper subgrade preparation is essential to prevent damage to the GCL layer as it is installed. This includes clearing away any roots or large particles that could potentially puncture the GCL and its geotextile or geomembrane components. The soil subgrade should be of the specified grading, moisture content, and density required by the installer and approved by a construction quality assurance engineer for placement of the GCL. Construction equipment deploying the rolls should not deform or rut the soil subgrade excessively. To help ensure this, the soil subgrade should be smooth rolled with a smooth-wheel roller and maintained in a smooth condition prior to deployment.

Joining Panels

GCLs are typically joined by overlapping panels, without sewing or mechanically connecting pieces together. To ensure proper joints, clearly specify minimum and maximum overlap distances. Typical overlap distances range from 150 to 300 mm (6 to 12 in.). For some GCLs, such as needle punched

[13] ASTM D-5993, *Standard Test Method for Measuring Mass per Unit Area of Geosynthetic Clay Liners.*

[14] ASTM D-4354, *Standard Practice for Sampling of Geosynthetics for Testing.*

[15] ASTM D-5890, *Test Method for Swell Index of Clay Mineral Components of Geosynthetic Clay Liners. GRI-GCL1, Swell Measurement of the Clay Component of Geosynthetic Clay Liners.*

[16] ASTM D-5321, *Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.*

[17] ASTM D-5084, *Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter. GRI-GCL2, Permeability of Geosynthetic Clay Liners (GCLs).*

[18] ASTM D-413, *Standard Test Methods for Rubber Property-Adhesion to Flexible Substrate.*

GCLs with nonwoven geotextiles, it may be necessary to place bentonite on the area of overlap. If this is necessary, prevent fugitive bentonite particles from coming into contact with the leachate collection system, as they may cause physical clogging.

Repair of Sections Damaged During Liner Placement

During installation, GCLs may incur some damage to either the clay component or to any geotextiles or geomembranes. For damage to geotextile or geomembrane components, repairs may include patching, using geotextile or geomembrane materials. If the clay component is disturbed, a patch made from the same GCL product should be used to perform any repairs.

Protective Backfilling

As soon as possible after completion of quality assurance and quality control activities, cover GCLs with either a soil layer or a geosynthetic layer to prevent hydration. The soil layer may be a compacted clay liner or a layer of coarse drainage material. The geosynthetic layer is typically a geomembrane; however, depending on site-specific designs, it can be a geotextile. As noted earlier, premature hydration before covering can lead to uneven swelling, resulting in a GCL with varied thickness. Therefore, a GCL should be covered with its subsequent soil or geosynthetic layer before a rainfall or snowfall occurs. Premature hydration is less of a concern for GCLs, where the geosynthetic components are needle punched or stitch bonded, because these types of connections can better limit clay expansion.

III. Composite Liners

A composite liner consists of both a geomembrane liner and a compacted clay liner (or a GCL). A composite liner provides an effective hydraulic barrier by combining the complementary properties of the two different liners into one system. The geomembrane provides a highly impermeable layer to maximize leachate collection and removal. The compacted clay liner serves as a backup in the event of any leakage from the geomembrane. This discussion refers only to a compacted clay liner and geomembrane composite liner. When a GCL is used as part of a composite liner, it typically replaces the compacted clay layer of the composite liner. With a composite liner design, construct a leachate collection and removal system above the geomembrane. Information on design and construction of leachate collection and removal systems is provided in Section V below.

What are the thickness and hydraulic conductivity recommendations for composite liners?

Each component of the composite liner should follow the recommendations for geomembranes, geosynthetic clay liners, and compacted clay liners described earlier. Geomembrane liners should have a minimum thickness of 30 mil, except for HDPE liners, which should have a minimum thickness of 60 mil. Similarly, compacted clay liners should be at least 2 feet thick and are typically 2 to 5 feet thick. For compacted clay liners and geosynthetic clay liners, use materials with maximum hydraulic conductivities of 1×10^{-7} cm/sec (4×10^{-8} in/sec) and 5×10^{-9} cm/sec (2×10^{-9} in/sec), respectively.

What issues should be considered in the design of a composite liner?

As a starting point, follow the design considerations discussed previously for single liners. In addition, to achieve the benefits of a combined liner system, install the geomembrane to ensure good contact with the compacted clay layer. The uniformity of contact between the geomembrane and the compacted clay layer helps control the flow of leachate. Porous material, such as drainage sand or a geonet, should not be placed between the geomembrane and the clay layer. Porous materials will create a layer of higher hydraulic conductivity, which will increase the amount of leakage below any geomembrane imperfection.

Consider the friction or shear strength between a compacted clay layer and a geomembrane. The friction or shear stress at this surface is often low and may form a weak plane on which sliding may occur. ASTM D-5321 provides a test method for determining the friction coefficient of soil and geomembranes.[19] When using bentonite-amended soils, account for how the percentage of bentonite added and the degree of saturation affect interface friction. To guarantee stable slopes, it is important to control both the bentonite and moisture contents. Consider using a textured geomembrane to increase the friction with the clay layer and improve stability.

What issues should be considered in the construction of a composite liner?

To achieve good composite bonding, the geomembrane and the compacted clay layer should have good hydraulic contact. To improve good contact, smooth-roll the surface of the compacted clay layer using a smooth, steel-drummed roller and remove any stones. In addition, place and backfill the geomembrane so as to minimize wrinkles.

The placement of geomembranes onto a compacted clay layer poses a challenge, because workers cannot drive heavy machines over the clay surface without potentially damaging the compacted clay component. Even inappropriate footwear can leave imprints in the clay layer. To avoid damaging the clay layer, unroll geomembranes by lifting the rolls onto jacks at a cell side and pulling down on the geomembrane manually. Also, the entire roll with its core may be unrolled onto the cell (with auxiliary support using ropes on embankments).

To minimize desiccation of the compacted clay layer, place the geomembrane over the clay layer as soon as possible. Additional cover materials should also be placed over the geomembrane. Exposed geomembranes absorb heat, and high temperatures can dry out and crack an underlying compacted clay layer. Daily cyclic changes in temperature can draw water from the clay layer and cause this water to condense on the underside of the geomembrane. This withdrawal of water can lead to desiccation cracking and potential interface stability concerns.

IV. Double Liners (Primary and Secondary Lined Systems)

In a double-lined waste management unit, there are two distinct liners—one primary (top) liner and one secondary (bottom) liner. Each liner may consist of compacted clay, a geomembrane, or a composite (consisting of a geomembrane and a compacted clay layer or GCL). Above the primary liner, construct a leachate collection and removal system to collect and

[19] ASTM D-5321, *Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.*

convey liquids out of the waste management unit and to control the depth of liquids above the primary liner. In addition, place a leak detection, collection, and removal system between the primary and secondary liner. This leak detection system will provide leak warning, as well as collect and remove any liquid or leachate that has escaped the primary liner. See Section V below for information on the design of leachate collection and removal systems and leak detection, collection, and removal systems.

What are the thickness and hydraulic conductivity recommendations for double liners?

Each component of the double liner should follow the recommendations for geomembranes, compacted clay liners, or composite liners described earlier. Geomembrane liners should have a minimum thickness of 30 mil, except for HDPE liners, which should have a minimum thickness of 60 mil. Similarly, compacted clay liners should be at least 2 feet thick and are typically 2 to 5 feet thick. For compacted clay liners and geosynthetic clay liners, use materials with maximum hydraulic conductivities of 1×10^{-7} cm/sec (4×10^{-8} in./sec) and 5×10^{-9} cm/sec (2×10^{-9} in/sec), respectively.

What issues should be considered in the design and construction of a double liner?

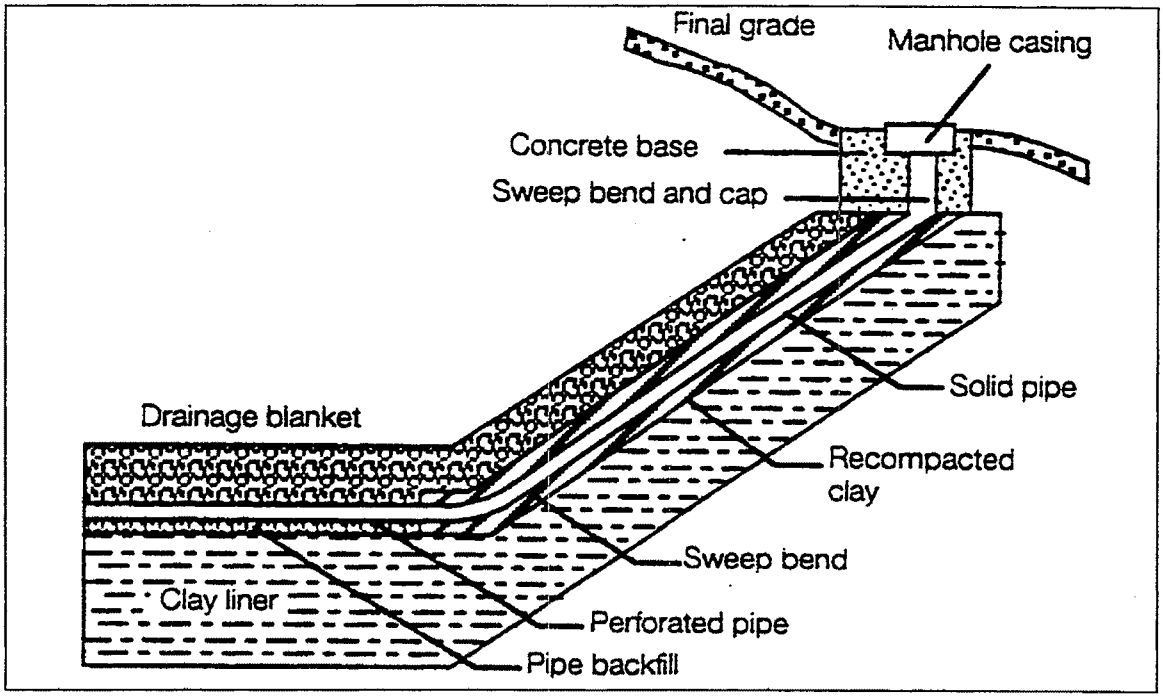
Like composite liners, double liners are composed of a combination of single liners. When planning to design and construct a double liner, consult the sections on composite and single liners first. In addition, consult the sections on leachate collection and removal systems and leak detection systems.

V. Leachate Collection and Leak Detection Systems

One of the most important functions of a waste management unit is controlling leachate and preventing contamination of the underlying ground water. Both leachate collection and removal systems and leak detection systems serve this purpose. Consult with the state agency too determine if such systems are required. The primary function of a leachate collection and removal system is to collect and convey leachate out of a unit and to control the depth of leachate above a liner. The primary function of a leak detection system is to detect leachate that has escaped the primary liner. A leak detection system refers to drainage material located below the primary liner and above a secondary liner (if there is one); it acts as a secondary leachate collection and removal system. After the leachate has been removed and collected, a leachate treatment system may be incorporated to process the leachate and remove harmful constituents.

The information in this section on leachate collection and leak detection systems is applicable if the unit is a landfill or a waste pile. Surface impoundments, which manage liquid wastes, will not have leachate collection and removal systems unless they will be closed in-place as landfills; they may have leak detection systems to detect liquid wastes that have escaped the primary liner. No leachate collection or leak detection systems are used with land application.

Figure 4.
Typical Leachate Collection System



Source: U.S. EPA. 1995. Decision Maker's Guide to Solid Waste Management, Volume II. EPA530-R-95-023

A. Leachate Collection System

A typical leachate collection system includes a drainage layer, collection pipes, a removal system, and a protective filter layer. Leachate collection systems are designed to collect leachate for treatment or alternate disposal and to reduce the buildup of leachate above the liner system. Figure 4 shows a cross section of a typical leachate collection system showing access to pipes for cleaning.

What are the recommendations for leachate collection and removal systems?

Design a leachate collection and removal system to maintain less than 30 cm (12 in.) depth of leachate, or "head," above the liner if granular soil is used. If a geosynthetic material is used, the leachate head should not exceed the thickness of the geosynthetic material (this mean the head cannot exceed 0.03 inches). The reason for maintaining this level is to prevent excessive leachate from building up above the liner, which could jeopardize the liner's performance. This should be the underlying factor guiding the design, construction, and operation of the leachate collection and removal system.

Design a leachate collection and removal system capable of controlling the estimated volume of leachate. To determine potential leachate generation, use water balance equations or models. The most commonly used method to estimate leachate generation is the EPA's *Hydrogeologic Evaluation of Landfill Performance* (HELP) model.[20] This model uses weather, soil, and waste management unit design data to determine leachate generation rates.

What issues should be considered in the design of a leachate collection and removal system?

Design a leachate collection and removal system to include the following elements: a low-permeability base, a high-permeability drainage layer, perforated leachate collection pipes, a protective filter layer, and a leachate removal system. During design, consider the stability of the base, the transmissivity of the drainage layers, and the strength of the collection pipes. Also consider methods to minimize physical, biological, and chemical clogging within the system.

Low-Permeability Base

A leachate collection system is placed over the unit's liner system. The bottom liner should have a minimum slope of 2 percent to allow the leachate collection system to gravity flow to a collection sump. This grade is necessary to provide proper leachate drainage throughout the operation, closure, and post-closure of the unit. Estimates of foundation soil settlement should include this 2 percent grade as a post-settlement design.

High-Permeability Drainage Layer

A high-permeability drainage layer consists of drainage materials placed directly over the low-permeability base, at the same minimum 2 percent grade. The drainage materials can be either granular soil or geosynthetic materials. For soil drainage materials, a maximum of 12 inches of materials with a hydraulic conductivity of at least 1×10^{-2} cm/sec (4×10^{-3} in./sec) is recommended. For this reason, sand and gravel are the most common soil materials used. If the drainage layer is going to incorporate sand or gravel, it should be demonstrated that the layer will have sufficient bearing capacity to withstand the waste load of the full unit. Additionally, if the waste management unit is designed on grades of 15 percent or higher, it should be demonstrated that the soil drainage materials will be stable on the steepest slope in the design.

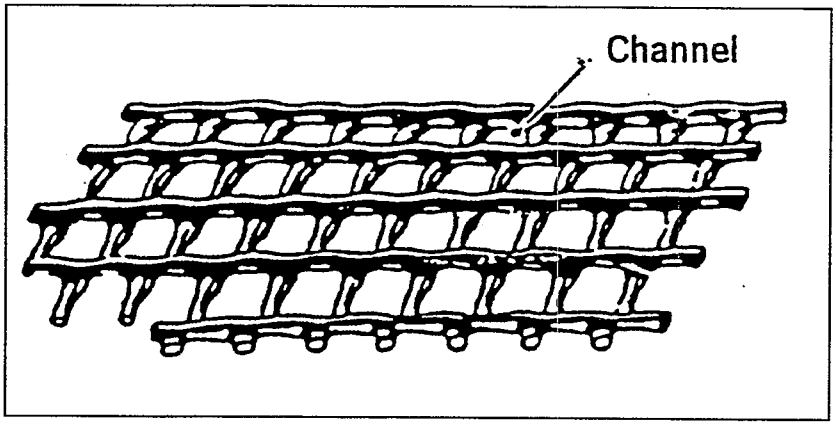
Geosynthetic drainage materials such as geonets may be used in addition to, or in place of, soil materials. Geonets promote rapid transmission of liquids and should always be used in conjunction with a filter layer or geotextile to prevent clogging. Geonets consist of integrally connected parallel sets of plastic ribs overlying similar sets at various angles. Geonets are often used on the side walls of waste management units because of their ease of installation. Figure 5 depicts a typical geonet material configuration.

The most critical factor involved with using geonets in a high-permeability drainage layer is the material's ability to transmit fluids under load. The flow rate of a geonet can be evaluated by ASTM D-4716.[21] Several additional measures for determining the transmissivity of geonets are discussed in the EPA document *Solid Waste Disposal Facility Criteria: Technical Manual* (EPA530-R-93-017).

[20] Available from the U.S. Army Corps of Engineers Web site **<http://www.wes.army.mil/el/elmodels/index.html#landfill>.**

[21] ASTM D-4716, *Standard Test Method for Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products.*

Figure 5.
Typical Geonet Configuration



Perforated Leachate Collection Pipes

Whenever the leachate collection system is a natural soil, a perforated piping system should be located within it to rapidly transmit the leachate to a sump and removal system. Through the piping system, leachate flows gravitationally to a low point where the sump and removal system is located. The design of perforated leachate collection pipes, therefore, should consider necessary flow rates, pipe sizing, and pipe structural strength. After estimating the amount of leachate using the HELP model or a similar water balance model, it is possible to calculate the appropriate pipe diameter and spacing. For the leachate collection system design, select piping material that can withstand the anticipated weight of the waste, construction and operating equipment stresses, and foundation settling. Most leachate collection pipes used in modern waste management units are constructed of HDPE. HDPE pipes provide great structural strength, while allowing significant chemical resistance to the many constituents found in leachate. PVC pipes are also used in waste management units, but they are not as chemically resistant as HDPE pipes.

Protective Filter Layer

To protect the drainage layer and perforated leachate collection piping from clogging, place a filter layer over the high-permeability drainage layer. To prevent waste material from moving into the drainage layer, the filter layer should consist of a material with smaller pore space than the drainage layer materials or the perforation openings in the collection pipes. Sand and geotextiles are the two most common materials used for filtration. Select sand that allows adequate flow of liquids, prevents migration of overlying solids or soils into the drainage layer, and minimizes clogging during the service life. In designing the sand filter, consider particle size and hydraulic conductivity. The advantages of using sand materials include common usage, traditional design, and durability.

Any evaluation of geotextile materials should address the same concerns but with a few differences. To begin with, the average pore size of the geotextile should be large enough to allow the finer soil particles to pass but small enough to retain larger soil particles. The number of openings in the geotextile should be large enough that, even if some of the openings clog, the remaining openings will be sufficient to pass the design flow rate. In addition to pore size, geotextile filter specifications should include durability requirements. The advantages of geotextile materials include vertical space savings and easy placement. Chapter 5 of EPA's 1993 technical guidance document *Quality Assurance and Quality Control for Waste Containment Facilities* (EPA600-R-93-182) offers guidance on protection of drainage layers.

Leachate Removal System

Leachate removal often involves housing a sump within the leachate collection drainage layer. A sump is a low point in the liner constructed to collect leachate. Modern waste management unit sumps often consist of prefabricated polyethylene structures supported on a steel plate above the liner. Especially with geomembrane liners, the steel plate serves to support the weight of the sump and protect the liner from puncture. Reinforced concrete pipe and concrete flooring may be used in place of the polyethylene structure but are considerably heavier.

To remove leachate that has collected in the sump, use a submersible pump. Ideally, the sump should be placed at a depth of 1 to 1.5 m (3 to 5 ft) to allow enough leachate collection to prevent the pump from running dry. Consider installing a level control, backup pump, and warning system to ensure proper sump operation. Also consider using a backup pump as an alternate to the primary pump and to assist it during high flow periods. A warning system should be used to indicate pump malfunction.

Standpipes, vertical pipes extending through the waste and cover system, offer one method of removing leachate from a sump without puncturing the liner. Alternatively, remove leachate from a sump using pipes that are designed to penetrate the liner. When installing pipe penetrations through the liner, proceed with extreme caution to prevent any liner damage that could result in uncontained leachate. Both of these options rely on gravity to direct leachate to a leachate collection pond or to an external pumping station.

Minimizing Clogging

Leachate collection and removal systems are susceptible to physical, biological, and chemical clogging. Physical clogging may occur through the migration of finer-grained materials into coarser-grained materials, thus reducing the hydraulic conductivity of the coarser-grained material. Biological clogging may occur through bacterial growth in the system due to the organic and nutrient materials in leachate. Chemical clogging may be caused by chemical precipitates, such as calcium carbonates, causing blockage or cementation of granular drainage material.

Proper selection of drainage and filter materials is essential to minimize clogging in the high-permeability drainage layer. Soil and geotextile filters may be used to minimize physical clogging of both granular drainage material and leachate collection pipes. When placed above granular drainage material, these filters may also double as an operations layer to prevent sharp waste from damaging the liner or leachate collection and removal systems. To minimize chemical and biological clogging for granular drainage material, the best procedure is to keep the interstices of the granular drainage material as open as possible.

The leachate collection pipes are also susceptible to similar clogging. To prevent this, incorporate measures into the design to allow for routine pipe cleaning, using either mechanical or hydraulic methods. The cleaning components can include pipes with a 15 cm (6-in.) minimum diameter to facilitate cleaning, access located at major pipe intersections or bends to allow for inspections and cleaning, and valves, ports, or other appurtenances to introduce biocides and/or cleaning solutions. Consider incorporating an antimicrobial additive into the plastic composition to delay or reduce biological growth. Also, ensure that the design does not include wrapping perforated leachate collection pipes directly with geotextile filters. If the geotextile becomes clogged, it can block flow into the pipe.

B. Leak Detection System

The leak detection system (LDS) is also known as the secondary leachate collection and removal system. It uses the same drainage and collection components as the primary leachate collection and removal system and identifies any leakage from the primary liner system. It also serves to collect and remove any leakage from the primary system. The LDS should be located directly below the primary liner and above the secondary liner.

What are the recommendations for leak detection systems?

The LDS should be designed to assess the adequacy of the primary liner against leachate leakage; it should cover both the bottom and side walls of a waste management unit. The LDS should be designed to collect leakage through the primary layer and transport it to a sump within 24 hours.

The LDS should allow for monitoring and collection of leachate escaping the primary liner system. Monitor the LDS on a regular basis. If the volume of leachate detected by the LDS appears to be increasing or is significant, consider a closer examination to determine possible remediation measures. A good rule of thumb is that if the LDS indicates a seepage level greater than 20 gallons per acre per day, the system may need closer monitoring or remediation.

C. Leachate Treatment System

Once the leachate has been removed from the unit and collected, take measures to characterize the leachate in order to ensure proper disposal. There are several methods of disposal for leachate, and the treatment strategy will vary according to the disposal method chosen. Leachate disposal options include discharging to or pumping and hauling to a publicly owned treatment works or to an on-site treatment system; treating and discharging to the environment; land application; and natural or mechanical evaporation.

When discharging to or pumping and hauling leachate to a publicly owned treatment works, a typical treatment strategy includes pre-treatment. Pre-treatment could involve equalization, aeration, sedimentation, Phone: adjustment, or metals removal.[22] If the plan for leachate disposal does not involve a remote treatment facility, pre-treatment alone is not sufficient.

There are two categories of leachate treatment, biological and physical/chemical. The most common method of biological treatment is activated sludge. Activated sludge is a "suspended-growth process that uses aerobic micro-organisms to biodegrade organic contaminants in leachate."[23] Among physical/chemical treatment techniques, the carbon absorption process and reverse osmosis are the two most common methods. Carbon absorption uses carbon to remove dissolved organics from leachate and is very expensive. Reverse osmosis involves feeding leachate into a tubular chamber whose wall acts as a synthetic membrane, allowing water molecules to pass through but not pollutant molecules, thereby separating clean water from waste constituents.

What are the recommendations for leachate treatment systems?

Review all applicable federal and state regulations and discharge standards to determine which treatment system will ensure long-term compliance and flexibility for the unit. Site-specific factors will also play a fundamental role in determining the proper leachate treatment system. For some facilities, onsite storage and treatment may not be an option due to

[22] Arts, Tom. "Alternative Approaches For Leachate Treatment." World Wastes.

space constraints. For other facilities, having a nearby, publicly owned treatment works may make pre-treatment and discharge to the treatment works an attractive alternative.

VI. Construction Quality Assurance and Quality Control

Even the best unit design will not translate into a structure that is protective of human health and the environment, if the unit is not properly constructed. Manufacturing quality assurance and manufacturing quality control (MQA and MQC) are also important issues for the overall project; however, they are discussed only briefly here since they are primarily the responsibility of a manufacturer. Nonetheless, select a manufacturer who incorporates appropriate quality assurance and quality control (QA and QC) mechanisms as part of the manufacturing process. The remainder of this section provides a general description of the components of a construction quality assurance and construction quality control (CQA and CQC) program for a project. CQA and CQC are critical factors for waste management units. They are not interchangeable, and the distinction between them should be kept in mind when preparing plans. CQA is third party verification of quality, while CQC consists of in-process measures taken by the contractor or installer to maintain quality. Establish clear protocols for identifying and addressing issues of concern throughout every stage of construction.

What is manufacturing quality assurance?

The desired characteristics of liner materials should be specified in the unit's contract with the manufacturer. The manufacturer is responsible for certifying that materials delivered conform to those specifications. MQC implemented to ensure such conformance might take the form of process quality control or computer-aided quality control. If requested, the manufacturer should provide information on the MQC measures used, allow unit personnel or engineers to visit the manufacturing facility, and provide liner samples for testing. The manufacturer should have a dedicated individual in charge of MQC who would work with unit personnel in these areas.

MQC, MQA, CQC, and CQA

Manufacturing quality control (MQC) is measures taken by the manufacturer to ensure compliance with the material and workmanship specifications of the facility manager.

Manufacturer quality assurance (MQA) is measures taken by facility personnel, or by an impartial party brought in expressly for the purpose, to determine if the manufacturer is in compliance with the specifications of the facility manager.

Construction quality control (CQC) is measures taken by the installer or contractor to ensure compliance with the installation specifications of the facility manager.

Construction quality assurance (CQA) is measures taken by facility personnel, or by an impartial party brought in expressly for the purpose, to determine if the installer or contractor is in compliance with the installation specifications of the facility manager.

[23] *Ibid.*

What is construction quality assurance?

CQA is a verification tool employed by the facility manager or regulatory agency, consisting of a planned series of observations and tests designed to ensure that the final product meets project specifications. CQA testing, often referred to as acceptance inspection, provides a measure of the final product quality and its conformance with project plans and specifications. Performing acceptance inspections routinely, as portions of the project become complete, allows early detection and correction of deficiencies, before they become large and costly.

On routine construction projects, CQA is normally the concern of the facility manager and is usually performed by an independent, third-party testing firm. The independence of the testing firm is important, particularly when a facility manager has the capacity to perform the CQA activities. Although the facility's in-house CQA personnel may be registered professional engineers, a perception of misrepresentation may arise if CQA is not performed by an independent third party.

The independent party should designate a CQA officer and fully disclose any activities or relationships that the officer has with the facility manager that may impact his or her impartiality or objectivity. If such activities or relationships exist, the CQA officer should describe actions that have been or can be taken to avoid, mitigate, or neutralize the possibility they might affect the CQA officer's objectivity. State regulatory representatives can help evaluate whether these mechanisms are sufficient to ensure acceptable CQA.

What is construction quality control?

CQC is an ongoing process of measuring and controlling the characteristics of the product in order to meet manufacturer's or project specifications. CQC inspections are typically performed by the contractor to provide an in-process measure of construction quality and conformance with the project plans and specifications, thereby allowing the contractor to correct the construction process if the quality of the product is not meeting the specifications and plans. Since CQC is a production tool employed by the manufacturer of materials and by the contractor installing the materials at the site, this guidance does not cover CQC in detail. CQC is performed independently of CQA. For example, while a geomembrane liner installer will perform CQC testing of field seams, the CQA program will require independent testing of those same seams by a third-party inspector.

How can implementation of CQA and CQC plans be ensured?

When preparing to design and construct a waste management unit, regardless of liner type, develop CQA and CQC plans customized to the project. To help the project run smoothly, the CQA plan should be easy to follow. Organize the CQA plan to reflect the sequence of construction and write it in language that will be familiar to an average field technician. For a more detailed discussion of specific CQA and CQC activities recommended for each type of waste management unit, consult the EPA document *Technical Guidance Document: Quality Assurance and Quality Control for Waste Management Containment Facilities* (EPA600-R-93-182). This document provides information needed to develop

comprehensive QA plans and to carry out QC procedures at waste management units.

CQA and CQC plans can be implemented through a series of meetings and inspections, which should be documented thoroughly. Communication among all parties involved in design and construction of a waste management unit is essential to ensuring a quality product. Define responsibility and authority in written QA and QC plans and ensure that each party involved understands its role. Preconstruction meetings are one way to help clarify roles and responsibilities. During construction, meetings may continue to be useful to help resolve misunderstandings and to identify solutions to unanticipated problems that may develop. Some examples of typical meetings during the course of any construction project include pre-bid meetings, resolution meetings, pre-construction meetings, and progress meetings.

A. Compacted Clay Liner Quality Assurance and Quality Control

Although manufacturing quality control and quality assurance are often the responsibility of the materials manufacturer, in the case of soil components, manufacturing and construction quality control testing can be the responsibility of the facility manager. In the CQA and CQC plans, specify procedures for quality assurance and quality control during construction of the compacted clay liners.

How can implementation of QA and QC be ensured for a compacted clay liner?

QC testing is typically performed by the contractor on materials used in construction of the liner. This testing examines material properties such as moisture content, soil density, Atterberg limits, grain size, and laboratory hydraulic conductivity. Additional testing of soil moisture content, density, lift thickness, and hydraulic conductivity ensures that the waste management unit has been constructed in accordance with the plans and technical specifications.

CQA testing for soil liners includes the same tests described for QC testing in the paragraph above. Generally, the tests are performed less frequently. CQA testing is performed by an individual or an entity independent of the contractor. Activities of the CQA officer are essential to document quality of construction. The responsibilities of the CQA officer and his or her staff may include communicating with the contractor; interpreting and clarifying project drawings and specifications with the designer, facility manager, and contractor; recommending acceptance or rejection by the facility manager of work completed by the construction contractor; and submitting blind samples, such as duplicates and blanks, for analysis by the contractor's testing staff or independent laboratories.

Also consider constructing a test pad prior to full-scale construction as a CQA tool. As described earlier in the section on compacted clay liners, pilot construction or test fill of a small-scale test pad can be used to verify that the soil, equipment, and construction procedures can produce a liner that performs according to the construction drawings and specifications.

Specific factors to examine or test during construction of a test fill include: preparation and compaction of foundation material to the required bearing strength; methods of controlling uniformity of the soil material; compactive effort, such as type of equipment and number of passes needed to achieve required soil density and hydraulic conductivity; and lift thickness and placement procedures

needed to achieve uniformity of density throughout a lift and prevent boundary effects between lifts or between placements in the same lift. Test pads can also provide a means to evaluate the ability of different types of soil to meet hydraulic conductivity requirements in the field. In addition to allowing an opportunity to evaluate material performance, test pads also allow evaluation of the skill and competence of the construction team, including equipment operators and QC specialists.

B. Geomembrane Liner Quality Assurance and Quality Control

As with the construction of soil liners, installation of geomembrane liners should be in conformance with a CQA and CQC plan. The responsibilities of the CQA personnel for the installation of the geomembrane are generally the same as the responsibilities for the construction of a compacted clay liner, with the addition of certain activities including observations of the liner storage area and liners in storage, and handling of the liner as the panels are positioned in the cell. Geomembrane CQA staff should also observe seam preparation, seam overlap, and materials underlying the liner.

How can implementation of QA and QC be ensured for a geomembrane liner?

Prior to installation, work with the geomembrane manufacturer to ensure the labeling system for the geomembrane rolls is clear and logical, allowing easy tracking of the placement of the rolls within the unit. In addition, examine the subgrade surface with both the subgrade contractor and the liner installer to ensure it conforms to specifications.

Once liner installation is underway, CQA staff may be responsible for observations of destructive testing conducted on scrap test welds prior to seaming. Geomembrane CQA staff may also be responsible for sending destructive seam sampling to an independent testing laboratory and reviewing the results for conformance to specifications. Other observations for which the CQA staff are typically responsible include observations of all seams and panels for defects due to manufacturing and/or handling and placement and observations of all pipe penetrations through a liner.

Test methods, test parameters, and testing frequencies should be specified in the CQA plan to provide context for any data collected. Allow for testing frequency to change, based on the performance of the geomembrane installer. If test results indicate poor workmanship, increase testing. If test results indicate high quality installation work, consider reducing testing frequencies. When varying testing frequency, establish well-defined procedures for modifying testing frequency. In evaluating testing methods, understand the differences among testing methods and request those methods appropriate for the material and seaming method used. Use nondestructive testing methods when possible to help reduce the number of holes cut into the geomembrane.

Geomembrane CQA staff also need to document the results of their observations and prepare reports indicating the types of sampling conducted and sampling results, locations of destructive samples, locations of patches, locations of seams constructed, and any problems encountered. In some cases, they may need to prepare drawings of the liner installation. Record drawing preparation is frequently assigned to the contractor, to a representative of the facility manager, or to the engineer. Request complete reports from any CQA staff

and the installers. To ensure complete CQA documentation, maintain daily CQA reports and prepare weekly summaries.

C. Geosynthetic Clay Liner Quality Assurance and Quality Control

Construction quality assurance for geosynthetic clay liners is still a developing area; the GCL industry is continuing to establish standardized quality assurance and quality control procedures. The CQA recommendation for GCLs can serve as a starting point. Check with the GCL manufacturer and installer for more specific information.

How can implementation of QA and QC be ensured for a geosynthetic clay liner?

Develop a detailed CQA plan, including product specifications; shipping, handling, and storage procedures; seaming methods; and placement of overlying material. Work with the manufacturer to verify that the product meets specifications. Upon receipt of the GCL product, verify that it has arrived in good condition.

During construction, CQA staff will want to ensure that seams are overlapped properly and conform to specifications. CQA staff should also check that panels, not deployed within a short period of time, are stored properly. In addition, as overlying material is placed on the GCL, it is important to restrict vehicle traffic directly on the GCL. Prohibit direct vehicle traffic, with the exception of small, 4-wheel, all terrain vehicles. Even with the small all-terrain vehicles, drivers should take extreme care to avoid movements, such as sudden starts, stops, and turns, which may damage the GCL.

As part of the CQA documentation, maintain records of weather conditions, subgrade conditions, and GCL panel locations. Also document any repairs that were necessary or other problems identified and addressed.

D. Leachate Collection System Quality Assurance and Quality Control

Leachate collection system CQC should be performed by the contractor. Similar activities should be performed for CQA by an independent party acting on behalf of the facility manager. The purpose of leachate collection system CQA is to document that the system is constructed in accordance with design specifications.

How can implementation of QA and QC be ensured for a leachate collection system?

Prior to construction, CQA staff should inspect all materials to confirm that they meet the construction plans and specifications. These materials include: geonets; geotextiles; pipes; granular material; mechanical, electrical, and monitoring equipment; concrete forms and reinforcements; and prefabricated structures such as sumps and manholes. The leachate collection system foundation, either a geomembrane or compacted clay liner, should also be inspected, upon its completion, to ensure that it has proper grading and is free of debris and liquids.

During construction, CQA staff should observe and document, as appropriate, the placement and installation of pipes, filter layers, drainage layers, geonets and geotextiles, sumps, and mechanical and electrical equipment. For pipes, observations may include descriptions of pipe bedding material, quality

and thickness, as well as the total area covered by the bedding material. Observations of pipe installations should focus on the location, configuration, and grading of the pipes, as well as the quality of connections at joints.

For granular filter layers, CQA activities may include observing and documenting material thickness and quality during placement. For granular drainage layers, CQA may focus on the protection of underlying liners, material thickness, proper overlap with filter fabrics and geonets (if applicable), and documentation of any weather conditions that may affect the overall performance of the drainage layer. For geonets and other geosynthetics, CQA observations should focus on the area of coverage and layout pattern, as well as the overlap between panels. For geonets, CQA staff may want to make sure that the materials do not become clogged by granular material that may be carried over, as a result of either wind or run-off during construction.

Upon completion of construction, each component should be inspected to identify any damage that may have occurred during its installation or during construction of another component. For example, a leachate collection pipe may be crushed during placement of a granular drainage layer. Any damage that does occur should be repaired, and the repairs should be documented in the CQA records.

Action Items for Lined Units (Landfills, Waste Piles, and Surface Impoundments)

- ☐ Review the recommended location considerations and operating practices for the unit.
- ☐ Select appropriate liner type—single, composite, or double liner—or in-situ soils, based on risk characterization.
- ☐ Evaluate liner material properties and select appropriate clay, geosynthetic, or combination of materials; consider interactions of liner and soil material with waste.
- ☐ Develop a construction quality assurance (CQA) plan defining staff roles and responsibilities and specifying test methods, storage procedures, and construction protocols.
- ☐ Ensure a stable in-situ soil foundation, for nonengineered liners.
- ☐ Prepare and inspect subgrade, for engineered liners.
- ☐ Work with manufacturer to ensure protective shipping, handling and storage of all materials.
- ☐ Construct a test pad for compacted clay liners.
- ☐ Test compacted clay liner material before and during construction.
- ☐ Preprocess clay material to ensure proper water content, remove oversized particles, and add soil amendments, as applicable.
- ☐ Use proper lift thickness and number of equipment passes to achieve adequate compaction.
- ☐ Protect clay material from drying and cracking.
- ☐ Develop test strips and trial seams to evaluate geomembrane seaming method.
- ☐ Verify integrity of factory and field seams for geomembrane materials before and during construction.
- ☐ Backfill with soil or geosynthetics to protect geomembranes and geosynthetic clay liners during construction.
- ☐ Place backfill materials carefully to avoid damaging the underlying materials.
- ☐ Install geosynthetic clay liner with proper overlap.
- ☐ Patch any damage that occurs during geomembrane or geosynthetic clay liner installation.
- ☐ Design leachate collection and removal system to allow adequate flow and to minimize clogging; include leachate treatment and leak detection systems, as appropriate.
- ☐ Document all CQA activities, including meetings, inspections, and repairs.

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Part IV
Protecting Ground Water

Chapter 7: Section C
Designing A Land Application Program

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Designing A Land Application Program

Follow the evaluation framework recommended in this section when applying waste directly to the land for combination of soil amendment, treatment, and disposal. Account for the designated ground-water constituents identified in the assessing risk section, as well as other waste parameters and factors such as soil properties and plant and microbial interactions.

Land application offers some distinct benefits. At the same time, because land application does not rely on liners to contain waste, there are some associated risks. With proper planning and design, a land application program can meet waste management and land preservation goals and avoid negative impacts such as anaerobic conditions, noxious odors, long-term damage to soil, and releases to ground water, surface water, or the air. This section recommends an evaluation framework to account for a variety of waste parameters in addition to the constituents outlined in the assessing risk section[1], and other factors such as soil properties and plant and microbial nutrient use[2]. A successful land application program takes the interaction among all these factors into account.

If agricultural benefit is the primary purpose of land application — to attenuate waste and maximize plant growth while minimizing environmental and health risks — the considerations are numerous. If this involves short-term application on a field, for example a year or two under a contractual relationship with a farmer, the evaluation may be completed more quickly, but it is still important to take these factors into account. If the primary purpose is waste treatment or disposal, the goal of maximizing plant growth is probably less important. However, ensure that the waste application will not result in environmental releases and have detrimental effects on future uses and revegetation of the site.

Examples of land application benefits include the following:

- **Biodegradation of Waste.** If a waste stream contains sufficient organic material, plants and microorganisms can significantly biodegrade the waste, assimilating its organic components into the soil. After allowing sufficient time for assimilation of the waste, more waste may be applied to a given site without significantly increasing the total volume of waste at the site. This

[1]The constituents incorporated in the EPAIWEM to assess risk, such as heavy metals and synthetic organic chemicals, typically have little or no agricultural value and can threaten human health and the environment even in small quantities. The term "waste parameters" refers to waste constituents, such as nitrogen, biodegradable organic matter content, and pH, that have considerable agricultural significance and that typically threaten human health and the environment only in larger quantities or at extreme levels.

[2]40 CFR Part 503 specifies requirements for land application of sludge from municipal sewage treatment plants. The Part 503 regulations apply to sewage sludge (now generally referred to as "biosolids") or mixtures of sewage sludge and industrial process wastes, not to industrial wastes alone. Some of the specifications in Part 503, for example concerning pathogens, may be helpful in evaluating land application for industrial wastes. For mixtures of sewage sludge and industrial waste, the ground-water and air risk assessments and the evaluation framework laid out in this guidance can help address constituents that are not covered under the Part 503 regulations.

is in contrast to landfills and waste piles, in which waste accumulates continually and does not biodegrade quickly enough to reduce its volume significantly.

- **Inclusion of Liquids.** Land application units can accept bulk, non-containerized liquid waste. The water content of liquid wastes may make them desirable at land application sites in arid climates. When managing liquid waste, land application may reduce the need for expensive dewatering processes.
- **Improvement of Soil.** Applied waste can improve soil quality if the waste contains appropriate levels of biodegradable organic matter and nutrients. Nutrients can improve the chemical composition of the soils to better support vegetation, while biodegradable organic matter can improve soil physical properties to increase water retention capacity. These chemical and physical soil improvement aspects of land application have led to its use in conditioning soil for agricultural use.

Figure 1 outlines a framework for evaluating land application that incorporates both the ground-water risk assessment recommended in this chapter, as well as the other waste parameters and factors important to land application. Be sure to address the waste parameters and other characteristics discussed in this evaluation framework when characterizing wastes for land application.

I. Risk Assessment

If waste leachate contains any of the 191 constituents covered in the Tier I and II ground-water models, follow the evaluation recommended in subsections II through IV. If the waste leachate does contain some of these constituents, there are some initial steps to follow:

1) Consider whether any of these constituents are already addressed in any permit, memorandum of understanding, or other agreement with a federal, state, or other regulatory agency concerning land application. The guidance is not meant to supersede conditions established in these regulatory mechanisms.[3]

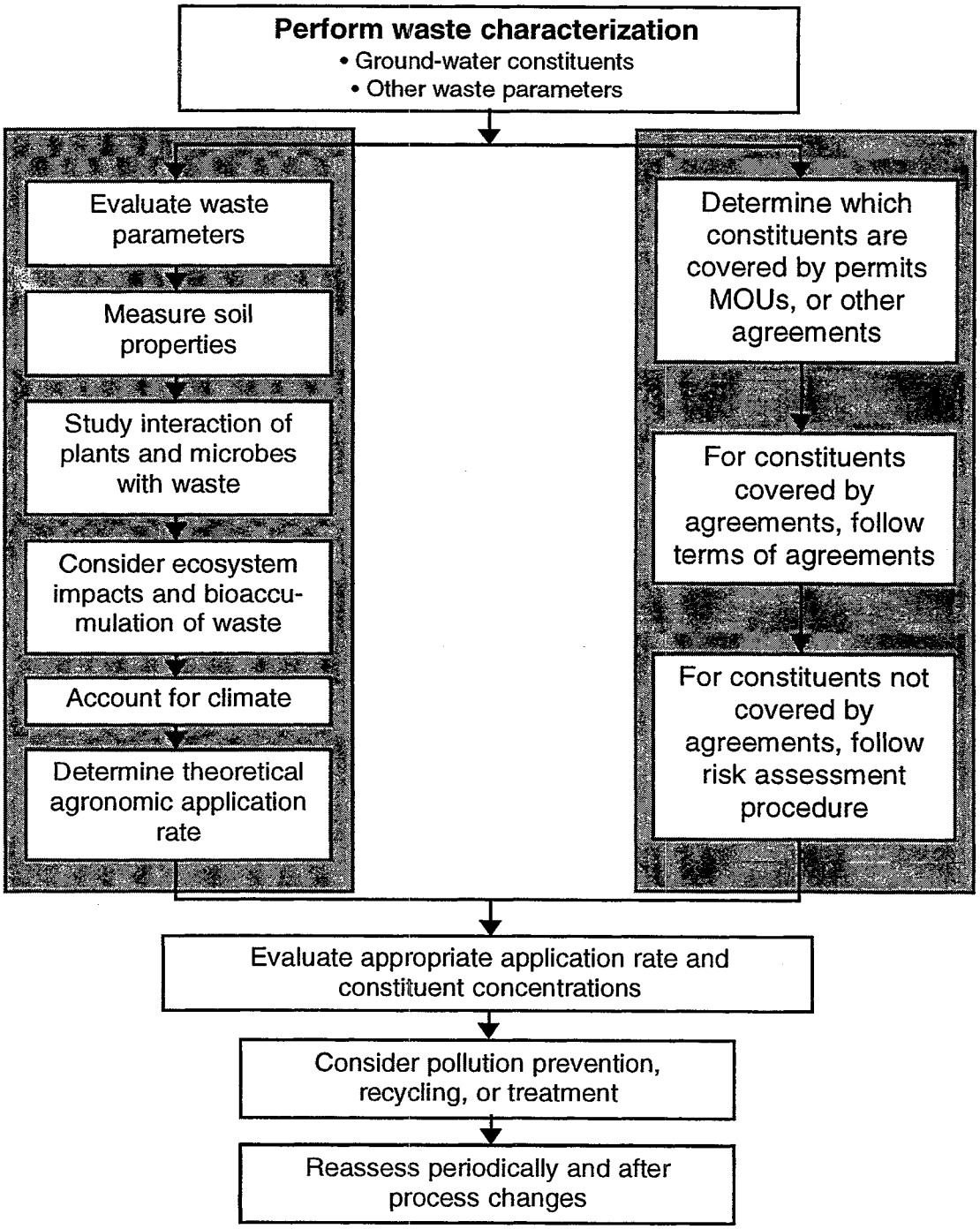
Some wastes may be designated by state or local regulators as essentially equivalent to a manufactured product or raw material. Such designations usually are granted only when use of the designated waste would not present a greater environmental and health risk than would use of the manufactured or raw material it replaces. Equivalence designations are included in the category of "other agreements" above. If there are no designated ground-water constituents other than those on which the designation is based, follow the guidelines offered in subsections II through IV to determine an application rate. If there are ground-water constituents other than those on which the designation is based, proceed with a risk analysis, such as that described in the section on assessing risk, for those constituents.

2) Evaluate ground-water and air risks using the modeling tools in this guidance or other site-specific models. The ground-water model recommends whether a waste is appropriate for land application. In some cases, pollution prevention or treatment may lower constituents levels so that a waste can be land applied. In other cases, land application may not be feasible. In this event, pursue other waste management options.

3) Consider direct exposure and ecosystem pathways. They are more important in land application, since only in land application is waste placed in and attenuated by the natural environment rather than contained by an

[3]EPA has signed agreements with states, industries, and individual sites concerning land application. One example is EPA's Memorandum of Understanding (MOU) between the American Forest and Paper Association (AFPA) and the U.S. EPA regarding the implementation of the land application agreements among AF&PA member Pulp and Paper Mills and the U.S. EPA, January 1994

Figure 1. A Framework for Evaluating Land Application



engineered structure. Although a qualitative tool to evaluate these pathways is not provided, take them into consideration when evaluating risks from a land application unit. During the unit's active life, direct human exposure to waste or waste-amended soil is primarily a risk to personnel involved in the operation. Follow OSHA standards and ensure that personnel use proper protective clothing and equipment when working onsite. Limit direct exposure to others through steps such as access control and vehicle washing to prevent tracking waste and waste amended soil off-site. Access control will limit exposure of some animals. If crops will be used for animal fodder or grazing, test harvested fodder for the designated ground-water constituents before use and restrict grazing times. After a site is closed, there may be long-term access risks to future land uses and the general public. To minimize these risks long-term access controls or deed restrictions may be appropriate. Consult the chapter on performing closure and post-closure care for further information.

Direct exposure of native animals is often impossible to control and may be an entry point for the ground-water constituents into the ecosystem. Worms, for example, may be present in the soil and take in these constituents. Birds or other animals could then consume the worms, and in doing so, not only bioaccumulate, but also transport them off-site. Furthermore, animals may ingest plants grown on waste-amended soil. Consider pathways such as these in evaluating risk.

II. Determining a Suitable Waste Application Rate for Land Application

The factors on the left side of Figure 1 provide the basics for determining a preliminary waste application rate. These factors are discussed below.

A. Waste Parameters

For land application, in addition to the designated ground-water constituents, important parameters to measure in the waste include total solids content, pH, biodegradable matter, pathogens, nutrients, metals, carbon to nitrogen ratio, soluble salts, and calcium carbonate equivalent. These parameters are summarized in Table 1 and discussed in the subsequent subsections. In addition to an initial analysis of these parameters, sample and characterize the waste on a regular basis and after process changes that may affect waste characteristics. This will help determine whether it is necessary to change land application practices or consider other waste management options.

B. Total Solids Content

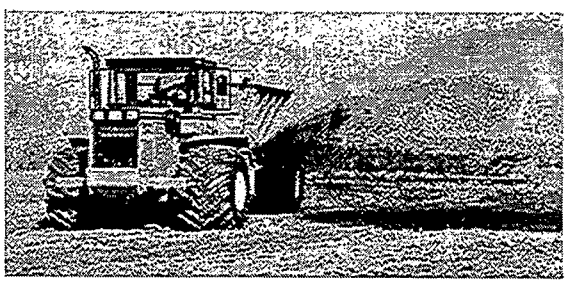
Total solids content indicates the ratio of solids to water in a waste. It includes both suspended and dissolved solids, and is usually expressed as a percentage of the waste. Total solids content depends on the type of waste, as well as whether the waste has been treated prior to land application. If waste is dried, composted, dewatered, thickened, or conditioned prior to land application, water content is decreased, thereby increasing the

Table 1
Summary of Important Waste Parameters

Waste parameter	Significance
Total solids content	Indicates ratio of solids to water in waste and influences application method.
pH	Controls metals solubility (and therefore mobility of metals toward ground water) and affects biological processes.
Biodegradable organic matter	Influences soil's water holding capacity, cation exchange, and other soil physical and chemical properties, and odor.
Nutrients (nitrogen, phosphorous, and potassium)	Affect plant growth; nitrogen is a major determinant of application rate; can migrate to and contaminate ground water or cause phytotoxicity if applied in excess.
Carbon to nitrogn ratio	Influences availability of nitrogen to plants.
Soluble salts	Can inhibit plant growth, reduce soil permeability, and contaminate ground water.
Calcium carbonate equivalent	Measures a waste's ability to neutralize soil acidity.
Pathogens	May threaten public health by migrating to ground water or being carried off-site by surface water, wind, or vectors.
Ground-water constituents designated in the risk assessment section including metals and organic chemicals	May present public health risk through ground-water contamination, direct contact with waste-soil mix, transport by surface water, and accumulation in plants. Metals inhibit plant growth and can be phytotoxic at elevated concentrations. Zinc, copper, and nickel are micronutrients essential to plant growth, but may inhibit growth at high levels.

total solids content (for some dry, fine, particulate wastes, conditioning may involve adding water, such as cement kiln dust).[4]

Understanding the total solids content will help plan appropriate storage and handling procedures and establish an application rate. Total solids content also will affect the choice of application method and equipment. Some methods, such as spray irrigation, may not work effectively if the solids content is too high. If it is low, meaning liquid content is correspondingly high, waste transportation costs could increase. If the total solids content of the waste is expected to vary, select equipment to accommodate materials with a range of solids contents. For example, selecting spreaders that will not clog if the waste is slightly drier than



Source: Ag-Chem Equipment Co., Inc.
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[4]Some states consider composted materials to be no longer wastes. Consult with the regulatory agency for applicable definitions.

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usual will help operations run more efficiently and reduce equipment problems.

C. pH

A waste's pH is a measure of its acidic or alkaline quality. Most grasses and legumes, as well as many shrubs and deciduous trees, grow best in the soil pH range from 5.5 to 7.5. If a waste is sufficiently acidic or alkaline[5] to move soil pH out of that range, it may hamper plant growth. Acidic waste promotes leaching of metals, because most metals are more soluble under acidic conditions than neutral or alkaline conditions. Once in solution, the metals would be available for plant uptake or could migrate to ground water. Alkaline conditions inhibit movement of most metals. Extreme alkalinity, where pH is greater than 11, impairs growth of most soil microorganisms and may increase the mobility of zinc, cadmium, and lead.

Waste with a pH of 2 or less or a pH of 12.5 or more meets the definition of hazardous waste under federal regulations. If the pH of a waste makes it too acidic for land application, consider adjusting waste pH before application. Lime is often used to raise pH, but other materials are also available. The pH is also important to consider as handling and storage procedures for a waste are planned.

D. Biodegradable Organic Matter

Wastes containing a relatively high percentage of biodegradable organic matter have greater potential as conditioners to improve the physical properties of soil. The percentage of biodegradable organic matter in soil is important to soil fertility, as organic matter can add nutrients; serve as an absorption and retention site for nutrients; and provide chemical compounds, such as chelating agents, that help change nutrients into more plant-available forms. Biodegradable organic matter content is typically expressed as a percentage of sample dry weight.

Biodegradable organic matter influences soil characteristics. Soils with high organic matter content often have a darker color (ranging from brown to black), increased cation exchange capacity—or capacity to take up and give off positively charged ions—and greater water holding capacity. Biodegradable organic matter also helps stabilize and improve the soil structure, decrease the density of the material, and improve aeration in the soil. In addition, organic nutrients are less likely than inorganic nutrients to leach.

How can biodegradable organic matter affect the waste application rate?

While organic materials provide a significant source of nutrients for plant growth, decomposition rates can vary significantly among materials. Food processing residues, for example, generally decompose faster than denser organic materials, such as wood chips. Account for the decomposition rate when determining the amount and frequency of waste application. Loading the soil with too much decomposing organic matter (such as by applying new waste before a previous

[5]A pH of 7 is neutral. Materials with pH less than 7 are acidic, while those with pH greater than 7 are alkaline

application of slowly decomposing waste has broken down) can induce nitrogen deficiency (see section E. below) or lead to anaerobic conditions.

E. Nutrients

Nitrogen, phosphorus, and potassium are often referred to as primary or macronutrients and plants use them in large amounts. Plants use secondary nutrients, including sulfur, magnesium, and calcium, in intermediate quantities. They use micronutrients, including iron, manganese, boron, chlorine, zinc, copper, and molybdenum, in very small quantities. Land application is often used to supply nutrients, especially primary nutrients, in an effort to improve plant growth.

Nutrient levels are key determinants of application rates. Excessive soil nutrient levels, caused by high waste application rates, may be phytotoxic or result in contamination of ground water, soil, and surface water. Nutrient loading is dependent on nutrient levels in both the waste and the soil, making characterization of the soil, as well as of the waste, important.

Nitrogen. Nitrogen content is often the primary factor determining whether a waste is agriculturally suitable for land application, and, if so, at what rate to apply it. Nitrogen deficiency is detrimental to the most basic plant processes, as nitrogen is an essential element for photosynthesis. Sufficient nitrogen promotes healthy growth and imparts a dark green color in vegetation. Lack of nitrogen can be identified by stunted plant growth and pale green or yellowish colored vegetation. Extreme nitrogen deficiency may cause plants to turn brown and die. On the other extreme, excessive nitrogen levels may result in nitrate leaching, which can contaminate ground-water supplies.

Although nitrate poses the greatest threat to ground water, nitrogen occurs in a variety of forms including ammonium, nitrate, nitrite, and organic nitrogen. These forms taken together are measured as total nitrogen. As a nutrient management plan is developed, consider that nitrogen transformations among these forms can continue after waste has been applied.

Phosphorus. Phosphorus plays a role in the metabolic process and reproduction of plants. When soil contains sufficient quantities of phosphorus, root growth and plant maturation improve. Conversely, phosphorus-deficient soils can cause stunted plant growth. Excessive phosphorus can lead to inefficient use of other nutrients and at extreme levels, zinc deficiency.

Potassium. Potassium is an essential nutrient for protein synthesis and fluid balance in plant growth. As with other nutrient deficiencies, symptoms include yellowing, burnt, or dying leaves, as well as stunted plant growth. In addition, signs of potassium deficiency include reduced disease resistance and reduced winter hardiness in certain plants.

How can I take nutrient levels into account?

Develop a nutrient management plan that accounts for the amount of nitrogen, phosphorus, and potassium being supplied by all sources at a site. The deciding nutrient is often nitrogen; however, do not overlook loading rates of other nutrients. If waste application rates are based solely on nitrogen levels, resulting levels of other nutrients can exceed crop needs or threaten ground water. Avoid excessive nutrient levels by monitoring waste concentrations and soil buildup of nutrients and reducing the application rate as

necessary, or by spacing applications to allow plant uptake between applications.

Maintaining appropriate phosphorus and potassium levels should be part of an overall nutrient management plan. The regional, state, or county agricultural extension services may have already developed materials on or identified software for nutrient management planning. Consult with them about the availability of such information. Northeast Regional Agricultural Engineering Services (NRAES) Cooperative Extension, for example, has compiled information on nutrient management software programs.[6]

F. Metals

A number of metals are included in the EPAIWEM for evaluating ground-water risk. Some metals, such as zinc, copper, and manganese, are essential soil micronutrients for plant growth. These are often added to inorganic commercial fertilizers. At excessive concentrations, however, some of these metals may be toxic to humans, animals, and plants. High concentrations of copper, nickel, and zinc, for example, cause phytotoxicity or inhibit plant growth. Also, the uptake and accumulation of metals in plants depends on a variety of plant and soil factors, including pH, biodegradable organic matter content, and cation exchange capacity. Therefore, evaluate levels of these metals in waste, soil, and plants from the standpoint of agricultural significance as well as health and environmental risk.

How can I determine acceptable metal concentrations?

Using the Tier I and II ground-water models will help to identify acceptable metals concentrations. Also consult with the local, state, or regional agriculture extension center on appropriate nutrient concentrations for plant growth. If the risk evaluation indicates that a waste is appropriate for land application, but subsequent soil or plant tissue testing finds excessive levels of metals, consider pretreating a waste with physical or chemical processes, such as chemical precipitation to remove some metals before application.

G. Carbon to Nitrogen Ratio

The carbon to nitrogen ratio refers to the relative quantities of these two elements in a waste or soil. Carbon is associated with organic matter, and the carbon to nitrogen ratio reflects the level of inorganic nitrogen available. Plants cannot use organic nitrogen, but can absorb inorganic nitrogen, such as ammonium. For many wastes, the carbon to nitrogen ratio is computed as the dry weight content of organic carbon divided by the total nitrogen content of waste.

Some wastes rich in organic materials (carbon) can actually induce nitrogen deficiencies. This occurs when wastes provide carbon in quantities that microbes cannot process without depleting available nitrogen. Soil microbes use carbon to build cells and nitrogen to synthesize proteins. Any excess organic nitrogen is then converted to inorganic nitrogen, which plants can use. The carbon to nitrogen ratio tells whether excess organic nitrogen will be available for this conversion.

When the carbon to nitrogen ratio is less than 20 to 1—indicating a high nitrogen content—organic nitrogen is mineralized, or converted from organic nitrogen to inorganic ammonium, and becomes available for plant growth. For maximal plant growth, the literature recommends maintaining a ratio below 20 to 1. When the carbon to nitrogen ratio is in the range of 20 to 1 to 30 to 1—a low nitrogen content—soil micro-organisms use much of the organic nitrogen to synthesize

[6]*Nutrient Management Software: Proceedings from the Nutrient Management Software Workshop.* To order, call NRAES at 607 255-7654 and request publication number NRAES-100.

proteins, leaving only small excess amounts to be mineralized. This phenomenon, known as immobilization, leaves little inorganic nitrogen available for plant uptake. When the carbon to nitrogen ratio is greater than 30 to 1, immobilization is the dominant process, causing stunted plant growth. The period of immobilization, also known as nitrogen or nitrate depression, will vary in length depending on the decay rate of the organic matter in the waste. As a result, plant growth within that range might not be stunted, but is not likely to be maximized.

How can I manage changing carbon to nitrogen ratios?

The cycle of nitrogen conversions within the soil is a complex, continually changing process. As a result, if applying waste based only on assumed nitrogen mineralization rates, it is often difficult to ensure that the soil contains sufficient inorganic nitrogen for plants at appropriate times. If you are concerned about reductions in crop yield, monitor the soil's carbon to nitrogen ratio and, when it exceeds 20 to 1, reduce organic waste application and/or supplement the naturally mineralized nitrogen with an inorganic nitrogen fertilizer, such as ammonium nitrate. Methods to measure soil carbon include EPA Method 9060 in Test Methods for Evaluating Solid Waste, Physical/Chemical Methods—SW-846. Nitrogen content can be measured with simple laboratory titrations.

H. Soluble Salts

Soluble salts are materials that dissolve in water or are already in solution in waste. Major soluble salt ions include calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), sulfate (SO_4^{2-}), bicarbonate (HCO_3^{-}), and nitrate (NO_3^{-}). The sum of all salt ions, sugars, and other materials in solution is referred to as total dissolved solids (TDS). The soluble salt content of a material may be determined by analyzing the concentration of the individual constituent ions and summing them, but this is a lengthy procedure. TDS of soil or waste can reasonably be estimated by measuring the electrical conductivity (EC) of a mixture of the material and water. EC can be measured directly on liquid samples. TDS is found by multiplying the electrical conductivity reading in millimhos/cm (mmhos/cm) by 700 to give TDS in parts per million (ppm) or mg/l.

Soluble salts are important for several reasons. First, saline soil, or soil with excessive salt concentrations, can reduce plant growth and seed germination. As salt concentration in soil increases, osmotic pressure effects make it increasingly difficult for plant roots to extract water from the soil. Through a certain range, this will result in reduced crop yield, up to a maximum beyond which crops will be unable to grow. The range and maximum for a few representative crops are shown in Table 2. For this reason, the salt content of the waste, rather than its nitrogen content, can be the primary determinant of its agricultural suitability for land application, especially on irrigated soils in arid regions.

The second reason soluble salts are important is that sodic soil, or soil with excessive levels of sodium ions (Na^{+}) relative to divalent ions (Ca^{2+}, Mg^{2+}), may alter soil structure and reduce soil permeability. The sodium absorption rate (SAR) of a waste is an indicator of its sodicity. To calculate the SAR of a waste or soil, determine the Na^{+}, Ca^{2+}, and Mg^{2+}concentrations in milliequivalents per liter[7] for use in the following equation[8]:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$

Table 2
Salinity Tolerance of Selected Crops

Crop	Soil Salinity (mmhos/cm)[a] that will result in:		
	0% yield reduction	50% yield reduction	100% yield reduction
Alfalfa	2.0	8.8	16
Bermuda grass	6.9	14.7	23
Clover	1.5	10.3	19
Perennial rye	5.6	12.1	19
Tall fescue	3.9	13.3	32

Source: Borrelli, J. and D. Brosz. 1986. Effects of Soil Salinity on Crop Yields.
[a]A rule of thumb from the irrigation industry holds that soil salinity will be 1½ times the salinity of applied irrigation water. The effect that waste salinity will have on soil salinity, however, is not as easily predicted and depends on the waste's water content and other properties and on the application rate.
[b]Reductions are stated as a percentage of maximum expected yield.

Soils characterized by both high salts (excessive TDS as indicated by EC) and excessive sodium ions (excessive Na^+ as indicated by SAR) are called saline-sodic soils, and can be expected to have the negative characteristics of both saline soils and sodic soils described above. Table 3 displays EC and SAR levels indicative of saline, sodic, and saline-sodic soils. The third reason soluble salts are important is that specific ions can induce plant toxicities or contaminate ground water. Sodium and chloride ions, for example, can become phytotoxic at high concentrations. To assess sodic- or toxic-inducing characteristics, conduct an analysis of specific ions in addition to measuring EC.

What can I do if a waste is either saline or sodic?

Saline Waste. If a waste is saline, careful attention to soil texture, plant selection, and application rate and timing can help. Coarse soils often have a lower clay content and are less subject to sodium-induced soil structure problems. While coarse soils help minimize soil structural problems associated with salinity, they also have higher infiltration and permeability rates, which allow for more rapid percolation or flushing of the root zone. This may increase the risk of waste constituents being transported to ground water.

Since plants vary in their tolerance to saline environments, plant selection also is

[7]The term milliequivalents per liter (meq/l) expresses the concentration of a dissolved substance in terms of its combining weight. Milliequivalents are calculated for elemental ions such as Na^+, Ca^{2+}, and Mg^{2+} by multiplying the concentration in mg/l by the valence number (1 for Na^+, 2 for Ca^{2+} or Mg^{2+}) and dividing by the atomic weight (22.99 for Na^+, 40.08 for Ca^{2+}, or 24.31 for Mg^{2+}).

[8]If the proper equipment to measure these concentrations is not available, consider sending soil and waste samples to a soil testing laboratory, such as that of the local extension service (refer to Appendix 1 for contact information) or nearby university. Such a laboratory will be able to perform the necessary tests and calculate the SAR.

Table 3
EC and SAR Levels Indicative of Saline, Sodic, and Saline-Sodic Soils

Soil Characterization			
Normal	Saline	Sodic	Saline-Sodic
EC[a] < 4 and SAR[b] < 13	EC > 4	SAR > 13	EC > 4 and SAR > 13

Source: Fipps, G. Managing Irrigation Water Salinity In the Lower Rio Grande Valley.
[a]In units of mmhos/cm [b]dimensionless

important. Some plant species, such as rye grass, canary grass, and bromegrass, are only moderately tolerant and exhibit decreased growth and yields as salinity increases. Other plants, such as barley and bermuda grass, are more saline-tolerant species.

Avoid applying high salt content waste as much as possible. For saline wastes, a lower application rate and thorough, tilling or plowing may help dilute the overall salt content of the waste by mixing it with a greater soil volume. To avoid the inhibited germination associated with saline soils, it also may help to time applications of high-salt wastes well in advance of seedings.

Sodic Waste. SAR alone will not tell how sodium in a waste will affect soil permeability; investigate the EC of a waste as well. Even if a waste has a high SAR, plants may be able to tolerate this level if the waste also has an elevated EC. As with saline waste, for sodic waste select a coarser-textured soil to help address sodium concerns. Adding gypsum ($CaSO^4$) to irrigation water may also help to reduce the SAR, by increasing soil calcium levels. Although this may help address sodium-induced soil structure problems, if choosing to add constituents to alter the SAR, the EC will also need to be monitored to ensure salinity levels are not increase too much.

I. Calcium Carbonate Equivalent

Calcium carbonate equivalent (CCE) is used to measure a waste's ability to neutralize soil acidity—its buffering capacity—as compared with pure calcium carbonate. Buffering capacity refers to how much the pH changes when a strong acid or base is added to a solution. A highly buffered solution will show only a slight change in pH when strong acids or bases are added. Conversely, if a solution has a low buffering capacity, its pH will change rapidly when a base or acid is added to it. If a waste has a 50 percent CCE, it would need to be applied at twice the rate of pure calcium carbonate to achieve the same buffering effect.

J. Pathogens

Potential disease-causing micro-organisms or pathogens, such as bacteria, viruses, protozoa, and the eggs of parasitic worms, may be present in certain wastes. Standardized testing procedures are available to help determine whether a waste contains pathogens. Consider using such tests especially if process knowledge indicates that a waste might contain pathogens. Fecal coliform bacteria can be quantified, for example, by using a membrane filtering technique, which involves passing liquid waste through a filter, incubating the filtrate (which

contains the bacteria) on a culture medium for 24 hours, and then counting the number of bacterial colonies formed.

Pathogens present a public health hazard if they are transferred to food or feed crops, contained in run-off to surface waters, or transported away from a land application site by vectors. If pathogen-carrying vectors are a concern at a site, establish measures to control them. For examples of methods to control vectors, refer to the chapter on operating the waste management system.

How can I reduce pathogenic risks?

Methods to reduce pathogenic risk include disinfecting or stabilizing a waste prior to land application. Examples of treatment methods recognized for sewage sludge stabilization are included in the sidebar. The services of a qualified engineer may be necessary to design an appropriate process for reducing pathogens in a waste. Consult with the state to determine whether there are any state-specific requirements for pathogen reductions for specific waste types.

What are methods for stabilizing waste prior to land application?

The following methods, recommended for stabilizing sewage sludge, may also be useful for reducing pathogens in waste:

- Aerobic digestion
- Air drying
- Anaerobic digestion
- Composting, and
- Lime stabilization

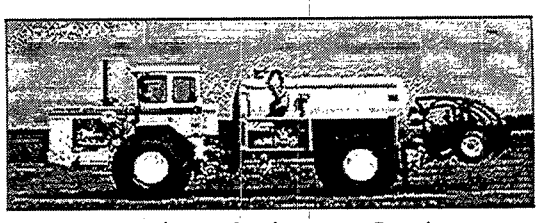
More detailed information on each of these and other methods can be found in EPA's *Control of Pathogens and Vector Attraction in Sewage Sludge* (EPA625-R-92-013).

III. Soil Properties

Physical, biological, and chemical characteristics of the soil are key factors in determining soil capacity for waste attenuation. If the soil is overloaded, rapid oxygen depletion, extended anaerobic conditions, and the accumulation of odorous and/or phytotoxic end-products could impair soil fertility and productivity over the long term as well as negatively impact adjacent properties. With proper design and operation, waste can be successfully applied to almost any soil; however, sites with highly permeable soil, such as sand; highly impermeable soil, such as clay; poorly drained soils; or steep slopes may present special design issues. Therefore, give such sites lower priority during the site selection process.

How can I evaluate the soil at a site?

To help evaluate the soil properties of a site, consult the U.S. Department of Agriculture (USDA) soil survey for the prospective area. These surveys provide information on properties such as soil type and permeability. USDA has prepared soil surveys for most counties in each state. To obtain a copy of the survey for an area, contact the Natural Resource Conservation Service offices,



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the county conservation district, agricultural cooperative extension service (refer to Appendix I for contact information), local health authorities, or planning agency. These soils surveys will help during site selection; however, conditions they describe may differ from the actual soil conditions.

For more site-specific data on actual soil conditions, sample and characterize the soil. It may be desirable to have a qualified soil scientist perform this characterization, which often investigates soil texture, percentage of organic matter, depth to water table, soil pH, and cation exchange capacity. At a minimum, characterize samples from an upper soil layer, 0 to 6 inches, and a deeper soil layer, 18 to 30 inches, and follow established soil sampling procedures to obtain meaningful results. If a detailed characterization is desired, or if it is suspected soil types vary considerably, further subdivision of soil horizons or collection of samples over a greater variety of depths might be appropriate. For more information about how to obtain representative soil samples and to submit them for analysis, consult federal manuals, such as EPA's *Laboratory Methods for Soil and Foliar Analysis in Long-Term Environmental Monitoring Programs* (EPA600-R-95-077) or state guides, such as *Nebraska's Guidelines for Soil Sampling*, G91-1000.

Why are chemical and biological properties of soil important?

Chemical and biological properties of the soil, like those of the waste, influence soil attenuation of waste constituents. These properties include pH, percentage of organic matter, and cation exchange capacity. Affected attenuation processes in the soil include absorption, adsorption, microbial degradation, biological uptake, and chemical precipitation. For example, adsorption—the process by which molecules adhere to the surface of other particles, such as clay—increases as the cation exchange capacity and pH of the soil increase. Cation exchange capacity, in turn, is dependent on soil composition, increasing as the clay content of the soil increases. Absorption through cation exchange is an important means of immobilizing metals in the soil. Organic chemicals, on the other hand, are negatively charged and can be adsorbed through anion exchange, or the exchange of negative ions. A soil's capacity for anion exchange increases as its pH decreases.

Why are physical properties of soil important?

Physical properties, such as texture, structure, and pore-size distribution, will affect infiltration and the capability of soil to filter or entrap waste constituents. Infiltration and permeability rates decrease as clay content increases. Sites with soils that have too high or too low permeability have lower land application potential. Soils with high permeability may allow wastes to move through without adequate attenuation. Soils with low permeability can cause pooling or excessive surface run-off during intense rainstorms. Excessive run-off conditions can be compensated for somewhat by minimizing surface slope during site selection. Soils with low permeability are also prone to hydraulic overloading.

The amount of liquid that can be assimilated by a soil system is referred to as its hydraulic loading capacity. In addition to a soil's permeability, hydraulic loading capacity is dependent on other factors such as climate, vegetation, site characteristics, and other site-specific soil properties such as soil types, depth to seasonally high water table, slope and erodibility, water intake rates, and underlying geology and hydrogeology. Exceeding the hydraulic loading

capacity of a site, hydraulic overloading, may lead to rapid leaching of waste constituents into ground water, reduction in biological activity, sustained anaerobic conditions, soil erosion, and possible contamination of surface waters. It may also result in evaporation becoming responsible for a significant part of waste treatment. This can cause excessive odor and unwanted airborne emissions. In order to avoid hydraulic overloading at a site, application of liquid or semi-liquid waste or wastewater should be managed so uncontrolled run-off or prolonged saturation of the soil does not occur.

Topography influences surface and subsurface water movement, which affects the potential for soil erosion and contaminated surface water run-off. Topography also can indicate the kinds of soil found on a site. Soils on ridge tops and steep slopes are typically well drained, well aerated, and shallow. Steep slopes, however, increase the likelihood of surface run-off of waste and of soil erosion into surface waters. State guidelines, therefore, often specify the maximum slopes allowable for land application sites for various waste characteristics, application techniques, and application rates. The agencies that regulate land application in a state can provide specific guidance concerning slopes. Soils on concave land and broad flat lands, on the other hand, frequently are poorly drained and may be waterlogged during part of the year. Soils in relatively flat areas may have intermediate properties with respect to drainage and run-off and could be more suitable for land application.

IV. Plant and Microbial Effects

The next step is to consider the crops that will grow on the site. This is important for several reasons. First, uptake of nutrients[9] by plants (and by microbes on plant roots or in soil) affects the rate of waste assimilation and biodegradation, usually increasing it. Second, the waste affects plant and microbes growth. In addition, certain waste characteristics, such as the presence of pathogens or toxic constituents, may render crops unusable for food or feed. It may be necessary to conduct greenhouse or field studies or other tests of plants, soil and microbes to understand and quantify these interactions. Consult with the state agricultural department, health department, and other appropriate agencies if considering land-application of wastes containing designated ground-water constituents or other potentially harmful properties to food or feed crops. Industry groups may also be able to provide information about plants with which they have land application experience.

A. Greenhouse and Field Studies

State agricultural extension services, departments of environmental protection, or public universities may have previous studies about plant uptake of nutrients, especially nitrogen, phosphorus and potassium, but it is important to recognize that the results of studies conducted under different conditions (such as different waste type, application rates, plant type, or climate) are only partially relevant to a specific situation. Furthermore, most studies to date have focused on relatively few plant species, such as corn, and only a handful of constituents, typically metals. Greenhouse studies or pilot-scale field studies attempt to model site-specific conditions by growing the intended crops in soil from the prospective application site. These studies are useful because individual parameters can be varied, such as plant type and waste application rate, to determine the effects of each factor. Additionally, greenhouse or field studies may be required by some states to certify that

[9] $\frac{\mu g \text{ pollutant}}{g \text{ dry plant tissue}}$ *per* $\frac{kg \text{ pollutant}}{hectare}$

This serves to place pollutant uptake in the context of the original amount of pollutant applied.

a waste has agricultural benefits. The first point of contact for assistance with studies is the state agricultural extension service. Many state extensions can conduct these studies; others may be able to provide guidance or expertise but will recommend engaging a private consultant to conduct the studies.

How do I conduct greenhouse or field studies?

Currently, no national guidelines exist for conducting greenhouse and/or field studies[10] but check to see if the state has guidance on accepted practices. Working with a state agricultural extension service or a local university will provide the benefit of their expertise and experience with local conditions, such as which plants are suitable for local soils and climate. If a particular industry sector has a large presence in a state, the state agricultural extension service may have previous experience with that specific type of waste.

Greenhouse Studies. Aside from their smaller scale, greenhouse studies differ from field studies primarily in that they are conducted indoors under controlled conditions, while field studies are conducted under natural environmental conditions. A greenhouse study typically involves distributing representative soil samples from the site into several pots to test different application rates, application methods, and crops. Using several duplicate pots for each rate, method, or crop allows averaging and statistical aggregating of results. It is also important to establish control pots, some with no waste and no plants, others with waste but no plants (to observe the extent to which waste assimilation effects are due to soil and pre-existing microbes) and still others with plants but without waste (as a baseline for comparison with waste-amended plant growth).

To the extent feasible, temperature, moisture, and other parameters should simulate actual site conditions. There should be a series of several duplicate pots grown with each combination of plant type, application rate, and other parameters. Pots should be arranged to avoid environmental conditions disproportionately affecting one series of pots. For example, avoid placing a whole series of pots in a row closest to a light source; instead, place one pot from each of several series in that row or randomize placement of pots.

The controlled greenhouse environment allows the study of a wide range of waste-soil interactions without risking loss of plants due to weather, animal hazards, and other environmental influences. At the same time, this may introduce differences from actual conditions. Root confinement, elevated soil temperature, and rapidly changing moisture levels, for example, may increase the uptake of pollutants by potted plants compared to uptake under field conditions.[11]

Field Studies. Field studies, on the other hand, test various application rates and suitable crops on plots at the proposed site. As with greenhouse studies, duplicate plots are useful for statistical purposes and controls are needed. Field study data may be found to be more useful because it more closely reflects real-world conditions, but more difficult to obtain if extreme environmental events (such as flooding or unusual pest damage) occur at the time of the study. Field studies may also be subject to siting, health and safety, and permitting requirements.

Field studies also help determine the actual land area required for land application and the quality of run-off generated. Soil and ground-water monitoring help to confirm

[10]Based on conversations with Dr. Rufus L. Chaney and Patricia Milner. U.S. Department of Agriculture.

that waste constituents are being taken up by plants and not leaching into the ground water. Results from field studies, however, might not be duplicated on actual working plots after multiple waste applications, due to long-term soil changes. Crop yields also may vary by as much as 15 to 25 percent under field conditions, even with good fertility and management.

Both greenhouse and field studies typically include extensive sampling of waste, soil before application, plants or representative parts of plants, soil after application and growth of plants, and, to the extent feasible, water. Sample soil at the surface and in lower horizons using core sampling. Some soil tests require mixing samples with water to form a paste or slurry. Plant tissue tests often require dry-weight samples, made by drying cut plants at about 65 °C. Water can be collected in lysimeters (buried chambers made from wide perforated pipe) and removed using hand pumps.

Monitoring waste effects on organisms in the soil during greenhouse and field studies is also possible. For example the literature suggests that effects of waste on earthworms are a good indicator of effects on soil organisms in general. It may be worthwhile, therefore, to stock greenhouse pots or field study plots with earthworms at the beginning of a study and monitor the waste constituent levels in and effects on the worms during and at the end of the study. Although these brief studies will not effectively model long-term exposure to waste constituents, it is possible to gauge short-term and acute effects.

B. Effects of Plants and Microbes on Waste Assimilation

After performing studies, measure the amounts of various nutrients, metals, and other constituents in tissue samples from plants grown in the greenhouses or on test plots. This tells approximately how much of these constituents the plants extracted from the soil-waste mix. By measuring plant-extracted quantities under these various conditions, you can determine a relationship between plant type, application rate, and nutrient extraction. From this, choose the conditions which result in the desired uptake rate while avoiding uptake of designated ground-water constituents at undesirable concentrations.

In choosing plants for a land application unit, consider growing seasons in relation to periods of peak waste generation. If greenhouse or field studies indicated that a specific waste application rate associated with a corresponding uptake of nutrients by plants, this will be the

case only during the growth phases covered by the study. At other times waste application may be infeasible because plants are not present to help assimilate waste, or because plants are too

[11]If a waste contains VOCs, ensure the possibility of VOCs accumulating within the enclosed greenhouse is addressed.

large to permit passage of application equipment without sustaining damage.

Certain microbes can biodegrade organic chemicals and other waste constituents. Some accomplish this by directly using the constituents as a source of carbon and energy, while others co-metabolize constituents in the process of using other compounds as an energy source. Aerobic microorganisms require oxygen to metabolize waste and produce carbon dioxide and water as end products. Anaerobic microbes function without oxygen but produce methane and hydrogen sulfide as end products. These gases can present a safety risk as well as environmental threats, and hydrogen sulfide is malodorous. For these reasons, maintain conditions that favor aerobic microbes.

For many microorganisms, these conditions include a pH of 6 to 8 and temperatures of 10 °C to 30 °C. In addition, microbes may be unable to transfer oxygen from soil efficiently if the moisture content is near saturation or they may be unable to obtain sufficient water if the soil is too dry. A water content of 25 to 85 percent of the soil's water holding capacity is recommended in the literature. Oxygen generally is available through diffusion from the atmosphere, but this mechanism may provide insufficient oxygen if there is too little pore space (less than 10 percent of soil volume) or if so much organic matter is applied that oxygen is consumed faster than it is replaced.

C. Effects of Waste on Plant and Microbe Growth

Greenhouse and field studies can tell what effect the waste will have on plant growth patterns. A typical method of quantifying plant growth is to state it in terms of biomass production, which is the dry weight of the cut plants (or representative parts of the plants). If the plants grown with waste applications show greater mass than the control plants[12], the waste may be providing useful nutrients or otherwise improving the soil. If the plants grown with waste applied at a certain rate weigh less than the controls, some constituent(s) in the waste may be excessive at the studied application rate. Comparing the results from several different application rates may help find the rate that maximizes growth and avoids detrimental and phytotoxic effects.

Analyzing soil and water after plant growth allows for a comparison between the planted pots or plots against the control to discern the differences due to plant action. If water samples show excessive nutrient (especially nitrogen) levels at and above a certain application rate, this may indicate that the plants were unable to use all the nutrients in the waste applied at that rate, suggesting that the application was excessive.

To check for microbial action, compare the control pots or plots with no waste and no plants grown to those with waste and no plants grown. If soil and water tests show that constituents are consumed, and if other possible causes can be ruled out, microbes might be responsible. If further investigation of microbial action is desired, laboratory methods allow sampling of microbes in soil, counting their population, and direct measurement of waste constituents and degradation byproducts.

D. Grazing and Harvesting Restrictions

If a waste may contain pathogens or designated ground-water constituents, and the established vegetative cover on the land application site is intended for animal consumption, it is important to take precautions to minimize exposure of animals to these

[12]Trends detected in studies assume that results have been subjected to tests of statistical validity before finding a trend significant.

contaminants. This is important because animals can transport pathogens and these ground-water constituents from a site to others, and can also act as an entry point of bioaccumulated waste constituents and pathogens into the food chain, or into humans if the animals are intended for human consumption.

If harvesting crops from a unit for use as animal fodder, test plants for the presence of undesirable levels of the designated ground-water constituents before feeding. Grazing animals directly on a unit is discouraged by some states[13]. If considering direct grazing, consult with the state to see if there are any restrictions on this practice. Growing crops for human consumption on soil amended with waste calls for even greater caution. In some states, this practice is prohibited or regulated, and in states where it is allowed, finding food processors or distributors willing to purchase such crops may be difficult.

When testing crops before feeding them to animals, local agricultural extension services may be able to help determine what levels are appropriate for animal consumption. In addition, take into account the potential for bioaccumulation and food chain effects. If plant tissue samples and/or findings of a fate and transport model (see the section on assessing risk) indicate waste constituents levels inappropriate for animal consumption, do not use harvested plants as fodder or allow grazing on the site. Additionally, plants with high constituent levels will probably be inappropriate for other agricultural use, necessitating disposal of such crops as a waste after harvest.

V. Climate

Climate considerations should enter into the planning for land application. For example, wastes high in soluble salts are less appropriate in arid climates than elsewhere, due to osmotic pressure from salts inhibiting root uptake of water, as discussed above. On the other hand, downward movement of water in the soil is minimal in arid climates, making migration of waste constituents to ground water less likely.

Climate also determines what plants can grow in a region and the length of the growing season. If the climate cannot support the plants most helpful in assimilating the particular constituents in the waste, land application use may be limited to other crops and waste application at a lower rate. If the climate dictates that the part of the growing cycle during which land application is appropriate is short, a larger area for land application may be necessary as well as providing more off-season waste storage capacity.

There are also operating considerations associated with climate. Since waste should not be applied to frozen or very wet soil, the application times may be severely limited in very cold or rainy climates. In climates where the ground can freeze, winter application poses problems even when the ground is not frozen, because if the ground freezes soon after application, waste that remained near the soil surface may run-off into surface waters during subsequent thaw periods. Waste nutrients are also more likely to leach through the soil and into the ground water following spring thaw, prior to crop growth and nutrient uptake. These problems can be partially solved by providing sufficient waste storage capacity for periods of freezing or rainy weather.

VI. Agronomic Rate

The purpose of a land application unit affects its application rate. When agricultural benefits are to be maximized, the application rate is governed by the agronomic rate. The agronomic rate is an application rate

[13]Grazing may also be unwise due to potential effects on soil physical structure. The weight of heavy animals can compact soil, decreasing pore space, which may reduce the soil's waste attenuation capacity.

designed to provide the amount of nitrogen plants need to attain a desired yield, while minimizing the amount of nitrogen that will pass below the root zone of the crop or vegetation to the ground water. The agronomic rate depends on the nitrogen content of the waste, but the levels of phosphorus and potassium in the waste and soil should also be considered. In setting a preliminary application rate, the agronomic rate often serves as a ceiling, but in some cases, phosphorus, potassium, or salt content, rather than nitrogen will be the limiting factor.

How do I determine the agronomic rate?

Computer models can help determine site-specific agronomic rates. Modeling nitrogen levels in waste and soil-plant systems can help provide information about soil physical and hydrologic conditions and about climatic influences on nitrogen transformations. Models recommended for use with sewage sludge include Nitrogen Leaching and Economic Analysis Package (NLEAP); DECOMPOSITION; Chemicals, Run-Off, and Erosion from Agricultural Management Systems (CREAMS); and Ground-Water Loading Effects of Agricultural Management Systems (GLEAMS)[14]. NLEAP uses monthly and event-by-event approaches throughout the year to compute water and nitrogen budgets. The computer model DECOMPOSITION is specifically designed to help predict sewage sludge nitrogen transformations based on sludge characteristics, as well as climate and soil properties (organic matter content, mean soil temperature, and water potential). Finally, the CREAMS and GLEAMS models, developed by the USDA, are other potentially useful models to assist with site-specific management of land application operations. Additional computer models include AMANURE, Cornell Nutrient Management Planning System (NMPS), Fertrec Plus v 2.1, and Michigan State University Nutrient Management v1.1[15]. If assistance is required in determining an appropriate agronomic rate for a waste, contact the regional, state, or county agricultural cooperative extensions, or a similar organization.

VII. Monitoring

Monitoring ground water can be helpful to verify whether waste constituents have migrated to ground water. Some state, tribal, or other regulatory authorities require ground-water monitoring at certain types of land application units; consult with the appropriate regulatory agency to determine whether such a requirement applies to the unit. Even if the unit is not required to monitor ground water, instituting a ground-water monitoring program for long-term, multiple application units where waste contain the designated ground-water constituents is recommended. Such units are more

[14]All of these models are referenced in EPA's *Process Design Manual Land Application of Sewage Sludge and Domestic Septage* (EPA625-R-95-001). According to that source, the NLEAP software, developed by Shaffer et al., is included in the purchase of *Managing Nitrogen for Groundwater Quality and Farm Profitability* by Follet, et al., which also serves as reference for information on parameters required for nitrogen calculations. Four regional soil and climatic databases (Upper Midwest, Southern, Northeastern, and Western) also are available on disk for use with NLEAP. These materials can be obtained from: Soil Science Society of America Attn: Book Order Department, 677 S. Segoe Road, Madison, WI 53711, 608/273-2021; Book $36.00; Regional Databases $10.00 each. Current updates of the NLEAP program can be obtained by sending original diskettes to: Mary Brodahl, USDA-ARS-GPSR, Box E, Fort Collins, CO 80522. Additional information on the DECOMPOSITION model, developed by Gilmour and Clark, can be obtained from: Mark D. Clark, Predictive Modeling, P.O. Box 610, Fayetteville, AR 72702. The CREAMS and GLEAMS models were developed by USDA.

[15]These models are referenced in the Northeast Regional Agricultural Engineering Cooperative Extension's *Nutrient Management Software: Proceedings from the Nutrient Management Software Workshop* from December 11, 1996.

likely to pose a threat to ground water than are single-application units or units receiving waste without these constituents. In most cases, lysimeters should be sufficient to monitor ground water. A lysimeter is a contained unit of soil, often a box or cylinder in the ground which is filled with soil, open on the top, and closed at the bottom, so that the water that runs through it can be collected. It is usually more simple and economical to construct and operate than a monitoring well. Consult with a qualified professional to develop an appropriate ground-water monitoring program for a land application unit.

If ground-water results indicate unacceptable constituent levels, suspend land application until the cause is identified. Then correct the situation that led to the high readings. If a long-term change in the industrial process, rather than a one-time incident, caused the elevated levels, reevaluate land application. Adjusting the application rate, adding pretreatment, or switching to another means of waste management may be necessary. After reevaluation, examine whether corrective action may be necessary for the ground water already contaminated. Pay particular attention to ensure that applications are not exceeding the soil's assimilative capacity.

Consider testing soil samples periodically during the active life of a land application unit. For this testing to be meaningful, first determine baseline conditions by sampling the soil before waste application begins. This may already have been done in preparation for greenhouse/field studies or for site characterization. Later, when applying waste to the unit, collect and analyze samples at regular intervals (such as annually or after a certain number of applications). Consider analyzing samples for macronutrients, micronutrients, and any of the designated ground-water constituents reasonably expected to be present in the waste. The location and number of sampling points, frequency of sampling, and constituents to be analyzed will depend on site-specific soil, water, plant, and waste characteristics. Local agricultural extension services, which have experience with monitoring, especially when coupled with ground-water monitoring, can detect contamination problems. Early detection allows time to change processes to remedy the problems, and to conduct corrective action if necessary before contamination becomes widespread.

Testing soils after the active life of a unit ends may also be appropriate, especially if the waste is likely to have left residues in the soil. The duration of monitoring after closure, like the location and frequency of monitoring during active life, is site-specific and depends on similar factors. For further information about testing soil after active life ends, refer to the chapter on performing closure and post-closure care.

Action Items for Designing a Land Application Program

- ☐ Use the evaluation framework to design a land application program before beginning a ground-water risk assessment, and to help determine a preliminary waste application rate.
- ☐ Be familiar with waste parameters, such as total solids content, pH, organic matter, nutrients carbon and nitrogen levels, salts, soil buffering capacity, and pathogens.
- ☐ Examine potential application sites, giving special consideration to physical and chemical properties of soil, topography, and any site characteristics that might encourage run-off or odor.
- ☐ Choose crops for the unit, considering plant uptake of nutrients and constituents.
- ☐ Account for climate and its effects.
- ☐ Determine an agronomic application rate.
- ☐ Evaluate ground-water and air risks from land application units and consider potential exposure pathways.
- ☐ Consider implementing a ground-water monitoring program and periodic sampling of unit soils.

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Part 5
Ensuring Long-Term Protection

Chapter 8
Operating The Waste Management System

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Operating the Waste Management System

Develop a waste management system that includes procedures to monitor and measure performance. The waste management system also needs to have operational elements to achieve environmental goals and to make continual improvements in waste management operations.

The key to safe and efficient waste management is implementing a waste management system that achieves protective environmental goals while having operational elements in place to monitor and measure performance of the waste management operations. Following an effective waste management system can help ensure proper functioning of the many interrelated systems that a unit depends on for waste containment, leachate management, and other important functions. If the elements of an overall waste management system are not regularly inspected, maintained, improved, and evaluated for efficiency, even the best-designed unit may not operate efficiently. Following an effective waste management system can also reduce long- and short-term costs, protect workers and local communities, and maintain good relations.

This chapter will help address the following questions:

- What is an effective waste management?
- What maintenance and operational aspects should be developed as a part of a waste management system?

I. An Effective Waste Management System

Having an effective waste management system requires an understanding of environmental laws and an understanding of how best to achieve compliance with these laws. An effective waste management system also requires that procedures be in place to monitor and measure performance in complying with environmental laws. Lastly, an effective waste management system involves operational procedures that seek to make continual improvements in waste management operations so that compliance with environmental laws is an ongoing accomplishment.

In addition to what is discussed in this chapter, consider reviewing and implementing the draft voluntary standards for good environmental practices developed by the International Standards Organization (ISO), as appropriate. The ISO 14000 series standards identify management system elements that are intended to lead to improved performance: a method to identify significant environmental aspects; a policy that includes a commitment to regulatory

compliance, the prevention of pollution, and continual improvement; environmental objectives and targets for all relevant levels and functions in the organization; procedures to ensure performance, as well as compliance procedures to monitor and measure performance; and a systematic management review process.

The ISO 14000 series of standards include "specification" standard, ISO 14001. The rest are guidance standards which provide optional guidance for companies developing and implementing management systems and product standards. The ISO 14001 specification standard contains only those requirements that may be objectively audited for certification/registration purposes and/or self declaration purposes. For more information about EPA's involvement in the ISO 14000 and 14001 standards, see Appendix A: ISO 14000 Resource Directory, October 1997, EPA625-R-97-003.

Additional Information on ISO 14000

The ISO 14000 series of standards are copyrighted and can be obtained by contacting any of the following organizations:

ANSI
7315 Wisconsin Avenue, Suite 250-E
Bethesda, MD 20814
301 469-3363

ASTM
100 Bar Harbor drive
West Conshohocken, PA 19428
610 832-9721

ASQC
611 East Wisconsin Avenue
P.O. Box 3005
Milwaukee, WI 53201

NSF International
2100 Commonwealth Boulevard
Ann Arbor, Michigan 48105
313 332-7333

II. Maintenance and Operation of Waste Management System Components

All of the work that has gone into planning, designing, and developing a unit will be jeopardized if proper site operations are not carried out. Operation is important for reasons of environmental protection, economy, efficiency, and esthetics. Operating control systems, therefore, need to be developed and maintained to ensure efficient and protective operation of a waste management system. These controls include conducting frequent inspections, performing routine maintenance, reporting of inspection results, and making necessary improvements to keep the system operating.

Unit inspections can help identify deterioration of or malfunction in control systems. Surface impoundments should be inspected for evidence of overtopping, sudden drops in liquid levels, and deterioration of dikes or other containment devices. Overtopping, or the flowing of waste over the top of the walls of the impoundment, occurs as a result of insufficient freeboard, wind or wave action, or other unusual conditions. Make visual inspections periodically to check waste levels, weather conditions, or draining during periods of heavy precipitation. In addition, consider devising a contingency plan to reinforce dikes when failure is imminent.

Waste piles and landfills should be inspected for adequate surface-water protection systems, leachate seeps, dust suppression methods, and daily covers, if applicable. Land application sites should be inspected for adequate surface-water protection systems and

dust suppression methods, if applicable. If conducted regularly, inspections of safety, emergency, and security devices; monitoring equipment; pipes; and mechanical equipment also will help ensure that a unit operates in a safe manner. In addition, inspections often prevent small problems from growing into more costly ones.

How should effective inspections be conducted?

To help ensure that routine inspections are performed regularly and consistently, consider developing a written inspection schedule and ensure that staff follow the schedule. The schedule could state the type of inspections to be conducted, the inspection methods to be used, the frequency of the inspections, and a plan of action highlighting preventative measures to address potential problems. Consider conducting additional inspections after extraordinary site-specific circumstances, such as storms or other extreme weather conditions.

Staff conducting the inspections should look for malfunctioning or deteriorating equipment, such as broken sump pumps, leaking fittings, eroding dikes, or corroded pipes or tanks; discharges or leaks from valves or pipes; and operator errors. A written schedule for inspections should be maintained at the facility, and inspections should be recorded in a log (see Figure 1) containing information such as date of inspection, name of inspector, conditions found, and recommended corrective action. Inspection personnel should be familiar with the inspection log to identify any malfunctions or deficiencies that remain uncorrected from previous inspections. The sample log is a unit-independent template. When designing an inspection form for a unit, add appropriate items for the unit type. Check with the state to see if it has an inspection form that can be used. For example, a landfill form

Figure 1. Example Inspection Log

Site Inspection Form

XYZ Industries • Waste Management Unit 1a • 123 Paved Road • Anytown, US 56789

Location Inspected: _____ Date: ___/___/___/

Name(s) of Inspector(s): _____

Temperature: ____ Wind: ____ Precipitation: ____ Other Conditions: _____

	Acceptable	Unacceptable	Notes
TRAFFIC MANAGEMENT			
Vehicle stacking room	☐	☐	_____
Collector working efficiently	☐	☐	_____
Route to active area clearly marked	☐	☐	_____
Access to road in good condition	☐	☐	_____
Spotter properly placing vehicles	☐	☐	_____
Truck wash and its drain working	☐	☐	_____
Covers/seals on trucks	☐	☐	_____
Route to active area clearly marked	☐	☐	_____
COVER OPERATION			
Cover material suitable and sufficient	☐	☐	_____
Waste covered to design depth	☐	☐	_____
ADC is being properly used	☐	☐	_____
DRAINAGE			
No ponded water	☐	☐	_____
No signs of erosion	☐	☐	_____
Erosion control systems working	☐	☐	_____
No leachate seeps	☐	☐	_____
All runoff flows to design endpoint	☐	☐	_____
Contact water handled as leachate	☐	☐	_____
SAFETY			
Emergency response plan up-to-date	☐	☐	_____
Fences/gates maintained and locked	☐	☐	_____
Warning signs in place and readable	☐	☐	_____
Speed limits observed	☐	☐	_____
Scavenging not evident	☐	☐	_____
NUISANCE CONTROL			
Odor controls working	☐	☐	_____
Dust controls working	☐	☐	_____
Vector controls working	☐	☐	_____
Noise controls working	☐	☐	_____
No waste/mud on public roads	☐	☐	_____

Comments, observations, or problems _____

_____

_____

_____

_____

would include a section about waste placement and a surface impoundment form might have an entry for sufficient freeboard. If ground water is monitored, consider making ground-water monitoring part of the unit inspection, and add check boxes for each monitoring point to ensure that inspectors collect samples from all monitoring points.

Ensure that all inspection reports are reviewed soon after the inspection so that any necessary repairs and improvements can be quickly identified and implemented. Consult the state to help determine if improvements are necessary.

A. Ground-Water Controls

Ground-water protection controls, such as a ground-water monitoring systems, unit covers, and leachate detection and collection systems should be incorporated into the design and construction of a unit, as well as routine unit inspections. Ground-water monitoring wells require continued maintenance. A major reason for maintenance is plugging of the gravel pack or screen. (See the chapter on monitoring performance for a discussion on the construction of ground-water monitoring wells.) The most common plugging problems are caused by precipitation of calcium or magnesium carbonates and iron compounds. Acid is most commonly used to clean screens clogged with calcium carbonate. In many instances, however, the cost of attempted restoration of a monitoring well may be more than the installation of a new well. Because many wells are installed in unconsolidated sand formations, silt and clay can be pumped through the system and cause it to fail. Silt and sand grains are abrasive and can damage well screens, pumps, flow meters, and other components. In some cases, the well becomes full of sediment and must be cleaned out. The most frequent method of cleaning is to pull the pump from the well, circulate clean water down the well bore through a drop, and flush the sediment out. If large amounts of sediments are expected to enter a monitoring well, consider incorporating a sediment sump, also called a silt trap or sediment trap, into the monitoring well construction. The sump consists of a blank section of pipe placed below the base of the screen. Its purpose is to provide a catch-trap for fine sand and silt which bypasses the filter pack and screen and settles out within the well. This sediment collects within the sump rather than within the screen, and therefore, does not reduce the functional screened length of the well and minimizes the need for periodic cleanouts of the screen. Regardless of the type of ground-water monitoring well installed, the well should be protected with a cap or plug at the upper end to prevent condensation, rust, and dirt from entering into the manhole or protective casing. Inspect the outer portion of the wells to ensure that they have not been damaged by trucks or other unit operations, and to ensure that the cap or plug are intact.

Inspect and maintain unit covers to ensure that they are intact. For optimal performance, covers should be designed to minimize permeability, surface ponding, and the erosion of cover material. The cover should also prevent the buildup of liquids within the unit. Consult the chapter on performing closure and post-closure care for a more detailed discussion on maintaining cover systems.

All components of leachate detection and collection systems must also be maintained properly. The main components include the leachate collection pipes, manholes, leachate collection tanks and accessories, and pumps. Consider cleaning the leachate pipes once a year to clear out any organic growth and visually inspecting the manholes, tanks, and pumps once a year as leachate can corrode metallic parts. Annual inspections and necessary repairs

will, therefore, prevent many future emergency type problems such as leachate overflow from the tank due to pump failure. Maintain a record of all repair activities to assess (or claim) long-term warranties on pumps and other equipment.

Also, monitor waste liquid levels. An unexpected decrease in liquid levels may be an indication of liner failure. If a surface impoundment fails, discontinue adding waste to the impoundment and contain any discharge that has occurred or is occurring. Repair leaks as soon as possible. If leaks cannot be stopped, empty the impoundment. Clean up any released waste and notify the appropriate state authorities of the failure and the remedial actions taken.

B. Surface-Water Controls

If a unit has a point source discharge, it must have a National Pollutant Discharge Elimination System (NPDES) permit and, in some states, may require a state discharge permit. Point source discharges include the release of leachate from a leachate collection or onsite treatment system into surface waters, disposal of solid waste into surface waters, or release of surface water runoff (storm water) that is directed by a run-off control system into surface-waters. Even if there are no point source discharges, surface-water controls may be necessary to prevent pollutants from being discharged or leached into surface waters, such as lakes and rivers.

Soil erosion and sedimentation controls, such as ditches, berms, dikes, drains, and silt fences, should be incorporated into the design and construction of a unit. Berms or dikes are often constructed from earthen materials, concrete, or other materials designed to be safely traversed during inspection or monitoring activities. Vegetation also is often used for erosion control. Trees or other deep rooted vegetation, however, should not be used near liners or other structures that could be damaged by roots. Grassing is often used for soil stabilization around surface impoundments. For a more detailed discussion of storm-water issues, consult the chapter on protecting surface water.

Most, if not all, of these surface-water controls should be inspected regularly and after each large storm event. Structures should be maintained as installed and any structural damage should be repaired as soon as possible to prevent further damage or erosion, and any trapped sediments should be removed and disposed of properly. Vegetative controls may need watering after planting and during periods of intense heat and/or lack of rain.

C. Air Controls

Gases, including methane, carbon dioxide, and hydrogen, are often produced at waste management units as byproducts of the microbial decomposition of solid waste containing organic material. Additionally, volatile organic compounds (VOCs) may be present in the waste, and particulate emissions and/or dust may be generated during unit operations. Analyze wastes carefully prior to designing a waste management unit to determine what airborne emissions are likely to come from these wastes. If airborne emission controls are needed in the design of a unit, maintenance of these controls should be considered as part of a waste management system. For further information on airborne emission controls, consult the chapter on protecting air.

Methane is the gas of main concern at most waste management units because it is odorless and can cause fires or explosions that can endanger employees and damage structures both on and off-site. Hydrogen gas may also form, and is also explosive, but it readily reacts with carbon or sulfur to form

methane or hydrogen sulfide. Hydrogen sulfide can be easily identified by its sulfur or "rotten egg" smell. Methane, if not captured, will either escape to the atmosphere or migrate underground. Underground methane may enter structures, where it may reach explosive concentrations or displace oxygen, causing a danger of asphyxiation. Methane in the soil profile may damage the vegetation on the surface of the landfill or on the land surrounding the landfill, thereby exposing the unit to increased erosion. Finally, methane is a potent "greenhouse" gas that contributes to global warming.

Methane is explosive when present in the ranges of 5 to 15 percent by volume in the air. The 5 percent level is known as the lower explosive limit (LEL) and 15 percent as the upper explosive limit (UEL). At levels above 15 percent by volume, methane will not explode when exposed to a source of ignition. Levels above the UEL remain a concern, however, as methane will burn at these concentrations and can still cause asphyxiation.

In the event that methane gas levels exceed 25 percent of the LEL in facility structures or other closed spaces, initiate safety measures, such as evacuating the site and structures. In such cases, or when the methane level exceeds 25 percent of the LEL in the soil at a monitoring point, implement a remediation plan to decrease gas levels and prevent future buildup of gases.

Gas control systems generally include mechanisms designed to control gas migration and to help vent gas emissions into the atmosphere. Systems using natural pressure and convection mechanisms are referred to as passive gas control systems (see Figure 2). Examples of passive gas control system elements include ditches, trenches, vent walls, perforated pipes surrounded by coarse soil, synthetic membranes, and high moisture, fine-grained soil.

Systems using mechanical means to remove gas from the unit are referred to as active gas control systems. Figure 3 illustrates an active gas system. Gas extraction wells are an example of active gas control systems. Gas control systems can also be used as part of corrective action measures should the concentration of methane rise to dangerous levels.

Figure 2. Passive Gas Venting System

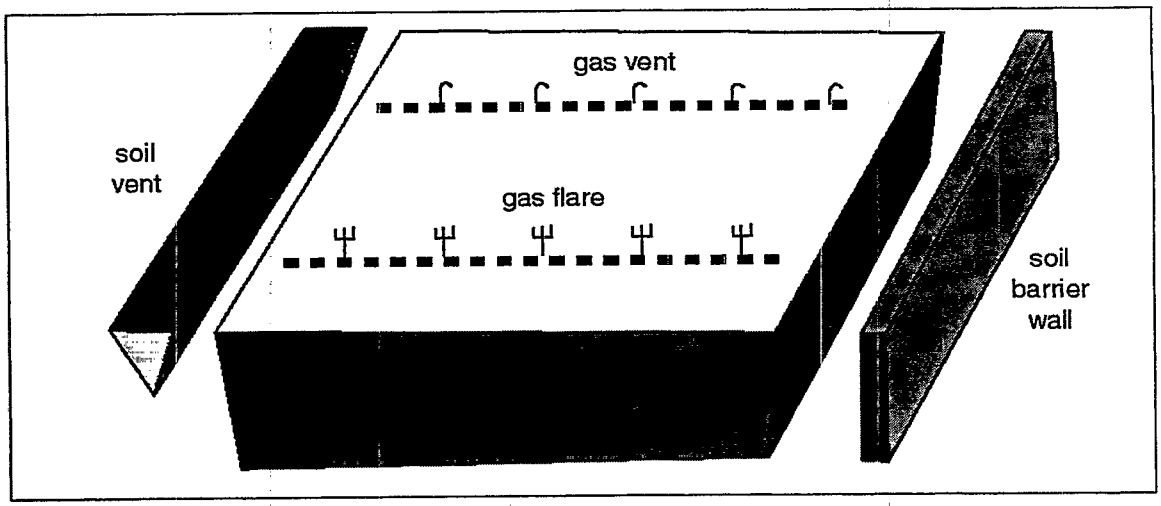

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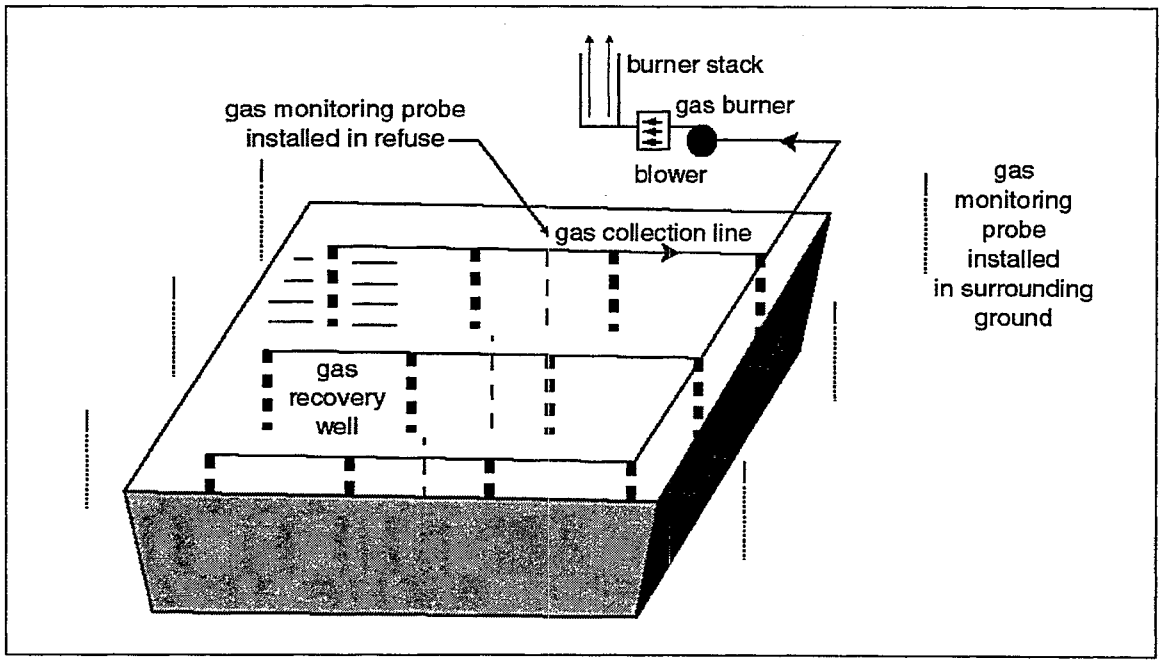
Figure 3. Active Gas Venting System



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As with all aspects of a waste containment system, construction quality assurance plays a critical role in the success of a gas management system. For deep wells, the number, location, and extent of the pipe perforations are important. Also, the depth of the well must be kept safely above the liner system beneath the waste. For continuous gas collection layers beneath the barrier layer, continuity is important for both soils and geosynthetics.

Knowing the rate of gas generation is essential to determining the quantity of gas that can be extracted from the site. Pumping an individual well at a greater vacuum will give it a wider zone of influence, which is acceptable, but obviously there are points of diminishing marginal returns. Larger suction pressures influence a larger region but expend more energy in the pumping. Pumping at greater vacuum also increases the potential for drawing in atmospheric air if the pumping rate is set too high. Significant air intrusion into the unit may result in elevated temperatures and even underground fires. Perform routine checks of gas generation rates to better ensure that optimal pumping rates are used.

The performance of gas extraction systems is affected by the following parameters. Consider these when designing and operating gas systems:

- Daily cover, which inhibits free movement of gas;
- Sludge or liquid wastes, which affect the ease at which gas will move;
- Shallow depth of unit, which makes it difficult to extract the gas, because atmospheric air will be drawn in during the pumping; and

- Permeability of the final cover, which affects the ability of atmospheric air to permeate the wastes in the unit.

With a geomembrane in the final cover barrier system, uplift pressures will be exerted unless the gas is quickly and efficiently conveyed to the wells, vents, or collection trenches. If this is not properly managed, uplift pressure will either cause bubbles to occur displacing the cover soil and appearing at the surface, or it decreases the normal stress between the geomembrane and its underlying material. This problem has led to slippage of the geomembrane and all overlying materials creating high tensile stresses evidenced by folding at the toe of the slope and tension cracks near the top.

Gas monitoring and extraction systems require regular maintenance to operate efficiently. As wastes settle over time, pipes may fail and condensate outlets may become blocked. Extracted gas is saturated, which causes moisture to collect within the pipes. Therefore, the condensate within the pipes must be dealt with, otherwise it will affect the pumping suction pressure. Since the plumbing on the top of the unit is quite involved, develop and adhere to a gas maintenance schedule to ensure the efficient operation of gas systems.

III. Operational Aspects of a Waste Management System

Consider developing practices to ensure compliance with applicable laws and regulations, train workers how to handle potential problems, and to ensure that all necessary improvements or changes are made to a waste management system. Proper planning and implementation of these operating practices are important elements in the efficient and protective operation of a unit. This section identifies and briefly discusses some of the important operational aspects including developing an operating plan, performing waste analyses and inspections, installing daily covers, placing wastes in a unit, implementing security and access control measures, providing employee training, addressing nuisance concerns, and maintaining important records.

A. Operating Plan

An operating plan should serve as the primary resource document for operating a waste management unit. It should include the technical details necessary for a unit to operate according to its design throughout the intended working life. At a landfill, for example, the operating plan should illustrate the chronological sequence for filling the unit, and it should be detailed enough to allow the facility manager to know what to do at any point in the operations phase of the unit.

An operating plan should consider:

- A daily procedures component;

- Lists of current equipment holdings and of future equipment needs;
- Procedures to inspect for inappropriate wastes and to respond when their presence is suspected;
- Procedures for addressing extreme weather conditions;
- Personnel needs and equipment utilization, including backup;
- Procedures to address emergencies, such as medical crises, fires, and spills;
- Quality control and employee performance standards;
- Record keeping protocols; and
- Means of compliance with local, state, and federal regulations.

Since a unit will likely operate for several years, it is important that staff periodically review the operating plan to refresh their memories and to ensure long-term conformity with the plan. If modifications to the operating plan are necessary, the changes and the date they were made should be noted in the operating plan. Documented operating procedures can be crucial, especially if questions arise in the future regarding the adequacy of site construction and management.

A key goal of a sound operating plan is to standardize daily procedures. This part of the operating plan outlines the day-to-day activities necessary to place waste, operate environmental controls, and inspect and maintain the waste management unit in accordance with its design. Daily procedures should be concise enough to be circulated among all employees and flexible enough to allow any adjustments necessary to accommodate weather variability, changing waste volume, and other contingencies. Revise and update daily procedures as needed to ensure the unit's continued safe operation within the parameters of the overall operating plan.

B. Waste Analysis

An effective waste management system relies on knowledge of the wastes being managed and the need to monitor for changes in waste characteristics. It is imperative that the chemical and physical composition of the wastes, and any changes to the wastes, be understood in order to prevent mixing of incompatible wastes, ensure proper handling of wastes, and make the most efficient use of unit capacity. Familiarity with wastes and changes in waste composition also helps to identify potential waste reduction and/or pollution prevention opportunities. The best way to determine waste characteristics is to perform a comprehensive waste analysis on the materials to be managed. This analysis will provide the necessary information for proper waste treatment, storage, or disposal. To ensure that this information remains accurate, repeat the analysis whenever there is a change in the industrial process generating the waste. For further information, consult the chapter on characterizing waste.

C. Waste Inspections

The purpose of performing waste inspections is to identify waste that may be inappropriate for the waste management unit, and to prevent problems and accidents before they happen. Hazardous wastes, PCBs, liquids (in landfills and waste piles), and state designated wastes are prohibited from disposal in

units designated solely for industrial nonhazardous waste. Some states have developed more stringent screening requirements that may require a spotter to be present at a unit to detect unauthorized wastes and to weigh and record incoming wastes.

As part of a waste management system, screening procedures need to be implemented to prevent inappropriate wastes from entering a unit. Such procedures typically call for

Inspect waste to ensure that hazardous waste is not placed in a unit.

screening waste as it enters a unit. Ideally, all wastes entering a unit should be screened, but this is not always practical. A decision may be made, therefore, to screen a percentage of incoming waste. It may be practical to use spot inspections, such as checking random loads of waste on a random day each week or every incoming load on one random day each month. Base the frequency of random inspections on the type and quantity of wastes expected to be received, the accuracy and confidence desired, and any state inspection requirements. Inspections need to be performed prior to placement of wastes in a unit.

Training employees to recognize inappropriate wastes during routine operations increases the chances that inappropriate waste arriving on non-inspection days will be detected. Some indications of inappropriate wastes are color, texture, or odor different from those of the waste a unit normally receives. Laboratory testing can be performed to identify different wastes.

A waste management system needs to include procedures to address suspected inappropriate waste. The procedures to implement when inappropriate wastes are found should include the following.

- Segregate the suspicious wastes;
- Use appropriate personal protective equipment;
- Contact the part of the industrial facility that generated the waste to find out more about it;
- Contact laboratory support to analyze the waste, if required;
- Call the appropriate state, tribal or federal agencies; and
- Notify a response agency, if necessary.

Should liquids be restricted from being placed in some units?

Bulk or containerized liquids should not be placed in landfills or waste piles, as liquids increase the potential for leachate generation. Liquid waste includes any waste material determined to contain free liquids as defined by Method 9095 (also known as the paint filter test) in EPA's *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (SW-846). Sludges are a common waste that may contain significant quantities of liquids. Consider methods such as drying beds to dewater sludges prior to placement in landfills and waste piles.

D. Daily Cover

It may be necessary to apply a daily cover to operating landfills and waste piles. Covering the waste helps control nuisance factors, such as the escape of odors, dust, and airborne emissions, and can control the population of disease vectors. Some cover materials, due to their ability to hold moisture, may reduce the infiltration of rain water, decreasing the generation of leachate and the potential for surface-water and ground-water contamination.

How is daily cover applied?

Covers most often consist of earthen material, although there are several alternative daily covers being used in the industry today, including coproducts, foam, geotextiles, and plastic sheets or tarps. Examples of coproducts that have been used as daily cover include granular wastes, automobile shredder fluff, foundry sand, dewatered sludges, and synthetic soils. When using coproduct covers that may themselves contain contaminants, ensure that run-off is either diverted before it contacts the cover material or captured and handled appropriately after contacting it. Granular wastes used as daily cover should be low in fine-grained particles to avoid waste being transported by wind. Before using alternative covers, especially coproducts, consult the state to determine what, if any, regulations apply.

Daily cover should be applied after the waste has been placed, spread, and compacted. Cover frequency, if not daily, is most often determined by the type of industrial waste disposed of at the landfill or waste pile. More frequent application of earthen material may be required if undesirable conditions persist. A typical daily soil cover thickness is 6 inches, but different thicknesses may be sufficient. When using earthen cover, avoid soils with high clay content. Clay, due to its low permeability, can block vertical movement of water and channel it horizontally through the landfill or waste pile.

Using alternative daily cover materials may save valuable space in a waste management unit. Some types of commercially available daily cover materials include foam that usually is sprayed on the working face at the end of the day; and geosynthetic products, such as a tarp or fabric panel that is applied at the end of the working day and removed at the beginning of the following working day. Some of these materials require specially designed application equipment, while others use equipment generally available at most units. Criteria to consider when selecting an alternative daily cover material include availability and suitability of the material, precipitation, chemical compatibility with waste, equipment requirements, and cost.

E. Placing Wastes

To protect the integrity of liner systems, the waste management system should prescribe proper waste placement practices. The primary physical compatibility issue is puncture of the liner by sharp objects in the waste. Ensure that the liner is protected from items angular and sharp enough to puncture it. Similarly, facility employees should be instructed to keep heavy equipment off the liner. Another physical compatibility issue is keeping fine-grained waste materials away from drainage layers that could be clogged by such materials.

To avoid differential settlement, focus on how the waste is placed on the liner material or on the protective layer above the liner.

Uneven placement of waste, or uneven compaction can result in differential settlement of succeeding waste layers or of final cover. Differential settlement, in turn, can lead to ponding and infiltration of water and damage to liners or leachate collection systems. In extreme cases, failure of waste slopes can occur. To avoid these problems, ensure that waste is sufficiently stabilized and, if possible, compacted.

To protect liner integrity in lined surface impoundments, consider placing an erosion guard or a concrete pad on the liner at the point where waste discharges into the unit. Otherwise, pressure from the waste hitting the liner may accelerate liner deterioration in that area. Inlet pipes can also be arranged so that liquid waste being discharged into the unit is diffused upward or to the side. Although inlet pipes can enter the surface impoundment above the water level, the point of discharge should be submerged to avoid generating odor and disturbing the circulation of stratified ponds. Discharging liquid waste straight into the unit without diffusion is not recommended as this can disrupt the intended treatment.

If significant amounts of sludge accumulate on the bottom of an impoundment, it may be necessary to dredge the impoundment and dispose of the sludge periodically. There are two main concerns regarding sludge management: protecting the liner while cleaning out sludge from the impoundment and properly disposing of any removed sludge. During dredging, heavy equipment can damage the liner. Avoid this by selecting equipment and methods that protect the liner during sludge removal. Further, any sludge removed should be evaluated and managed in an appropriate manner, based on its chemical properties.

F. Climate Considerations

Waste management operations may be affected by weather conditions, especially rain, snow, or wind. Rainy or snowy weather can create a variety of problems, such as inhibited vehicle access and difficulty in spreading and compacting waste. To combat these difficulties, consider altering drainage patterns, maintaining storm-water controls, maintaining all-weather access roads (if appropriate), or designating a wet-weather disposal area.

Extremely cold conditions may prevent efficient excavation of soil from a borrow pit and can also inhibit the spreading and compaction of soil cover on the waste. Freezing temperatures can also inflict excessive wear on equipment. To combat these problems, use coarse-textured soil during winter operations, stockpile cover soil for winter use, and protect cover soil with leaves, plastics, or other insulating materials.

Consider using special inclement weather disposal areas during extreme wet and windy weather. In wet weather, placing waste in a part of the unit near the entrance reduces the likelihood of trucks causing ruts on site roadways or being stranded in mud. Under windy conditions, waste may need to be wetted or placed in downwind areas of a unit to reduce blowing waste or particulates.

G. Security Measures, Access Control, and Traffic Management

To prevent injury to members of the public, consider implementing security and access control measures to block unauthorized entry to a unit. These measures may also help to prevent scavenging, vandalism, and illegal dumping of unauthorized wastes.

Examples of access control measures include fences, locked gates, security guards, surveillance systems, or natural barriers, such as, berms, trees, hedges, ditches, and embankments. The site perimeter should be clearly marked or fenced. Additionally, consider posting signs that warn of restricted access and alert the public to the potential for harm associated with heavy equipment operations.

How can onsite traffic best be managed?

Even though access to the unit is limited, it is necessary to provide clear transportation routes for emergency response equipment to access the waste management unit. Traffic management is often overlooked as part of waste management unit operations. Proper traffic routing can help a unit operate more smoothly and prevent injuries and deter intruders. Access roads should be designed and built to be safe and efficient, without blind spots or unmarked intersections. They should also be located to provide long-term service without requiring relocation. Posting clear directional signs can help direct traffic and reduce the potential for vehicle accidents. Providing all-weather access roads (if appropriate) and temporary storage areas can improve waste transport to and from a unit and allow equipment to move about more freely. In addition, consider imposing onsite speed limits or constructing speed bumps.

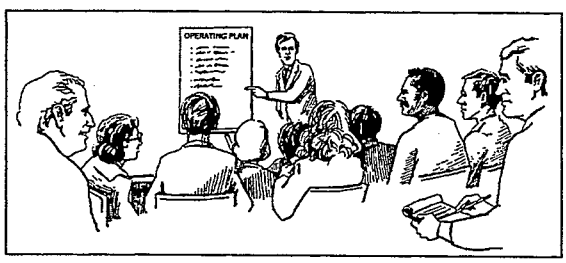
Access roads should be maintained properly at all times. Adequate drainage of road beds is essential for proper operation of a unit. Heavy, loaded vehicles traveling to and from a unit deteriorate the roads on which they travel. Equipment without rubber tires should not be allowed on the paved stretches of roads as they may damage the roads. Sufficient funds should be allocated up front for the maintenance of access roads.

What are some other prudent safety measures?

There are a number of considerations associated with ground-water monitoring wells. The tops of monitoring wells should be clearly marked and accessible. In traffic areas, posts and/or bumper guards around monitoring wells may help protect aboveground installations from damage. Posts and/or bumper guards come in various sizes and strengths and are typically constructed for high visibility and trimmed with reflective tape or highly visible paint containing reflective material. Proper labeling of monitoring wells is important for several reasons. Monitoring wells should be distinguished from underground storage tank fill lines, for example. Also, different monitoring wells should be distinguished from each other. Monitoring wells, therefore, should be labeled on immovable parts of the well.

H. Providing Employee Training

One of the most important aspects of a waste management system is employee training. Employees should be trained before their initial assignment, upon changing assignments, and any time a new health or safety hazard is introduced into the work area. A good training program uses concrete examples to improve and maintain employee skill, safety, and teamwork. Training can be provided by in-house



Classroom training helps familiarize employees with operating procedures.

trainers, trade associations, or specialized consultants. In some states, proactive safety and training programs are required by law.

What types of training can be provided for employees?

The following categories of training programs may be applicable to employees:

- Manager and supervisor training;
- Equipment operator training and heavy equipment maintenance;
- Laborer training; and
- Safety training for all employees.

Safety is a primary concern because waste management operations can present a variety of risks to workers. In addition, employee right-to-know laws require employers to provide training and information about safety issues pertinent to a given occupation. Furthermore, accidents can be expensive, with hidden costs often amounting to several times the apparent costs. Accidents at waste management units can include injury from explosions or fire, inhalation of contaminants and dust, asphyxiation from poorly vented leachate collection system manholes or tanks, falls from vehicles, injury associated with operating heavy earth-moving equipment, exposure to extreme cold or heat, and onsite traffic accidents.

To minimize risks to workers, provide an ongoing safety training program to ensure all staff are properly and regularly trained on safety issues. A safety training program should be consistent with the requirements specified by the U.S. Occupational Safety and Health Administration (OSHA) and include initial training and frequent refresher sessions on at least the following topics:

- Waste management operations;
- Hazardous waste identification;
- Monitoring equipment operations;
- Emergency shut-off procedures;
- Overview of safety, health, and other hazards present at the site;
- Symptoms and signs of overexposure to hazards;
- Proper lifting methods, material handling procedures, equipment operation, and safe driving practices;
- Emergency response topics, such as spill

Sample Manager and Supervisor Training Agenda

- Introduction
- Unit basics:
  - —Siting
  - —Waste containment
  - —Daily operations
- Owning and operating machines
- Machine types
- Equipment maintenance
- Maximizing airspace
- Labor management
- Production analysis
- Application of production rate data
- Budgets and data tracking:
  - —Operating budget
  - —Cover soil budget
  - —Airspace budget
- Waste handling techniques
- Waste management techniques
- Cover soil placement
- Safety issues and safety meetings
- Record keeping
- Emergency response plan
- State requirements for operation

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response, fire suppression, hazard analysis, and location and operation of emergency equipment; and

- Requirements for personal protective gear, such as hard hats, gloves, goggles, safety shoes, and high-visibility vests.

Weave a common thread of teamwork into every training program. Breaks in communication between site engineers and field operations personnel can occur. Bridging this gap is an important step toward building an effective unit team that can work together. Consider periodic special training to update employees on new equipment and technologies, to improve and broaden their range of job-related skills, and to keep them fresh on the basics. Training can also include such peripheral topics as liability concerns, first aid, avoidance of substance abuse, and stress management.

How should training programs be conducted?

Keep records of the type and amount of training provided to employees, and obtain documentation (employee signatures) whenever training is given. Consider establishing regular (at least monthly) safety meetings, during which specific topics can be addressed and employees can voice concerns, ask questions, and present ideas. Keep meetings short and to the point, and steer discussion toward topics

Sample Laborer Training Agenda

- Introduction
- Unit basics:
  - —Siting
  - —Waste containment
  - —Daily operations
- Traffic management and safety
- Interacting with the public
- Load segregation and placement
- Hazardous material identification procedure
- Unit equipment types and applications
- Cover operations
- Equipment maintenance
- Unit safety
  - —Heavy equipment safety
  - —Traffic safety
  - —Personal protective equipment
- Emergency response plans

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Equipment Operator Training Agenda

- Introduction
- Unit basics:
  - —Siting
  - —Waste containment
  - —Daily operations
- Heavy equipment types and applications:
  - —Scraper, dozer, and compactor operations
  - —Support equipment
  - —Fluids
  - —Fueling, maintenance and its hazards, and fuel spill prevention.
- Cover operations:
  - —Types of cover soil
  - —Placement of cover soil
- Drainage control
- Surveying and staking
- Unit safety:
  - —Emergency response plans
  - —Safe operating techniques
- Owning and operating costs

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that are applicable to those employees present. In addition, do not waste time talking about issues not applicable to a site. If a site experiences extreme weather conditions, develop safety meeting topics that address weather-related safety. Many safety-related videos are available and can add variety to meetings.

Closely monitor worker accident and injury reports to try to identify conditions that warrant corrective or preventive measures. In addition, it is wise to document all safety meetings. Assistance in establishing a safety program is available from insurance companies with worker's compensation programs, the National Safety Council, safety consultants, and federal and state government safety organizations. The overall cost of an aggressive, preventive safety program is almost certain to be offset by the savings from a decrease in lost work time and injuries.

I. Emergency Response Plan and Procedures

There are three major types of waste management emergencies: accidents, spills, and fires/explosions. A waste management system should include emergency response plans for each of these scenarios that considers not only the waste management unit but also all surrounding facility areas. The plans should be reviewed and revised periodically to keep the procedures fresh in employees' minds and to reflect any changes in such items as the unit operating procedures, facility operations, physical/chemical changes in the wastes, generated volumes, addition or replacement of emergency equipment, and personnel changes. If an emergency does arise, or if hazardous waste is inadvertently disposed of in a unit, notify appropriate agencies, adjacent land owners, and emergency response personnel, if needed. After emergency conditions have been cleared, review the waste management system and revise it, if necessary, to prevent similar mishaps in the future.

How should an appropriate emergency response plan be developed?

An emergency response plan needs to consider the following:

- Description of types of emergencies that would necessitate a response action;
- Names, roles, and duties of primary and alternate emergency coordinators;
- Spill notification procedures;
- Who should be notified;
- Fire department or emergency response telephone number;
- Hospital telephone number;
- Primary and secondary emergency staging areas;
- Location of first aid supplies;
- Designation and training of several first aid administrators;
- Location of and operating procedures for all fire control, spill control, and decontamination equipment;
- Location of hoses, sprinklers, or water spray systems and adequate water supplies;
- Description and listing of emergency response equipment;
- Maintenance and testing log of emergency equipment;
- Plans to familiarize local authorities, local emergency response organizations, and neighbors with the characteristics of the unit and appropriate and inappropriate responses to various emergency situations;

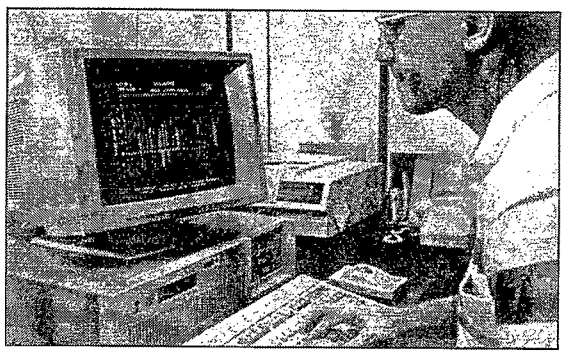
- Information on state emergency response teams, response contractors, and equipment suppliers;
- Properties of the waste being handled at the unit, and types of injuries that could result from fires, explosions, releases, or other mishaps;
- An evacuation plan for unit personnel (if applicable); and
- Requirements for prominent posting of the above information.

The emergency plan should instruct all employees what to do if an emergency arises, and all employees should be familiar with the plan and their responsibilities under it. In order to ensure that everyone knows what to do in an emergency, conduct periodic drills. These practice responses could be planned ahead of time or they could be unannounced. Either way, the drills are treated as real emergencies and serve to hone the skills of the employees who may have to respond to actual emergencies. The key to responding effectively to an emergency is knowing in advance what to do.

Communication is vital during an emergency and should be an inherent component of any emergency response plan. Two-way radios and bullhorns can prove invaluable in the event of an emergency, and an alarm system can let employees know that an emergency situation is at hand. Designate one or more employees who will not be essential to the emergency response to handle public affairs during a major emergency. These employees should work with the press to ensure that the public receives an accurate account of the emergency.

J. Record Keeping

Record keeping is a vital part of cost-effective, efficient waste management unit operations. Records should be maintained for an appropriate period of time, but it is a good idea to keep a set of core records indefinitely. Some facilities have instituted policies that records are to be maintained for up to 30 years while other facilities maintain records for only 3 years. Some states have record keeping requirements for certain waste management units and associated practices. Check with state authorities to determine what, if any, record keeping is required by law and to determine how long records should be kept.



Besides being required by some states, records help evaluate and optimize unit performance. Over time, these records can serve as a valuable almanac of activities, as well as a source of cost information to help fine tune future expenditures and operating budgets. Data on waste volume, for example, can allow a prediction of remaining site life, any special equipment that may be needed, and personnel requirements. Furthermore, if a facility is ever involved in litigation, accurate, dated records can be invaluable in establishing a case.

What type of records should be kept?

Operational records that should be maintained include the following, as appropriate:

- Waste analysis results;

- Liner compatibility testing;
- Waste volume;
- Location of waste placement, including a map;
- Depth of waste below the final cover surface;
- Cover material used and available;
- Frequency of waste application;
- Equipment operation and maintenance statistics;
- Environmental monitoring data and results;
- Inspection reports, including photographs;
- Design documents, including drawings and certifications;
- Cost estimates and other financial data;
- Plans for unit closure and post-closure care;
- Information on financial assurance mechanisms;
- Daily log of activities; and
- Calendar of events.

Health and safety records that should be maintained include the following:

- Personal information and work history for each employee, including health information such as illness reports;
- Accident records;
- Work environmental records; and
- Occupational safety records, including safety training and safety surveys.

K. Addressing Nuisance Concerns

Minimizing nuisances, such as noise, odor, and disease vectors, is of great importance for the health of personnel working in the industrial facility and of neighbors that live or work near a unit. This section describes many of the nuisance concerns typical of waste management units and offers measures to address them. Measures, besides those listed can be used to achieve the same objective.

How can noises be minimized?

Noise resulting from the operation of heavy equipment may be a concern for waste management units located near residential areas. Noise may also disrupt animal habitats and behavior. In addition, workers' hearing and stress levels can be adversely affected by long-term exposure to noise. At waste management units where noise is a concern, limiting hours of operation may reduce potential problems. Design access routes to minimize the impact of site traffic noise on nearby neighborhoods. Equipment should also be maintained to minimize unnecessary noise, and affected workers should wear ear protection (plugs or muffs). Berms, wind breaks, or other barriers can be erected to help mute sounds. OSHA has established standards for occupational exposure to noise (see 29 CFR §1910.95).

How can odor be minimized?

Increased urbanization has led to industrial facilities being situated in close proximity to residential areas and commercial developments. This has resulted in numerous complaints about odors from industrial waste management units and industrial processes such as poultry processing, slaughtering and rendering, tanning, and manufacture of

volatile organics. Some of the major sources of odors are hydrogen sulfide and organic compounds generated by anaerobic decomposition. The latter may include mercaptans, indole, skatole, amines, and fatty acids. Odor may be a concern at a unit, depending on proximity to neighbors and the nature of the wastes being managed. In addition to causing complaints, odors may be a sign of toxic or irritating gases or anaerobic conditions in a unit that could have adverse health effects or environmental impacts. Plan to be proactive in minimizing odors, and establish procedures to respond to citizen complaints about odor problems and to correct the problems.

Odors may be seasonal in nature and, therefore, can often be anticipated. Some odors at landfills, waste piles, and land application units arise either from waste being unloaded or from improperly covered in-place waste. If odor from waste being unloaded becomes a problem, it may be necessary to place these loads in a portion of the unit where they can be immediately covered with soil. At land application units, quick incorporation or injection of waste can help prevent odor. It also may be necessary to establish a system whereby unit personnel are notified when odorous wastes are coming to the unit to allow them to prepare accordingly. Odors from in-place waste can effectively be minimized by maintaining the integrity of cover material over everything but the currently active face. Proper waste compaction also helps to control odors. Consider implementing gas controls if odors are associated with gases generated from a unit.

If odors emanate from surface impoundments, there are several options available for control, including biological and chemical treatment. The type of treatment for an impoundment should be determined on a site-specific basis, taking into account the chemistry of the waste.

Practices to control odor are especially important at land application units. If land application is used, apply waste at appropriate rates for site conditions, and design and locate waste storage facilities to minimize odor problems. Make it a priority to minimize potential odors by applying wastes as soon as possible after delivery and incorporating wastes into the soil as soon as possible after application. Cleaning trucks, tanks, and other equipment daily (or more frequently, if necessary) may also help reduce odor. Avoid applying waste when soils are wet or frozen or when other soil or slope conditions would cause ponding or poor drainage.

Other methods of controlling odors include:

- Covering or enclosing the unit;
- Adding chemicals such as chlorine, lime, and ferric chloride to reduce bacterial activity and oxidize many products of anaerobic decomposition;
- Using biofilters;
- Applying a deep soil cover, whose upper layers consist of silty soils or soils containing a large percentage of carbon or humic material;
- Applying a layer of relatively impermeable soil, so as to reduce gas generation rates by reducing the amount of rainfall water percolating into the waste;
- Covering leachate collection areas; and
- Restoring landfill surface covers when subsidence and cracks occur.

Choosing a method for controlling odors requires a comprehensive understanding of wastes and how they react under certain circumstances. Consult with state agencies to determine the most effective odor control method for the wastes in question.

In addition to these steps to control odor generation, consider steps to manage those

odors that are generated. When designing a waste management unit, consider installing barriers such as walls, berms, embankments, and dense plantings of trees set at right angles to the flow of cold, odorous nighttime air. These measures may help to impede the odor and dilute it through mixture with higher layers of fresh air. Alternatively, consider placing an impermeable fence or wall on top of a berm or embankment, on its downwind side. This will increase odor plume height, and odors will be diluted on the steep downslope side of the barrier as a result of turbulent mixing of air layers as the cold air flows over it. Try to locate such barriers as close to the unit as possible.

Another design suggestion is to plant fast-growing evergreen trees, which have good windbreak properties, in buffer-zones around a unit. In addition to dispersing odors, dense plantings of evergreen trees will also help to protect the unit itself from strong winds, reducing the possibility of windblown soil erosion.

How can disease vectors be controlled?

Disease vectors are animals or insects, such as rodents, flies, birds, and mosquitos, that can transmit disease to humans. Burrowing pests, such as gophers, moles, and groundhogs, may not only carry disease but can also damage vital unit structures, such as liners, final cover materials, drainage ditches, and sedimentation ponds. As a result, these animals can create costly problems.

Putrescible wastes, along with standing water, can provide an ideal food source and potential breeding medium for disease vectors. If putrescible wastes are being managed, consider the following methods to control disease vectors:

- Apply adequate daily cover. This simple action is often all that is needed to control many disease vectors;
- Reduce the size of the working face at a landfill so that less waste is exposed;
- Make sure the unit is properly drained, reducing the amount of standing water that acts as a breeding medium for insects;
- Use predator decoys and acoustic controls to scare away birds; and
- As a last resort, or when the application of cover material is impractical, consider using repellents, insecticides, rodenticides, or pest reproductive control. Care must be taken to make sure that pesticides are used only in accordance with specified uses and application methods.

Follow the instructions carefully when using these products. Trapping animals may also be considered, but trapping alone rarely eliminates the problem.

If land applying wastes, subsurface injection and prompt incorporation of waste can help control vectors. Both of these methods work by using the soil as a barrier between the waste and vectors. If a waste storage facility exists, these may attract vectors as well and should not be overlooked in the implementation of vector control. If vector problems arise at a site, take steps to address them promptly.

General Waste Management System Action Items

- ☐ Develop a waste management system identifying the standard procedures necessary for a unit to operate according to its design throughout the intended working life.
- ☐ Provide proper maintenance and operation of ground-water, surface-water, and air controls.
- ☐ Develop daily procedures to place waste, operate environmental controls, and inspect and maintain the unit.
- ☐ Review at a regular interval, such as annually, whether the waste management system needs to be updated.
- ☐ Develop a waste analysis procedure to ensure an understanding of the physical and chemical composition of the waste to be managed.
- ☐ Develop regular schedules for waste screening and for unit inspections.
- ☐ If daily cover is recommended, select an appropriate daily cover and establish processes for placing and covering waste.
- ☐ Consider how operations may be affected by climate conditions.
- ☐ Implement security measures to prevent unauthorized entry.
- ☐ Provide personnel with proper training.
- ☐ Establish emergency response procedures and familiarize employees with emergency equipment.
- ☐ Develop procedures for maintaining records.
- ☐ Establish nuisance controls to minimize dust, noise, odor, and disease vectors.

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Part V
Ensuring Long-Term Protection

Chapter 9
Monitoring Performance

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Monitoring Performance

Carefully designed and implemented monitoring programs are essential to evaluate whether a unit meets performance objectives and whether there are releases and impacts on the surrounding environment that need to be corrected. Effective monitoring programs protect the environment, improve unit performance and help reduce long-term costs and liabilities associated with industrial waste management.

Monitoring the performance of a waste management unit is a very important part of a comprehensive waste management system. A properly implemented monitoring program provides an indication of whether a waste management unit is functioning in accordance with its design, and detects any changes in the quality of the environment caused by the unit. The detection information obtained from a monitoring program can be used to ensure the proper types of wastes are being managed in the unit, discover and repair any damaged area(s) of the unit, or determine if an alternative management approach may be appropriate. By implementing a monitoring program, facility managers will be able to identify problems or releases in a timely fashion, and take the appropriate measures to limit contamination. Continued detection of contamination in the environment may require the implementation of more aggressive corrective action measures to remediate releases.

This chapter will help address the following questions:

- What site characterizations need to be performed to develop an effective monitoring program?
- What are the basic elements of a monitoring program?
- How should sampling and analytical protocols be used in a monitoring program?
- What procedures should be used to evaluate monitoring data?
- What elements of the basic monitoring program can be modified to address site conditions?

This chapter highlights issues associated with establishing a ground-water monitoring program because most industrial waste management units need to have a ground-water monitoring program. The chapter also provides a brief discussion of air, surface water, and soil monitoring that may be applicable to some units managing industrial waste. Consult with qualified professionals, such as engineers and ground-water specialists[1], for technical

[1]For the purpose of this chapter, a qualified "ground-water specialist" refers to a scientist or engineer who has received a baccalaureate or post-graduate degree in the natural sciences or engineering and has sufficient training and experience in ground-water hydrology and related fields as may be demonstrated by state registration, professional certifications, or completion of accredited university programs that enable that individual to make sound professional judgements regarding ground-water monitoring, contaminant fate and transport, and corrective action.

assistance in making decisions about the design and operation of a ground-water monitoring program. In addition when questions arise concerning soil, air, or surface-water monitoring, consult specialists in these areas as each media requires different expertise.

I. Ground-Water Monitoring

A. Hydrogeological Characterization

An accurate hydrogeological characterization is the essential foundation of an effective ground-water monitoring system. Hydrogeologic conditions determine ground-water flow and influence contaminant transport. It is important to thoroughly understand the ground-water flow beneath a site to decide on the complexity and location of a ground-water monitoring system that will provide representative background and downgradient water measurements.

The goal of a hydrogeological characterization is to acquire site-specific data to enable the development of an appropriate ground-water monitoring program. The site-specific data that should be developed includes:

- The lateral and vertical extent of the uppermost aquifer;
- The lateral and vertical extent of the upper and lower confining units/layers;
- The geology at the waste management unit's site, such as stratigraphy, lithology, and structural setting;
- The chemical properties of the uppermost aquifer and its confining layers relative to local ground-water chemistry and wastes managed at the unit; and
- Ground-water flow, including
  - The vertical and horizontal directions of ground-water flow in the uppermost aquifer,
  - The vertical and horizontal components of the hydraulic gradient in the upper most and any hydraulically connected aquifer,
  - The hydraulic conductivities of the materials that comprise the upper-most aquifer and its confining units/layers, and

Why is it important to use a qualified professional?

- Site characterizations can be extremely complex.
- Incorrect or incomplete characterizations could result in inaccurate detection of contamination in the ground water due to improper placement of ground-water monitoring wells and may cost a significant amount of money. In addition incorrect or incomplete characterizations could result in the installation of unnecessary monitoring wells also costing a significant amount of money.
- Always use a qualified professional to conduct site characterizations. Check to see if the professional has sufficient training and experience in ground-water hydrology and related fields as may be demonstrated by state registration, professional certifications, or completion of accredited university programs. These professionals should be experienced at analyzing ground-water flow and contaminant fate and transport. Ensure that these professionals are familiar with the contaminants in the waste and thoroughly

- The average linear horizontal velocity of ground-water flow in the uppermost aquifer.

To perform a hydrogeological characterization and develop an understanding of a site's hydrogeology, a number of investigations can be used:

- **Existing information.** Investigate the waste management history of the site, such as documented records describing wastes managed on site and releases. Some hydrogeological information may also have been developed in the past. It may be useful to conduct literature reviews for reports of research performed in the area of the unit and examine federal and state geological and environmental files/ reports related to the site or to the region where the site is to be located.
- **Site geology.** A geologic unit is typically considered to be any distinct or definable native rock or soil stratum. Characterize thickness, stratigraphy, lithology, and hydraulic characteristics of saturated and unsaturated geologic units and fill materials overlying the uppermost aquifer, materials of the uppermost aquifer, and materials of the lower confining unit of the uppermost aquifer using soil borings or geophysical methods. Conventional soil borings are typically used to characterize onsite soils through direct sampling. Geophysical equipment, such as ground-penetrating radar, electromagnetic detection equipment, and electrical resistivity arrays, provides a non-invasive measurement of physical, electrical, or geochemical properties of the site. Understanding the different strata will help locate the appropriate ground-water monitoring well locations and screen depths.
- **Ground-water flow beneath the site.** Across the United States, ground-water flow velocities range from several feet to over 2,000 feet per year. Characterize the aquifer thickness, ground-water flow rate and direction, including seasonal and temporal fluctuations in flow, effect of site construction and operations on ground-water flow direction, and variations in ground-water elevation. To determine ground-water flow directions, flow rates and hydraulic gradient, a water level monitoring program should be implemented. This program should be structured to provide specific water level measurements. Information on water level-monitoring program and procedures for obtaining accurate water level measurements can be found in *Solid Waste Disposal Faciltiy Criteria: Technical Manual* (EPA530-R-93-017).

Integrate all of this information to make the best decisions regarding the number, locations, depths, and screened intervals for wells to monitor unit performance. As an example, understanding the horizontal and vertical ground-water flow makes it possible to estimate where monitoring wells will most likely intercept contaminant flow. The level of effort to characterize a site sufficiently to design an adequate ground-water monitoring system depends on the geologic and hydrogeologic complexity of the site. The complexity of a site should not be assumed; a soil boring program can help determine the complexity of a site's hydrogeology. Appendix I presents a topical list of more than 80 American Society for Testing and Materials (ASTM) guides and practices related to waste and site characterization and sampling. Appendix I, Section A.2 identifies 31 major ASTM guides related to site characterization. (See, *Ground-Water Monitoring: Draft Technical Guidance*, EPA530-R-93-001 and *Solid Waste Disposal Facility Criteria: Technical Manual*, EPA530-R-93-017 for additional information on ground-water monitoring.)

B. Basics of Ground-Water Monitoring

The basic elements of a ground-water monitoring program include:

- The monitoring method;
- The number of wells;
- Location and screened intervals of wells;
- Well design, installation, and development;
- The duration and frequency of monitoring; and
- Sampling parameters to be monitored.

The remainder of this section provides a brief overview of the six basic elements of a ground-water monitoring program.

1. Monitoring Methods

Ground-water monitoring usually involves installation of permanent monitoring wells for periodic collection of ground-water samples. Waste migration can be monitored by sampling ground water directly for contaminants or by sampling ground water for geophysical parameters. Ground water also can be sampled directly through semi-permanent conventional monitoring wells or by temporary direct-push sampling. Conventional monitoring wells, direct-push sampling, and geophysical methods are described below.

a. Conventional Monitoring Wells

The conventional monitoring well is the most common well type used to target a single screened interval. Figure 1 presents an illustration of a single screened interval. Specific construction features are described in more detail below. The conventional monitoring well is semi-permanent, meaning it can be used for sampling over an extended period of time and should be located by surveyed reference points. To monitor more than one depth at a single location, install conventional monitoring wells in clusters or with multilevel sampling devices.

b. Direct-Push Ground-Water Sampling

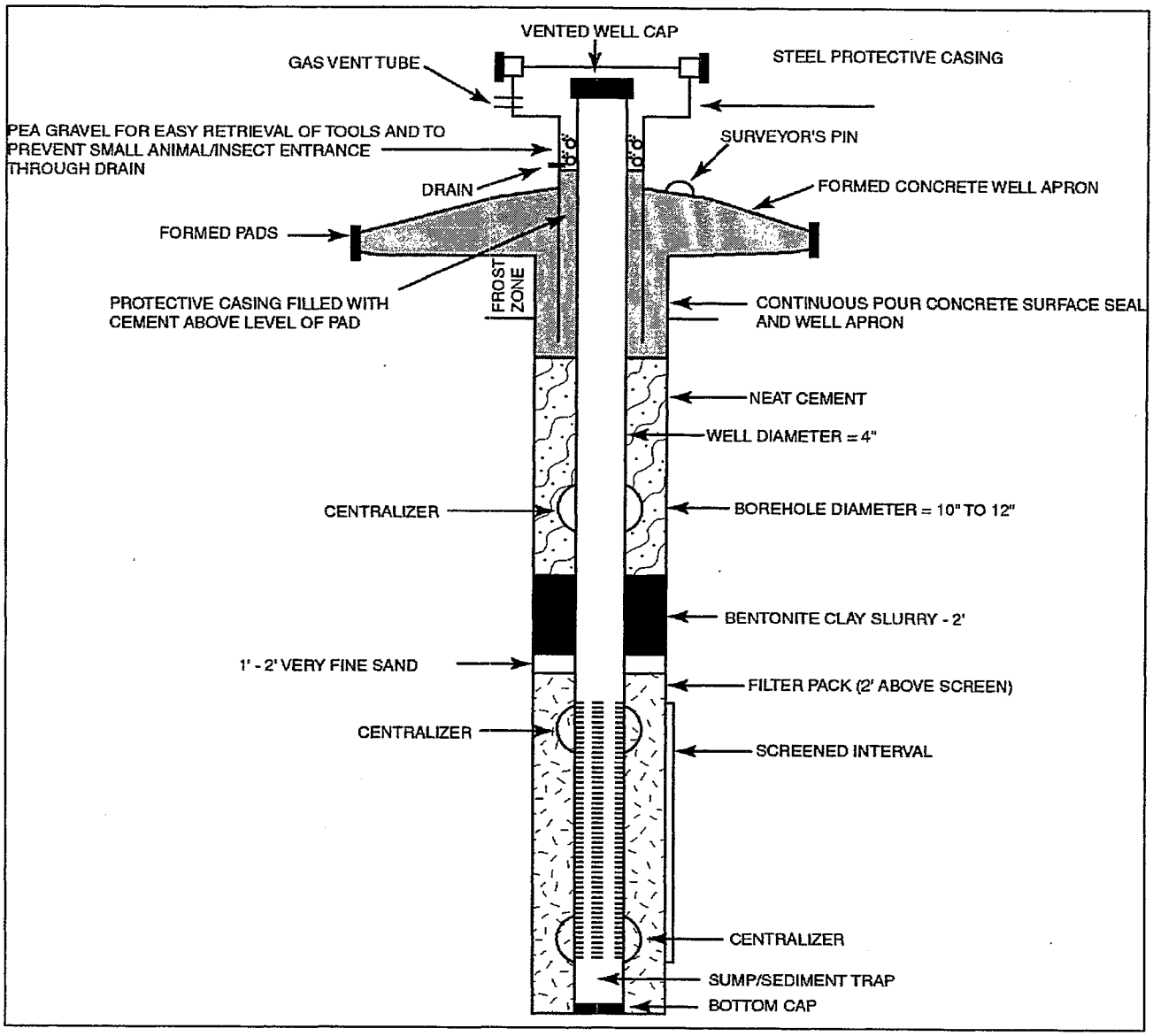
Using the direct-push technique, ground water is sampled by hydraulically pressing and/or vibrating a probe to the desired depth and retrieving a ground-water sample through the probe. The probe is removed for reuse elsewhere after the desired volume of ground water is extracted.

What are the benefits of direct-push sampling?

Given favorable geology, the direct-push method of ground-water sampling can be a simpler and less expensive alternative to conventional wells. Conventional monitoring wells, because they are semi-permanent, generally cost more and take longer to install. Direct-push technology, however, does not provide a semi-permanent structure from which to sample the ground water over an extended period of time, as do conventional wells.

In sandy aquifers, however, the direct-push technology can be used to install a well similar to a conventional monitoring well. Relatively recent advances in direct-push technology use pre-packed screens with grouts and seals attached to a metal pipe that are driven into the ground, forming an assembly similar to a conventional well. Consult with the appropriate state agency to determine whether direct-push well installations are acceptable.

Figure 1. Cross-Section of a Generic Monitoring Well



c. *Geophysical Methods*

Geophysical methods measure potential changes in ground-water quality by measuring changes in the geophysical characteristics of the sub-surface soils, and in some cases, in the ground water itself. For example, increases in the levels of certain soluble metals in ground water can change the resistive properties of the ground water, which can be measured using surface resistive technologies. Similarly, changes in the resistive properties of the vadose zone may indicate the migration of leachate toward ground water. Geophysical characteristics, such as DC-resistivity, electromagnetic induction, pH, and temperature, can provide important preliminary indications of the performance of the

waste unit liner design. Consult with the appropriate state agency regarding the use of a geophysical method. (See *Subsurface Characterization and Monitoring Techniques*, EPA625-R-93-003a, for additional information on the use of geophysical methods.)

How useful is geophysical method data?

Geophysical methods are more commonly used to map the initial extent of contamination at waste management units than for ongoing monitoring. Initial monitoring data can guide placement of permanent monitoring wells for ongoing monitoring. As discussed later, geophysical methods, used in conjunction with ground-water monitoring, can reduce the frequency of well sampling, which could reduce monitoring costs. The usefulness of geophysical methods, however, will depend on the local hydrogeology, the contaminant concentration levels, and type of contaminants

2. Number of Wells

A ground-water monitoring system requires a minimum of one upgradient or background monitoring well and three downgradient monitoring wells to make statistically meaningful comparisons of ground-water quality. The actual number of upgradient and downgradient wells will vary from unit-to-unit and will depend on the actual site-specific conditions. The upgradient or background well(s) permit the assessment of background quality of the onsite ground water, and the downgradient wells permit detection of any contaminant plumes from a waste management unit. This configuration of one upgradient and three downgradient wells may be adequate when hydrologic conditions and potential contaminant movement are straightforward.

How many wells are needed?

To determine the number of monitoring wells, evaluate the following factors:

- Geology of the waste management unit site;
- Ground-water flow direction and velocity, including seasonal and temporal fluctuations;
- Permeability or hydraulic conductivity of any water-bearing formations; and
- Physical/chemical characteristics of contaminants.

The number of wells is dictated by the lateral and vertical placement of monitoring wells. Site-specific hydrogeologic data obtained during site characterization should be used to determine the lateral placement of monitoring wells and to select the length and vertical position of monitoring well intakes. The lateral placement of monitoring wells should be based on the number and spatial distribution of potential contaminant migration pathways and on the depths and thickness of stratigraphic horizons that can serve as contaminant migration pathways. The vertical position and lengths of monitoring well intakes are functions of hydrogeologic factors and the chemical and physical characteristics of contaminants.

The local ground-water flow direction and gradient are the major factors in determining lateral placement of monitoring wells. In a homogenous setting, well placement can be based on general aquifer characteristics and potential contaminant fate and transport characteristics. However, geology is variable and preferential pathways exist that control migration of contaminants. The next section provides information on the lateral and vertical placement of monitoring wells.

A larger number of monitoring wells may be needed at sites with complex hydrogeology.

If a site has multiple waste management units, use of a multi-unit ground-water monitoring system may reduce the necessary number of wells. Consult with the appropriate state agency when determining a site's ground-water monitoring well requirements.

3. Lateral and Vertical Placement of Wells

Monitoring wells must yield ground-water samples from the targeted aquifer(s) that are representative of both the quality of background ground water and the quality of ground water at a downgradient monitoring point.

The lateral and vertical placement of monitoring wells is very site-specific. Locate monitoring wells at the closest practicable distance from the waste management unit boundary to detect contaminants before they migrate away from the unit. Early detection provides a warning of potential waste management unit design failure and allows time to implement appropriate abatement measures and potentially eliminate the need for more extensive corrective action. It also reduces the area exposed and may limit overall liability.

a. Lateral Placement

Monitoring wells should be placed laterally along the down gradient edge of the waste management unit to intercept potential contaminant migration pathways. Ground-water flow direction and gradient are two major determining factors in monitoring well placement. The number and spatial distribution of potential contaminant migration pathways and the depths and thickness of stratigraphic horizons that can serve as contaminant migration pathways also must be considered. In homogeneous, isotropic hydrogeologic sites ground-water flow direction and gradient, along with the potential contaminant chemical and physical characteristics, will primarily determine lateral well placement. In more complex site where hydrogeology and geology are variable and preferential pathway exist, (a heterogeneous, anisotropic hydrogeologic site) the well placement determination becomes more complex. Potential migration pathways are influenced by site geology including varying hydraulic conductivity, fractured or faulted zones, and soil chemistry. Human-made features that influence ground-water flow must also be considered. These features may include things such as ditches, filled areas, buried piping, buildings, leachate collection systems and other adjacent disposal units.

Another point of consideration is seasonal changes in ground-water flow. Seasonal changes in ground-water flow can result from tidal influences, lake or river stage fluctuations, well pumping, or land use pattern changes. At some sites it may even be possible that ground water flows in all directions from a waste management unit. These contingencies may require placement of monitoring wells in a circular pattern to monitor on all sides of the waste management unit. Seasonal fluctuations may cause certain wells to be downgradient only part of the time, but such configurations ensure that releases will be detected.

Lateral placement of monitoring wells also must be based upon the chemical and physical characteristics of a waste management unit's potential contaminants. Consider potential contaminant characteristics such as solubility, Henry's law constant, partition coefficients, specific gravity (density), potential for natural attenuation and the resulting reaction or degradation products, and the potential for contaminants to degrade confining layers. A Dense non-aqueous phase liquid (DNAPL), for instance, because of its density may not necessarily migrate only in the direction of the ground-water flow. The presence of DNAPL, therefore, may require placing wells in more locations than just the normal downgradient sites.

b. *Vertical Placement and Screen Lengths*

Similar to lateral placement, vertical well placement in the ground water around a waste management unit is determined by geologic and hydrogeologic factors, as well as the chemical and physical characteristics of the potential contaminants. The vertical placement of each well and its screen lengths will be determined by the number and spatial distribution of potential contaminant migration pathways and the depths and thickness of potential migration pathways. Site-specific geology, hydrogeology, and constituent characteristics influence the location, size, and geometry of potential contaminant plumes, which in turn determine monitoring well depths and screen lengths.

The chemical and physical characteristics of potential contaminants from a waste management unit plays a significant role in determining vertical placement. The specific properties of a particular contaminant will determine what potential migration pathway it may take in an aquifer. The specific characteristics of a contaminant, such as its solubility, Henry's law constant, partition coefficients, specific gravity (density), potential for natural attenuation and the resulting reaction or degradation products, and the potential for contaminants to degrade confining layers, will all influence the vertical placement and screen lengths of a unit's monitoring wells. A DNAPL, for instance, will sink to the bottom of an aquifer and migrate along geologic gradients (rather than hydrogeologic gradients), thus requiring a monitoring well's vertical placement to correspond with the depth of the appropriate geologic feature. LNAPLs (light nonaqueous phase liquids) on the other hand would move along the top of an aquifer, and require wells and wells screens at the surface of the aquifer.

Well screen lengths are also determined by site and constituent specific parameters. These parameters and the necessity of taking vertically discrete ground-water samples, factor into the determination of well screen size. Highly heterogeneous (complex) geologic sites require shorter well screen lengths to allow for the sampling of discrete migration pathways. Screens that span more than a single contaminant migration pathway may cause cross contamination, possibly increasing the extent of contamination. Shorter screen lengths allow for a more concentrated monitoring of the aquifer or the portion of the aquifer of concern. Excessively large well screens may lead to the dilution of samples making contaminant detection more difficult. The depth or thickness of an aquifer also determines the length of the well screen. Sites with highly complex geology or relatively thin aquifers may require multiple screens at varying depths. Conversely, an extremely thick and homogenous aquifer may allow for fewer wells with longer screen lengths.

Consult with state officials on the lateral and vertical placement of monitoring wells. In the absence of specific state requirements, it is recommended that the monitoring points be no more than 150 meters downgradient from a waste management unit boundary, on facility property, and placed in potential contamination migration pathways. This maximum distance is consistent with the 40 CFR Part 258 criteria for municipal solid waste landfills and approaches that many states have adopted in order to protect waters of the state.

4. Monitor Well Design, Installation, and Development

Ground-water monitoring wells are tailored to suit the hydrogeologic setting, the type of constituents to be monitored, the

Table 1
Factors Affecting Number of Wells Per Location (CLUSTER)

One Well per Sampling Location	More Than One Well Per Sampling Location
No light non-aqueous phase liquids (LNAPLs) or dense non-aqueous phase liquids (DNAPLs) (immiscible liquid phases)	Presence of LNAPLs or DNAPLs
Thin flow zone (relative to screen length) Horizontal flow predominates	Thick flow zones Vertical gradients present
Homogeneous isotropic uppermost aquifier, simple geology	Heterogeneous anisotropic uppermost aquifier, complicated geology - multiple, interconnected aquifiers - variable lithology - perched water zones - discontinuous structures Discrete fracture zones in bedrock Solution conduits, such as caves, in karst terrains Cavernous basalts

overall purpose of the monitoring program, and other site-specific variables. Consult with the state agency and qualified professionals to discuss the construction specifications for ground-water monitoring wells before beginning well designs. Figure 1 illustrates the monitoring well design components that are discussed in this section. Appendix I, Section A.3 identifies ASTM guides and practices related to monitoring well design, construction, development, maintenance, and decommissioning. EPA's *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells* (EPA600-4-89-034) also contains this information.

a. Well Design

The typical components of a monitoring well include a well casing, a well intake, a filter pack, an annular and surface seal, and surface completion. Each of these components is briefly described below.

Well Casing

The well casing is a pipe which is installed temporarily or permanently to counteract caving, to advance a borehole, and to isolate the zone

being monitored. The well casing provides access from the surface of the ground to some point in the subsurface. The casing, associated seals, and grout prevent borehole collapse and interzonal hydraulic communication. Access to the monitored zone is through the casing and into either the open borehole or the screened intake. The casing thus permits piezometric head measurements and groundwater quality sampling.

A well casing can be made of any rigid tubular material. The most frequently evaluated characteristics that directly influence the performance of casing material in groundwater monitoring applications are strength, chemical resistance, and interference. Monitoring well casings should be strong enough to resist the forces exerted on it by the surrounding geologic materials and the forces imposed on it during installation. Casings should exhibit structural integrity for the expected duration of the monitoring program under natural and man-induced subsurface conditions. Well casing materials should also be durable enough to withstand galvanic or electrochemical corrosion and chemical degradation. Metallic casing materials are most subject to corrosion and thermoplastic casing materials are most subject to chemical degradation. In addition, casing materials should not exhibit a tendency to either sorb (take constituents out of solution by either adsorption or absorption) or leach chemical constituents from or into the water that is sampled from the well. If casing materials sorb selected constituents, the water-quality sample will not be representative. The three most common types of casing materials are fluoropolymer materials, including polytetrafluoroethylene and tetrafluoroethylene; metallic materials, including carbon steel, galvanized steel, and stainless steel; and thermoplastic materials, including polyvinyl chloride and acrylonitrile butadiene styrene.

Well Screen

A well screen is a filtering device used to retain the primary or natural filter pack; usually a cylindrical pipe with openings of a uniform width, orientation, and spacing. It is often necessary to design the monitoring well with a well intake (well screen) placed opposite the zone to be monitored. The intake should be surrounded by materials that are coarser, have a uniform grain size, and have a higher permeability than natural formation material. This allows ground water to flow freely into the well from the adjacent formation material while minimizing or eliminating the entrance of fine-grained materials such as clay or sand, into the well.

A well screen design needs to consider: intake opening (slot) size, intake length, intake type, and corrosion and chemical degradation resistance. Proper sizing of monitoring well intake openings is one of the most important aspects of monitoring well design. The selection of the length of a monitoring well intake depends on the purpose of the well. Most monitoring wells function as both groundwater sampling points and piezometers[2] for a discrete interval. To accomplish these objectives, well intakes are typically 2 to 10 feet in length and only rarely equal or exceed 20 feet in length. The hydraulic efficiency of a well intake depends primarily on the amount of open area available per unit length of intake. The amount of open area in a well intake is controlled by the type of well intake and opening size. Many types of well intakes have been used in monitoring wells, including: the louvered (shutter-type) intake, the bridge-slot intake, the machine-slotted well casing, and the continuous-slot wire-wound intake.

Filter Pack

Filter pack is the material placed between the well screen and the borehole wall which allows ground water to flow freely into the

[2]A piezometer is a non-pumping well, generally of small diameter, used to measure the elevation of the water table.

well while filtering out fine-grained materials. In the construction of a monitoring well, distort the natural stratigraphic setting as little as possible. Hence, it may be necessary to filter-pack boreholes that are over-sized with regard to the casing and well intake diameter. The filter pack prevents formation material from entering the well intake and helps stabilize the adjacent formation. The filter-pack materials should be chemically inert to alleviate the potential for alteration of ground-water sample quality. Commonly used filter-pack materials include clean quartz sand, gravel, and glass beads. The filter pack should generally extend from the bottom of the well intake to approximately two to five feet above the top of the well intake, provided the interval above the well intake does not result in a hydraulic connection with an overlying zone.

Annular Seal

Annular space is the space between the casing and the borehole wall. Any annular space that is produced as a result of the installation of the well casing in a borehole provides a channel for vertical movement of water and/or contaminants unless the space is sealed. The annular seal in a monitoring well is placed above the filter pack in the annulus between the borehole and the well casing. The seal serves several purposes: to provide protection against infiltration of surface water and potential contaminants from the ground surface down the casing/borehole annulus; to seal off discrete sampling zones, both hydraulically and chemically; and to prohibit vertical migration of water. Such vertical movement can cause "cross contamination" which can influence the representativeness of ground-water samples. The annular seal may be comprised of several different types of permanent, stable, low-permeability materials including pelletized, granular or powdered bentonite, neat cement grout, and combinations of both. The most effective seals are obtained by using expanding materials that will not shrink away from either the casing or the borehole wall after curing or setting.

Surface Seal

A surface seal is an above-ground seal that protects a monitoring well from surface water and contaminant infiltration. Monitoring wells should have a surface seal of neat cement or concrete surrounding the well casing and filling the annular space between the casing and the borehole at the surface. The surface seal may be an extension of the annular seal installed above the filter pack or it may be a separate seal emplaced on top of the annular seal. The surface seal will generally extend to at least three feet away from the well casing at the surface and taper down to the size of the borehole within a few feet of the surface. In climates with alternating freezing and thawing conditions, the cement surface should extend below the frost depth to prevent potential well damage caused by frost heaving.

Surface Completions

Surface completions are protective casings installed around the well casing. Two types of surface completions are common for ground-water monitoring wells: above-ground completion, and flush-to-ground completion. The primary purposes of either type of completion are to prevent surface run-off from entering and infiltrating down the annulus of the well and to protect the well from accidental damage or vandalism. In an above-ground completion, the preferred alternative, a protective casing is generally installed around the well casing by placing the protective casing into the cement surface seal while it is still wet and uncured. The protective casing discourages unauthorized entry into the well, prevents damage by contact with vehicles, and reduces

degradation caused by direct exposure to sunlight. The protective casing should be fitted with a locking cap and installed so that there is at least one to two inches clearance between the top of the in-place inner well casing cap and the bottom of the protective casing locking cap when in the locked position. Like the inner well casing, the outer protective casing should be vented near the top to prevent the accumulation and entrapment of potentially explosive gases and to allow water levels in the well to respond naturally to barometric pressure changes. Additionally, the outer protective casing should have a drain hole installed just above the top of the cement level in the space between the protective casing and the well casing. This drain allows trapped water to drain away from the casing. In high-traffic areas or in areas where heavy equipment may be working, consider the installation of additional protection such as "bumper guards." Bumper guards are brightly-painted posts of wood, steel, or some other durable material set in cement and located within three or four feet of the well.

b. Well Installation

To ensure collection of representative ground-water samples, the well intake, filter pack, and annular seal must be properly installed. In cohesive unconsolidated material or consolidated formations, well intakes should be installed as an integral part of the casing string by lowering the entire unit into the open borehole and placing the well intake opposite the interval to be monitored. Centralizing devices are typically used to center the casing and intake in the borehole to allow uniform installation of the filter pack material around the well intake. There are other standardized techniques to ensure the proper installation of wells in non-cohesive, unconsolidated materials, such as a casing hammer, a cable tool technique, the dual-wall reverse-circulation method, or installation through the hollow stem of a hollow-stem auger.

c. Well Development

Monitoring well development is the removal of fine particulate matter, commonly clay and silt, from the geologic formation near the well intake. If particulate matter is not removed, as water moves through the formation into the well, the water sampled will be turbid, and the viability of the water quality analyses will be impaired. When pumping during well development, the movement of water is unidirectional toward the well. Therefore, there is a tendency for the particulates moving toward the well to "bridge" together or form blockages that restrict subsequent particulate movement. These blockages may prevent the complete development of the well capacity. This effect potentially impacts the quality of the water entering the well. Development techniques should remove such bridges and encourage the movement of particulates into the well. These particulates can then be removed from the well by bailer or pump and, in most cases, the water produced will subsequently be clear and non-turbid. In most instances, monitoring wells installed in consolidated formations can be developed without great difficulty. Monitoring wells also can usually be developed rapidly and without great difficulty in sand and gravel deposits. However, many installations are made in thin, silty, and/or clayey zones. It is not uncommon for these zones to be difficult to develop sufficiently for adequate samples to be collected.

5. Duration and Frequency of Monitoring

The duration of ground-water monitoring will depend on the length of the active life of the waste management unit and of its post-closure care period. Continued monitoring after a waste management unit has closed is

important because the potential for contaminant releases remains even after a unit has stopped receiving waste.

The ground-water monitoring program establishes the frequency of sampling. Monitoring frequency should be sufficient to allow detection of ground-water contamination. This frequency usually ranges from quarterly to annually. The ground-water monitoring program also establishes a list of constituents, based on the specifics of the site, whose levels are monitored to indicate if the site's ground-water quality is changing.

What site characteristics should be evaluated to determine the frequency of monitoring?

Ground-water flow velocity is important in establishing an appropriate ground-water monitoring frequency to ensure that samples collected are physically and statistically independent. For example, in areas with high ground-water flow velocity, more frequent monitoring may be necessary to detect a release before it migrates and contaminates large areas. In areas with low flow velocity, less frequent monitoring may be appropriate. Analyze background ground-water conditions, such as flow directions and velocities and seasonal ground-water fluctuations, to help determine a suitable monitoring frequency for a site. Consult with the state agency to determine an appropriate monitoring frequency. In the absence of state requirements, it is recommended that semi-annual monitoring be conducted to detect contamination as part of a basic monitoring program.

6. Sampling Parameters

Selection of parameters to be monitored in a ground-water monitoring program is based on the characteristics of waste in the management unit. Additional sampling and analysis information can be found in EPA SW-846 *Test Methods for Evaluating Solid Waste* and in ASTM's standards. Appendix I, Section A.1 identifies 18 ASTM guides and practices for performing waste characterization and sampling.

What are sampling parameters?

Analyzing a large number of ground-water quality parameters in each sampling episode can be costly. To minimize expense, select only contaminants that can be reasonably expected to migrate to the ground water and other geochemical indicators of contaminant migration. These are called sampling parameters. Sampling parameters should provide an early indication of a release from a waste management unit. Once contamination is detected, consider expanding the original sampling parameters and monitor for additional constituents to fully characterize the chemical makeup of the release.

What sampling parameters should be used?

Initially analyze a broader range of parameters to establish background ground-water quality and use the results to select the sampling parameters to be monitored subsequently at a site. Due to the broad universe of industrial solid waste, it is not possible to recommend a list of indicator parameters that are capable of identifying every possible release. Table 2 lists potential parameters for a basic ground-water monitoring program, by different categories. Modify these parameters, as appropriate, to address site-specific circumstances.

Use knowledge of the actual waste streams or existing analytical data as a preliminary guide for what should be monitored, or use leachate sampling data to select or

Table 2
Potential Parameters for basic Ground-Water Monitoring
(Potential Parameters Should be Selected Based on Site-Specific Circumstances)

Category	Specific Parameters
Field-Measured Parameters	Temperature pH Specific electrical conductance Dissolved oxygen Eh oxidation-reduction potential Turbidity
Leachate Indicators	Total organic carbon (TOC-filtered) pH Specific conductance Manganese (Mn) Iron (Fe) Ammonium (NH_4 as N) Chloride Sodium (Na) Biochemical oxygen demand (BOD) Chemical oxygen demand (COD) Volatile organic compounds (VOCs) Total Halogenated Compounds (TOX) Total Petroleum Hydrocarbons (TPH) Total dissolved solids (TDS)
Additional Major Water Quality Parameters	Bicarbonate (HCO_3) Boron (Bo) Carbonate Calcium (Ca) Fluoride (Fl) Magnesium (Mn) Nitrate (as N) Nitrogen (dissolved N_2) Potassium (K) Sulfate (SO_2) Silicon (H_2SiO_4) Strontium (Sr) Total dissolved solids (TDS)
Minor and Trace Inorganics	Initial background sampling of inorganics for which drinking water standards exist (arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver); ongoing monitoring of any con-constituents showing background near or above drinking water standards

Table 3
Factors Affecting Number of Wells Per Location (CLUSTER)

Monitoring Component	Recommended Minimum
Number of Wells	Minimum 1 upgradient and 3 downgradient.[3]
Point of Monitoring	As appropriate for site conditions and waste management unit boundary or out to 150 meters downgradient of the waste management unit area.[4]
Duration of Monitoring	Active life plus post-closure care.
Frequency of Monitoring	Semi-annual during active life.[5]
Sampling Parameters	Metal and organic scans, use of indicators, leachate analysis, and/or knowledge of the waste. See Table 2

adjust sampling parameters. Where there is uncertainty concerning the chemistry of the waste, perform metal and organic scans at a minimum. Consult with the state agency to ensure that appropriate sampling parameters are selected.

What are the minimum components of a basic monitoring program?

Table 3 summarizes the recommended minimum components of a basic ground-water monitoring program described above. Potential modifications to the basic monitoring program that may be appropriate based on site-specific waste management unit conditions are discussed later in this chapter.

C. Sampling and Analytical Protocols and Quality Assurance and Quality Control

The best designed monitoring program will not provide useful data without sound sampling and analytical protocols. Sampling and analytical protocols are generally contaminant specific. A correctly designed and implemented sampling and analysis protocol ensures that sampling results accurately represent ground-water quality and can be compared over time. The accurate representation is achieved through statistical analysis.

Whether an established quality assurance and quality control (QA/QC) program is required on a federal, state, or local level, it is a good management practice to develop and strictly implement such a plan. The sampling protocol should incorporate federal, state,

[3]The actual number of both upgradient and downgradient wells will vary from unit-to-unit and will depend on the actual site-specific conditions.

[4]Rationale for discussion that point of monitoring could be out to 150 meters from a unit's boundary was for consistency with the 40 CFR Part 258 criteria.

[5]Also, ground-water flow rate may dictate that more or less frequent monitoring may be appropriate. More frequent monitoring might be appropriate at the start of a monitoring program to establish background. Less frequent and/or reduced in scope monitoring may also be appropriate during the post-closure care period.

and local QA/QC requirements. Ground-water sampling QA/QC procedures detail steps for collection and handling of ground-water samples. Sample collection, preservation, shipment, storage, and analysis should be performed in accordance with an approved QA/QC program to ensure data of known quality are generated.

Rely on qualified professionals who are properly trained to conduct sampling. Poorly-conducted sampling may give false evidence of a contamination problem or can miss early warnings of contaminant leaching. Erring in either direction is an avoidable and costly mistake.

At a minimum, include the following in your sampling protocol:

- Data quality objectives including lists of important tracking parameters, such as the date and name of samples;
- Sample collection procedures, including description of well purging methods, lists of necessary field analyses, and sample withdrawal method;
- Instructions for sample preservation and handling;
- Other QA/QC procedures such as chain-of-custody; and
- The name of the person who conducted the sampling.

States have developed guidance documents addressing sampling plans, protocols, and reports. Work with the state to develop an effective sampling protocol.

1. Data Quality Objectives

In any sampling and analysis plan, it is important to understand the data needs for a ground-water monitoring program. Tailoring sampling protocol and analytical work to data needs ensures cost-efficient sampling. A sampling and analysis plan should specify: (1) clear objectives (such as what data is needed and how the data is to be used); (2) lists of target contaminants; and (3) level of accuracy requirements for data to be conclusive. Chapter 1 of EPA SW-846 *Test Methods for Evaluating Solid Waste* and ASTM Guide D5792 provide guidance on developing data quality objectives for waste management activities.

2. Sample Collection

Sample collection techniques should be carefully designed to ensure sampling quality and avoid cross-contamination or background contamination of ground-water samples. Appendix I, Section A.4 lists ASTM guides for ground-water sampling. Consider the following factors when preparing for sample collection.

- **Well Inspection.** Check the wells for cracks and/or loose casings.
- **Water Elevation.** Take water level elevation measurements and calculate the amount of stagnant water that needs to be purged.
- **Well Purging.** Because the water standing in a well prior to sampling may not represent in situ ground-water quality, purge

a sufficient volume of stagnant water from each monitoring well and filter pack prior to sampling. Purging should remove standing ground water from the well at low flow rates. A low purge rate will reduce the possibility of stripping VOCs from the water and will reduce the likelihood of mobilizing colloids in the sub-surface. (See *Low Flow Ground Water Sampling*, EPA540-S-95-504, for additional information on low flow well purging and sampling techniques to improve representativeness of ground-water samples.)

- **Sample Withdrawal and Collection.** The equipment used to withdraw a ground-water sample from a well should be appropriate for the monitoring parameters. Sampling equipment should cause minimal agitation of the sample and reduce or eliminate contact between the atmosphere and the sample during transfer to ensure a sample is representative of the ground water.
- **Field Analysis.** Some constituents or parameters may be physically or chemically unstable and should be tested at the well site rather than waiting for shipment to a laboratory. Examples of unstable parameters include pH, redox (oxidation-reduction) potential, dissolved oxygen, temperature, and specific conductance.

3. Sample Preservation and Handling

Sample preservation and handling protocols are designed to minimize alterations of the chemistry of water quality samples between the time the sample is collected and when it is analyzed. Consider the following.

- **Sample Containers.** To avoid altering sample quality, transfer samples from the sampling equipment directly into a contaminant free container. U.S. EPA SW-846, identifies proper sample containers for different constituents. Samples should never be combined in a common container and then split later in the field.

- **Sample Preservation.** The time between sampling and sample analysis can range from several hours to several weeks. Immediate sample preservation and storage assists in maintaining the natural chemistry of the samples. Refer to the latest edition of SW-846 for specific preservation methods and holding times for each constituent analyzed. SW-846 recommends preservation methods, such as pH adjustment, chemical addition, and refrigeration.
- **Sample Transport.** To document sample possession from the time of collection to the laboratory, include a chain-of-custody record in every sample shipment. A chain-of-custody record generally includes the date and time of collection, signatures of those involved in the chain of possession, time and dates of possession, and other notations to trace samples.

4. Quality Assurance and Quality Control

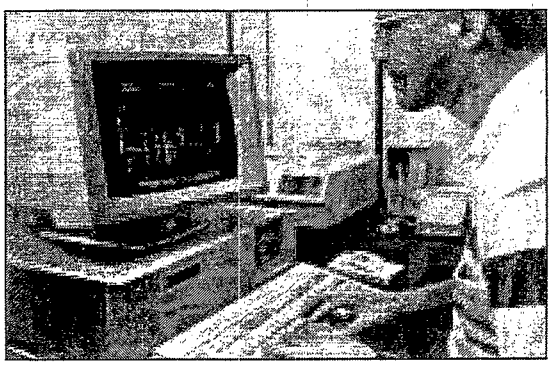
To verify the accuracy of field sampling procedures, collect field quality control samples, such as trip blanks, equipment blanks, and duplicates. Analyze quality control samples for the required monitoring parameters.

Other QA/QC practices include sampling equipment calibration, equipment decontamination, and use of chain-of-custody forms. ASTM Guide D-5283 provides guidance on QA/QC planning and implementation for waste management activities. Chapter 1 of SW-846 also provides guidance on QA/QC practices.

5. Analytical Protocols

Ground-water monitoring programs should employ analytical methods that accurately measure the constituents being monitored. SW-846 recommends specific analytical methods to test for various constituents. Similarly, individual states may recommend other analytical methods for ground-water analysis.

Ensure the reliability and validity of analytical laboratory data as part of the ground-water monitoring program. Most facility managers use commercial laboratories to conduct analyses of ground-water samples; others may use their own internal laboratories if they are equipped and qualified to perform such analyses. In selecting an analytical laboratory, check for the following: laboratory certification by a state or professional association for the type of analyses needed; qualified lab personnel; good quality analytical equipment with back-up instrumentation; a laboratory QA/QC program; proper lab documentation; and adherence to standard procedures for data handling, reporting, and record keeping. Laboratory QA/QC programs should describe chain-of-custody procedures, calibration procedures and frequency, analytical standard operating procedures, and data validation and reporting procedures. A good QA/QC program helps ensure the accuracy of laboratory data.



D. Analysis of Monitoring Data, Contingency Planning, and Assessment Monitoring

Once ground-water monitoring data have been collected, analyze the data to determine whether contaminants are migrating in the subsurface from a waste management unit. Develop a contingency plan to address the situations where contamination is detected.

1. Statistical Approaches

Statistical procedures should be used to evaluate ground-water monitoring data and determine if there is evidence of a release from a waste management unit. Anomalous data may result from sampling uncertainty, laboratory error, or seasonal changes in natural site conditions. Qualified statistical professionals can determine if statistically significant changes in water quality have occurred or whether the quantified differences could have arisen solely because of one of the above-listed factors. After consulting with the state agency and statistical professional and selecting a statistical approach, continue to use the selected method in all statistical analyses. Do not switch to a different test when the first method generates unfavorable results.

What is important in selecting a statistical approach?

An appropriate statistical approach will minimize false positives or negatives in terms of potential releases. The approach should account for historical data, site hydrogeologic conditions, site operating practices, and seasonal variations. While there are numerous statistical approaches used to evaluate ground-water monitoring data, check with the state to determine if a specific statistical approach is recommended.

Common methods for evaluating ground-water monitoring data include the following statistical approaches:

- **Parametric analysis of variance (ANOVA).** This analysis, as well as rank-based (non parametric) ANOVA, attempts to determine whether different wells have significantly different average concentrations of constituents.
- **Tolerance intervals.** Tolerance intervals are statistical intervals constructed from data designed to contain a portion of a population, such as 95 percent of all sample measurements. These intervals can be used to compare data from a downgradient well to data from an upgradient well.
- **Prediction intervals.** These intervals approximate future sample values from a population or distribution with a specific probability. Prediction intervals can be used both for comparison of downgradient wells to upgradient wells (inter-well comparison) and for comparison of current well data to previous data for the same well (intra-well comparison).
- **Control charts.** These charts use historical data for comparison purposes and are, therefore, only appropriate for initially uncontaminated wells.

There are many different ways to select an appropriate statistical method. More detailed guidance on statistical methods for ground-water contaminant detection monitoring can be found in U.S. EPA *Addendum to Interim Final Guidance Document on Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities* (EPA530-R-93-003), U.S. EPA *Guidance Document on Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities-Interim Final Guidance*, and ASTM provisional guide PS 64-96 (Appendix I, Section A.8.1).

2. Contingency Planning

Contingency plans identify the procedures to follow if a statistically significant increase in one or more contaminants has been detected. A contingency plan should include procedures to determine whether an increase in sample concentrations was caused by the waste management unit or by unrelated factors; procedures for developing and conducting an assessment monitoring program; procedures for remediating the waste management unit to stop the release of contaminants; and a determination of the magnitude of contamination that would require initiation of corrective action, such as a statistical exceedance of an MCL or HBN.

3. Assessment Monitoring

The purpose of assessment monitoring is to evaluate the rate, extent, and concentrations of contamination. Once a statistically significant increase has been confirmed for one or more of the sampling parameters, determine whether the increase was caused by factors unrelated to the unit. Factors unrelated to the unit that may cause an increase in the detected concentration(s) are:

- Contaminant sources other than the waste management unit being monitored;

- Natural variations in ground-water quality;
- Analytical errors;
- Statistical errors; and
- Sampling errors.

If the increase was caused by a factor unrelated to the unit, then additional measures may not be necessary and the original ground-water monitoring program can be resumed. If, however, these factors have been ruled out, begin an assessment monitoring program. Consult with the state agency to determine the type of assessment monitoring to conduct at the unit. Assessment monitoring typically involves resampling all wells, both upgradient and downgradient, and analyzing the samples for a larger list of parameters than used during the basic ground-water monitoring program. More than one sampling event may be necessary and additional monitoring wells may need to be installed to adequately determine the scope or extent of any contamination. Work with state officials to establish background concentrations and ground-water protection standards for all additional constituents that were detected during assessment monitoring.

If assessment monitoring results indicate there is not a statistically significant increase in the concentrations of one or more of the constituents over the established ground-water protection standards, then resume the original ground-water monitoring program. If, however, there is a statistically significant increase in any of these constituents, consult with state officials to identify the next steps. Typically, it may be necessary to install additional monitoring wells to characterize the nature and extent of the contamination and to notify persons who own or reside on the land that directly overlies any part of the plume of contamination if it has migrated beyond the facility boundary.

Detection of contamination may be an indicator that the design of a waste management unit is not working properly. During this assessment phase, component(s) of the unit (cover, liner, or leachate collection system) that are not working properly should be determined and, if possible, remediated. Sometimes sealing a hole in the liner of a small surface impoundment may be sufficient to stop the source of contamination. Other times, more extensive response may be required. One example could be the subsidence of a unit's final cover creating a hole that requires repairing of the final cover. Evaluation of other remedial alternatives, as discussed in the corrective action chapter, may become necessary if waste system components can not be remediated.

E. Potential Modifications to a Basic Ground-Water Monitoring Program

It may be appropriate to modify certain elements of a basic ground-water monitoring program described above to accommodate site specific circumstances. When using the IWEM software to evaluate the need for a liner system, if the recommendation is to use a composite liner, then the basic ground-water monitoring program should probably be enhanced. If the recommendation using the software is that no liner is appropriate, then it may be possible to scale back some aspects of the basic ground-water monitoring program.

Components that may be subject to modification include the duration and frequency of monitoring, sampling parameters, and the use of vadose zone monitoring. Possible modifications of these elements are discussed further below. Consult with state officials on their requirements for ground-water monitoring programs. In some states, a unit may be eligible for a no-migration exemption from the state's ground-water monitoring requirements.

1. Duration and Frequency of Monitoring

The duration of monitoring (active life plus post-closure care) is not likely to be modified in either a reduced or an enhanced ground-water monitoring program. Adjustments to the frequency of monitoring, however, may be appropriate, based primarily on the mobility of contaminants and ground-water velocity. For example, if the sampling parameters are slow moving metals, annual rather than semi-annual monitoring may be appropriate. Conversely, quarterly monitoring might be required at a unit with a rapid ground-water flow rate or a mobile contaminant such as cyanide over a permeable sand and gravel aquifer.

2. Sampling Parameters

The basic recommended ground-water monitoring program already recommends the use of a parameter list that is tailored to the waste characteristics and site hydrogeology. Where the use of the IWEM software indicates no liner is appropriate, it may be possible to reduce the list of parameters routinely analyzed in downgradient wells to only a few indicator parameters. More complete analysis would only be initiated if concentrations of the indicator parameters indicate that contaminant movement has occurred.

3. Vadose Zone Monitoring

Vadose zone monitoring detects migration of contaminants before they reach ground water, serving as an early warning system if a waste management unit is not functioning as designed. The vadose zone is the region between the ground surface and the saturated zone. Depending on climate, soils, and geology, the vadose zone may range in thickness from several feet to hundreds of feet. Vadose zone monitoring provides three main potential benefits: (1) early warning of contaminant migration before it reaches the ground water, (2) reduced time and cost of remediation, and (3) possible reduction in ground-water monitoring efforts. If site conditions permit, it may be desirable to include vadose zone monitoring as part of the overall ground-water monitoring program. If vadose zone monitoring is incorporated, the recommended number of ground-water monitoring wells would still be determined by the basic ground-water monitoring program, and background quality would still need to be characterized with ground-water monitoring. The ground-water monitoring program becomes a backup, however, with full use only being initiated if contaminant migration is detected in the vadose zone.

The sections below describe some of the commonly used methods for vadose zone monitoring, vadose zone characterization, and elements to consider in the design of a vadose zone monitoring system.

a. Vadose Zone Monitoring Methods

There are dozens of specific techniques for indirect measurement and direct sampling of the vadose zone. The more commonly used methods with potential value for waste management units are described briefly below.

Soil Water and Tension Monitoring

Measuring changes in soil water content,

or soil water tension over time is a relatively simple and inexpensive method for leak detection. Periodic measurements of soil water content or soil moisture tension beneath a lined waste management unit should show only small changes. Significant increases in water content or decreases in soil moisture tension would indicate a leak.

What method should be used to measure soil moisture?

Soil moisture characteristics can be measured in two main ways: (1) water content, usually expressed as weight percentage, and (2) soil moisture tension or suction, which measures how strongly water is held by soil particles due to capillary effects. As soil water content increases, soil moisture tension decreases. Measurements will not indicate, however, whether contaminants are present.

Figure 2 shows three major methods that are available for in-situ monitoring of soil moisture changes. Porous cup tensiometers (Figure 2a) measure soil moisture tension, with the pressure measurements indicated by either a mercury manometer, a vacuum gauge, or using pressure transducers. Soil moisture resistivity sensors (Figure 2b) measure either water content or soil moisture tension (depending on how they are calibrated). Time domain reflectometry probes (Figure 2c) measure water content using induced electromagnetic currents. For vadose zone monitoring applications, the devices are usually placed during construction of a waste management unit and electrical cables run to one or more central locations for periodic measurement.

The other commonly used method for monitoring soil water content is to use neutron or dielectric probes. These require placement of access tubes, through which probes are lowered or pulled, and allow continuous measurement of changes in water content along the length of the tubes.

Soil-Pore Liquid Sampling

Sampling and analysis of soil-pore liquids can determine the type and concentration of contaminants that may be moving through the vadose zone. Soil-pore liquids can be collected by applying either a vacuum that exceeds the soil moisture tension, commonly done using vacuum or pressure-vacuum lysimeters, or by burying collectors that intercept drain water. Figures 3a and 3b illustrate different methods for collecting soil-pore liquids.

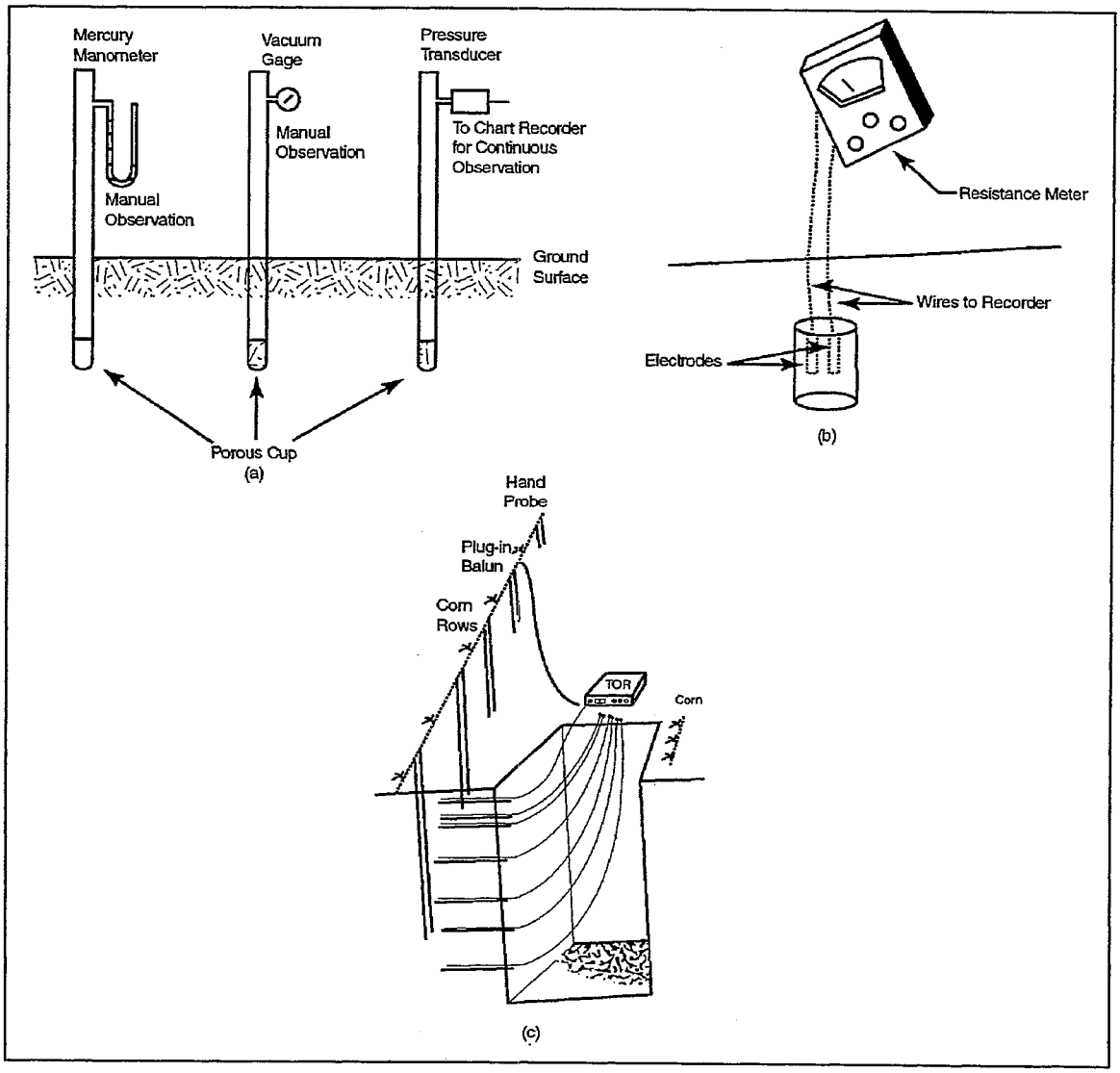
Soil Gas Sampling

Soil gas sampling is a relatively easy and inexpensive way to detect the presence or movement of volatile contaminants and gases associated with degradation of waste within a waste management unit, such as carbon dioxide and methane. Of particular concern are gases associated with the breakdown of organic materials and toxic organic compounds. Permanent soil gas monitoring installations consist of a probe point placed above the water table, a vacuum pump which draws soil gas to the surface, and a syringe used to extract the gas sample, as shown in Figure 4a. Installing soil gas probes at multiple levels, as shown in Figure 4b, allows detection of downward or upward migration of soil gases.

b. Vadose Zone Characterization

Just as the design of ground-water monitoring systems requires an understanding of the ground-water flow system, the design of vadose zone monitoring systems requires an understanding of the vadose zone flow system.

Figure 2. Major Methods for In-Situ Monitoring of Soil Moisture or Matrix Potential

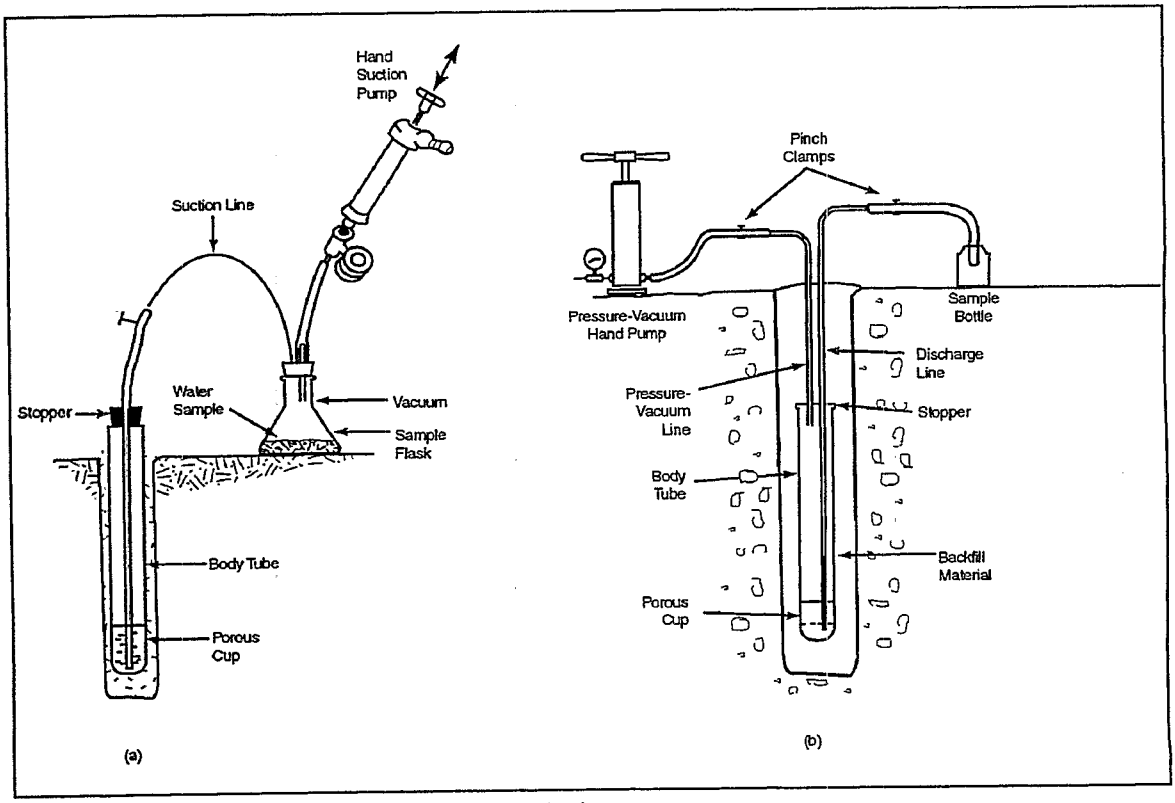


(a) Three Types of Porous Cup Tensiometers, (b) Resistance Sensors, and (c) Time Domain Reflectometry Probes

Sources: (a) Morrison, 1983. (b) U.S. EPA, 1993. (c) Topp and Davis, 1985, by permission.

For example, in ground-water systems, hydraulic conductivity does not change over time at a particular location, whereas in the vadose zone, hydraulic conductivity changes with soil water content and soil moisture tension. To estimate the speed with which water will move through the vadose zone, the relationship between soil water content, soil moisture tension, and hydraulic conductivity should be measured or estimated. Unsaturated zone numerical modeling programs, such as HYDRUS 2-D or Seep (2-D) are designed to characterize the vadose zone.

Figure 3. Example Methods for Collecting Soil-Pore Samples



(a) Vacuum Lysimeter, (b) Pressure-Vacuum Lysimeter
Source: ASTM, 1994. Copyright ASTM. Reprinted with permission.

c. *Vadose Zone Monitoring System Design*

A vadose zone monitoring system combined with a ground-water monitoring system may reduce the cost of corrective measures in the event of a release. Remedial action is usually easier and less expensive if employed before contaminants reach the ground-water flow system.

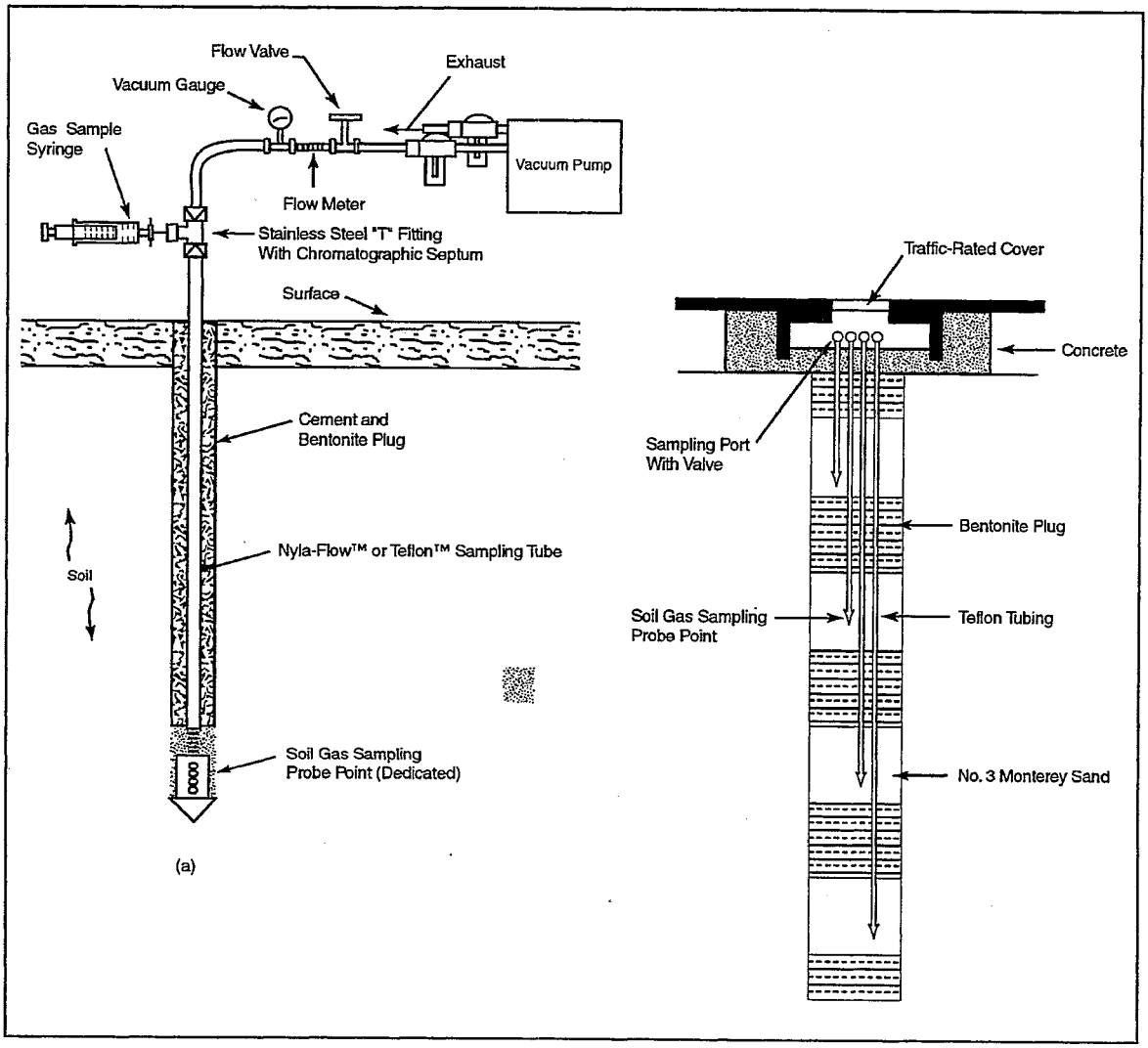
The design and installation of a vadose zone monitoring system are easiest with new waste management facilities, where soil water monitoring and sampling devices can be placed below the site. Relatively recent improvements in horizontal drilling technology, however, now allow installation of access tubes for soil moisture monitoring beneath existing facilities.

Important factors in choosing the location and depth of monitoring points in a leak detection network include: (1) consideration of the potential area of downward leakage, and (2) determination of the effective detection area of the monitoring device.

Cullen et al. (1995) suggest an approach to vadose zone monitoring that includes the following:

- Identification and prioritization of critical areas most vulnerable to contaminant migration;
- Selection of indirect monitoring methods that provide reasonably comprehensive coverage and cost-effective, early warning of contaminant migration;

Figure 4. Soil Gas Sampling Systems



(a) Gas Sampling Probe and Sample Collection Systems, (b) Typical Installation of Nested Soil Gas Probes

Source: Reprinted with permission from Wilson, et al., *Handbook of Vadose Zone Characterization and Monitoring*, 1995. Copyright CRC Press, Boca Raton, Florida.

- Selection of direct monitoring methods that provide diagnostic confirmation of the presence and migration of contaminants;
- Identification of background monitoring points that will provide hydrogeologic monitoring data representative of preexisting site conditions; and
- Identification of a cost-efficient, temporal monitoring plan that will provide early warning of contaminant migration in the vadose zone.

This approach is very similar to what is described for the basic ground-water monitoring program.

II. Surface-Water Monitoring

Controlling storm-water run-on and run-off from industrial waste units in order to minimize surface-water contamination is another waste management responsibility. Surface-water sampling identifies the types and amounts of pollutants present, and can help determine whether existing storm-water controls are adequate. Sampling guidance may be obtained from EPA's *NPDES Storm Water Sampling Guidance Document* (EPA833-B-92-001) and *Interim Final RCRA Facility Investigation (RFI) Guidance: Volume III* (EPA530-SW-89-031). In addition, states also have guidance on appropriate sampling methods. If a facility is subject to a federal or state storm-water permit that requires sampling, collect and analyze samples according to the permit. Otherwise, consider implementing a sampling program to monitor the quality of run-off and the performance of best management practices (BMPs). For further information on BMPs relating to surface-water controls, refer to the chapter on protecting surface water. Implementing BMPs, along with regular maintenance inspections, will greatly reduce the potential for surface-water contamination.

Due to the variable nature of storm-water flows during a rainfall event, and the different analytical considerations for certain constituents, the quality of storm-water discharges and sampling requirements for different unit types and locations will vary as well. Outlined below are the requirements for general sampling procedures to be considered when preparing a sampling strategy for a site.

Sample a representative storm. Using climatic data, determine the average depth and duration of rainfall events at a site. Sample during a rainfall event that is between 50 and 150 percent of average depth and duration. The storm should be preceded by at least 72 hours of dry weather. Collect individual grab samples during the first flush–the first 30 minutes of the event–and collect composite samples over the first 3 hours or the entire event if less than 3 hours. These guidelines ensure that pollutants in the sampled run-off will not be so concentrated or so dilute as to be unrepresentative of the overall run-off.

Sample Type. Take grab and composite samples as needed to properly characterize storm-water run-off. A grab sample is a discrete, individual sample taken within a short period of time, usually less than 15 minutes. Analysis of a grab sample characterizes the quality of a storm water-discharge at the time the sample was taken. These types of samples can be used to characterize the maximum concentration of a pollutant in the discharge. A composite sample is a mixed or combined sample that is formed by combining a series of individual and discrete samples of specific volumes at specified intervals. These intervals can be either time-weighted or flow-weighted. Time-weighted composite samples are collected and combined in proportion to time, while flow-weighted composite samples are combined in proportion to flow. Composite samples characterize the quality of a storm-water discharge over a specific period of time, such as the duration of a storm event.

Sample Techniques. Grab and composite samples can be collected by either manual or automatic sampling techniques. Manual samples are simply collected by hand, while automatic samples are collected by powered devices according to preprogrammed criteria. Both techniques have advantages and disadvantages that need to be weighed when choosing a sampling technique for a specific site. The advantages of manual sampling include its appropriateness for all constituents and its lower cost compared to

automatic sampling. Manual sampling , however, can be labor intensive, expose personnel to potentially hazardous conditions, and is subject to human error. The advantages of automatic sampling are the convenience it offers, its minimum labor requirements, its reduction of personnel exposure to hazardous conditions, and its low risk of human error. Unfortunately, automatic sampling is not suitable for all constituent types. Volatile organic compounds (VOCs), for example, can not be sampled automatically due to the agitation during sample collection. This agitation can cause the VOC constituents to completely volatilize from the sample. Other constituents such as fecal streptococcus, fecal coliform, and chlorine may not be amenable to automatic sampling either due to their short holding times. Since sample temperature and pH need to be measured immediately, the option for using automatic sampling for these parameters may be limited as well. Automatic sampling also can be expensive, and does require a certain amount of training.

Sample at the outfall point. Storm-water samples should be taken at a storm-water point source. A "point source" is defined as any discernible, confined, and discrete conveyance. The ideal sampling location is the lowest point in a drainage area where a conveyance discharges, such as the discharge at the end of a pipe or ditch. The sample point should be easily accessible on foot and in a location that will not cause hazardous sampling conditions. Do not sample during dangerous wind, lightning, flooding, or other unsafe conditions. If these conditions are unavoidable during an event, then the sampling should be delayed until a less hazardous event occurs. Preferably, the sampling location will be located on-site, but if it is not, obtain permission from the owner of the property where the discharge is located. Inaccessible discharge points, numerous small point discharges, run-on from other property, and infinite other scenarios may cause logistical problems with sampling locations. If the discharge is inaccessible or not likely to be representative of the run-off, samples may need to be taken at a point further upstream of the discharge pipe or at several locations to best characterize site run-off.

Coordinate with the laboratory. Be sure to collect adequate sample volumes to complete all necessary analyses. When testing for certain pollutants, samples may need to be cooled and/or otherwise preserved until analyzed to yield meaningful results. Section 3.5 of EPA's *NPDES Storm Water Sampling Guidance Document* (EPA833-B-92-001) contains information on proper sample handling and preservation procedures. Submitting the proper information to the laboratory also is important in ensuring proper sample handling by the laboratory. Proper sample documentation guidelines are outline in the section 3.7 of the *NPDES Storm Water Sampling Guidance Document.* Coordination with the laboratory that will be performing the analysis will ensure that these issues are adequately addressed.

Follow all sampling requirements in a storm water permit. If there are no sampling requirements, analyze samples for basic constituents, such as oil and grease, pH, biochemical oxygen demand, chemical oxygen demand, total suspended solids, phosphorus, and nitrogen, as well as any other pollutant known or suspected to be present in the waste.

III. Soil Monitoring

Soil monitoring helps characterize soil properties at a proposed land application unit site and monitors the performance of a land application unit. Characterizing the soil properties at a land application site helps determine application rates that maximize waste assimilation.

Table 4
Comparison of Manual and Automatic Sampling Techniques

Sample Method	Advantages	Disadvantages
Manual Grabs	Appropriate for all pollutants Minimum equipment required	Labor-intensive Environment possibly dangerous to field personnel May be difficult to get personnel and equipment to the storm water outfall within the 30 minute requirement Possible human error
Manual Flow-Weighted Composites (multiple grabs)	Appropriate for all pollutants Minimum equipment required	Labor-intensive Environment possibly dangerous to field personnel Human error may have significant impact on sample representativeness Requires flow measurements taken during sampling
Automatic Grabs	Minimizes labor requirements Low risk of human error Reduced personnel exposure to unsafe conditions Sampling may be triggered remotely or initiated according to present conditions	Samples not collected for O&G may not be representative Automatic samplers cannot properly collect samples for VOCs analysis Costly if numerous sampling sites require the purchasse of equipment Requires equipment installation and maintenance Requires operator training May not be appropriate for pH and temperature May not be appropriate for parameters with short holding times (e.g., fecal streptococcus, fecal coliform, chlorine) Cross-contamination of aliquot if tubing/bottles not washed
Automatic Flow-Weighted Composites	Minimizes labor requirements Low risk of human error Reduced personnel exposure to unsafe conditions May eliminate the need for manual compositing of aliquots Sampling may be triggered remotely or initiated according to on-site conditions	Not acceptable for VOCs sampling Costly if numerous sampling sites require the purchase of equipment Requires equipment installation and maintenance, may malfunction Requires initial operator training Requires accurate flow measurement equipment tied to sampler Cross-contaminaton of aliquot if tubing/bottles not washed

Source: U.S. EPA, 1992.

To obtain site-specific data on actual soil conditions, sample and characterize the soil. The number and location of samples necessary for adequate soil characterization is primarily a function of the variability of the soils at a site. If the soil types occur in simple patterns, a composite sample of each major type can provide an accurate picture of the soil characteristics. The depth to which the soil profile is sampled, and the extent to which each horizon is vertically subdivided, will depend on the parameters to be analyzed, the vertical variations in soil character, and the objectives of the soil sampling program. Rely on a qualified soil scientist to perform this characterization. Poorly conducted soil sampling may result in an inaccurate soil characterization which could lead to improper waste application and the unit's failure to properly attenuate applied waste.

Sampling Location and Frequency

Prior to sampling divide the unit into uniform areas, then collect representative samples from each area. One recommended approach is to divide the unit into areas no larger than 20 acres and collect at least one sample from each of these areas. These divisions should be based upon soil type, slope, degree of erosion, cropping history, known crop growth differences, and any other factors that may influence nutrient levels in the soil.

Each sample for a designated area consists of a predetermined number of soil cores. A soil core is an individual boring or coring at one spot in the field. The recommended number of cores per sample are 15-20 cores for a surface soil sample, and 6-8 cores for a subsurface sample. If using a soil probe, a single core may be separated into its horizontal layers to provide samples for each layer being analyzed. For example, a single core may be divided into three predefined layers such as surface soil, subsurface soil, and deep subsurface soil. For a designated area all the individual cores are combined, according to soil level, and mixed to provide a composite sample for the area. From the mixed cores a composite subsample should be taken and analyzed. Each grab sample may be analyzed individually, rather than combined as part of a composite sample (see below), but composite samples generally provide reliable data for soil characterization.

The soil core grab samples can be collected at random or in a grid pattern. Random collection generally requires the least amount of time, but cores need to be collected from the entire area to ensure reliable site characterization. When performed properly, random sampling will provide an accurate assessment of average soil nutrient and constituent levels. While the preparation required for collecting core samples in a grid pattern can be more costly and time consuming, it does ensure the entire area is sampled. One advantage of grid sampling is the ability to generate detailed nutrient level maps for a unit. This requires analysis of each individual grab sample from an area, rather than compositing samples. Analyzing each individual grab sample is time consuming and expensive, but software and computerized applicators are becoming available that can use this data to tailor nutrient application to soil needs.

Soil Sampling Equipment

There are a number of soil sampling devices available. A soil probe or tube is the most desirable as it provides a continuous core with minimal disturbance of the soil. Sample cores from a soil probe can be divided by depth and provide surface, subsurface, and deep subsurface samples from a single boring. Soil probes are not very effective when the soil is too wet, too dry, or frozen.

The presence of gravel in the soil will also prevent the use of a soil probe. When sampling excessively wet, dry, or frozen soils, or soils with gravel, a soil auger maybe used in place of a soil probe. The primary drawback of soil augers are their tendency to mix soils from different depths during sample collection, because of this use a soil auger only when the use of a soil probe is not possible. A spade also may be used for surface samples, but is not effective for subsurface sampling. Post-hole diggers may can be used for collecting deeper subsurface samples, but present the same mixing problem as soil augers. EPA's *Description and Sampling of Contaminated Soils: A Field Pocket Guide* (EPA625-12-91-002) contains a summary of hand-held and power-driven tube samplers. The summary outlines the recommended applications and limitations for each device.

Sample Collection

For initial soil characterization samples typically are taken from each distinct soil horizon down to a depth of 4-5 feet (120-150 cm). For example, a single core sample might provide the following four horizon sample: surface (0-6 inches), subsurface (6-18 inches), and two deep subsurface (18-30 inches and 30-42 inches). It is important to sample more than just the surface layer to get a complete soil characterization, and to determine if the land application is working. Sampling subsurface layers will show whether constituents are being removed and assimilated as expected and not leaching into subsurface layers or the groundwater. As a minimum practice, sample at least the upper soil layer (0 to 6 inches), and a deeper soil layer (18 to 30 inches for instance). Consult the local university extension service, county agricultural agent, or other experts for recommended soil sampling depths for the specific area in which the land application unit is located.

Once the samples have been taken they need to be prepared for chemical analysis. This typically is done by having the sample air dried, ground and mixed, and then passed through a 2 mm sieve as soon as possible after collection. If the samples are to be analyzed for nitrate, ammonia, or pathogens, then they should be refrigerated under moist field conditions and analyzed as soon as possible. For more information on sample handling and preparation refer to the "General Protocol for Soil Sample Handling and Preparation" section in EPA's *Description and Sampling of Contaminated Soils: A Field Pocket Guide* (EPA625-12-91-002). ASTM method D-4220 *Practices for Preserving and Transporting Soil Samples* also addresses proper sample handling protocols.

Obtain professional assistance from qualified soil scientists and laboratories to properly interpret soil samples. For more information on obtaining representative soil samples and submitting them for analysis, consult federal manuals, such as EPA's *Laboratory Methods for Soil and Foliar Analysis in Long-Term Environmental Monitoring Programs* (EPA600-R-95-077) or state guides, for example, *Nebraska's Guidelines for Soil Sampling, G991-1000.* The following ASTM methods may also prove helpful in soil sampling: D-1452 *Practice for Soil Investigation and Sampling by Auger Borings, D-1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils,* D-1587 *Practice for Thin-Walled Tube Sampling of Soils,* and D-3550 *Practice for Ring-Lined Barrel Sampling of Soils.*

Determine baseline conditions by sampling the soil before waste application begins. Subsequent sampling will depend on land use and any state or local soil monitoring requirements. Once waste is being applied to the land application unit, collect and analyze samples at regular intervals, or after a certain number of applications. Sample annually at a

minimum, or more frequently if appropriate. Analyze samples for macronutrients, micronutrients, and any constituents reasonably expected to be present in the waste. The location and number of sampling points, frequency of sampling, and constituents to be analyzed will depend on site-specific soil, water, plant, and waste characteristics. Local agricultural extension services, which have experience with designing soil sampling regimens, can assist in this area. Soil monitoring, especially when coupled with ground-water monitoring, can detect contamination problems. Early detection allows changes to be made to the land application process to remedy the problems, and to conduct corrective action if necessary. Finally, testing soils after the active life of the unit is a good idea to determine if any residues are left in the soil.

Sampling and Analytical Protocols and Quality Assurance and Quality Control

The best designed soil monitoring program will not provide useful data without sound sampling and analytical protocols. Sampling and analytical protocols are generally contaminant specific. A correctly designed and implemented sampling and analysis protocol ensures that sampling results accurately represent soil characteristics and can be compared over time. The accurate representation is achieved through statistical analysis.

Whether an established quality assurance and quality control (QA/QC) program is required on a federal, state, or local level, it is a good management practice to develop and strictly implement such a plan. The sampling protocol should incorporate federal, state, and local QA/QC requirements. Soil sampling QA/QC procedures detail steps for collection and handling of soil samples. Sample collection, preservation, shipment, storage, and analysis should be performed in accordance with an approved QA/QC program to ensure data of known quality are generated.

At a minimum, include the following in the sampling protocol:

- Data quality objectives;
- Sample collection procedures;
- Instructions for sample preservation and handling;
- Other QA/QC procedures such as chain-of-custody; and
- The name of the person who conducted the sampling.

States have developed guidance documents addressing sampling plans, protocols, and reports. Work with the state to develop an effective sampling protocol. Chapter 1 of EPA SW-846 *Test Methods for Evaluating Solid Waste* and ASTM Guide D-5792 provide guidance on developing data quality objectives for waste management activities.

Sample collection techniques should be carefully designed to ensure sampling quality and avoid cross-contamination of soil samples. Some constituents or parameters may be physically or chemically unstable and should be tested at the site rather than waiting for shipment to a laboratory. Examples of unstable parameters include pH, redox (oxidation-reduction) potential, dissolved oxygen, temperature, and specific conductance.

Sample preservation and handling protocols are designed to minimize alterations of the chemistry of samples between the time the sample is collected and when it is analyzed. Incorporate proper sample containers, sample preservation, and sample transport practices into the sampling plan. Quality assurance and quality control, and analytical protocols also are necessary to ensure the validity and reliability of the sample data.

IV. Air Monitoring

The development of appropriate air monitoring data can be technically complex and resource intensive. The Industrial Waste Air Model on the CD ROM version of this Guide provides a simple tool that relies on waste characterization information rather than actual air monitoring data, to evaluate risks from VOC emissions at a unit. The air modeling tool uses an emissions model to estimate emissions from a waste management unit based on the waste characterization. Review the protecting air chapter of this guide and the supporting background document developed for the air model to understand the limitations of the model and whether it is applicable to a specific unit. If the model is not appropriate for a specific site or if it indicates that there is a problem with VOC emissions, use an alternative (emissions) model which may be more appropriate for the site or consider air monitoring to gather more site specific data.

Air monitoring could take three different forms. Each type of monitoring provides data to use in air emission and dispersion modeling. The first involves measuring emissions from the unit using some type of collection device or by direct measurement.

The second form of air monitoring involves ambient air monitoring at selected locations around the unit or site. The data is used to monitor dispersion of airborne contaminants to the surrounding areas.

The third form of monitoring measures meteorological conditions at a site. This type of monitoring involves measurement of wind speed, wind direction, temperature, etc., because other off-site meteorological information does not adequately characterize the weather conditions at the site. This is most likely to occur for mountainous or hilly terrain or for a site near a large body of water. In addition, site-specific meteorological information is generally needed whenever emissions or ambient monitoring take place in order to make proper use of all the monitoring data. This information would be used for both emission and dispersion models.

Consult with air modeling professionals and the state and local authorities as well as EPA's Office of Air Quality and Standards in Research Triangle Park, NC before implementing an air monitoring program or choosing alternative emission and dispersion models.

If air monitoring is necessary to adequately characterize a site, the following references may be helpful:

Method 204D -Volatile Organic Compounds Emissions in Uncaptured Stream From Temporary Total Enclosures, 40 CFR Part 51, Appendix M.

Method 204E -Volatile Organic Compounds Emissions In Uncaptured Streams From Building Enclosures, 40 CFR Part 51, Appendix M.

Method 2E -Determination of Landfill Gas: Gas Production Flow Rate, 40 CFR Part 60, Appendix A.

Method 25C -Determination of Nonmethane Organic Compounds (NMOC) in MSW Landfill Gases, 40 CFR Part 60, Appendix A.

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Interim Final RCRA Facility Investigation (RFI) Guidance, Volume III (EPA530-SW-89-31).

Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber: Users' Guide (EPA600-8-86-008).

Monitoring Performing Action Items

Consider the following for each media when developing a monitoring program for industrial waste management units:

Ground Water

- ☐ Perform site characterization, including investigation of the site's geology, hydrology, and subsurface hydrogeology to determine areas for ground-water monitoring; and select parameters to be monitored based on the characteristics of the waste managed.
- ☐ Identify qualified engineers and ground-water specialists to assist in designing and operating the ground-water monitoring program.
- ☐ Consult with qualified professionals to identify necessary program components including the monitoring well design; number, lateral and vertical placement of monitoring wells; duration and frequency of monitoring; and appropriate sampling parameters.
- ☐ Determine the appropriate method of ground-water monitoring considering conventional well monitoring, direct push sampling, geophysical monitoring, and vadose zone monitoring.
- ☐ Develop sample collection, preservation, storage, transport, and handling protocols tailored to data needs, and establish quality assurance and quality control procedures to check the accuracy of the monitoring samples.
- ☐ Eliminate cross-contamination or background contamination of any samples by purging the wells, using appropriate sampling equipment, and ensuring that any unstable parameters, such as pH, dissolved oxygen, and temperature, have been tested at the site.
- ☐ Identify appropriate analytical methods and statistical approaches for the sampling data considering parametric analysis of variance (ANOVA), tolerance intervals, prediction intervals, and control charts.
- ☐ Determine need for assessment monitoring and abatement.

Surface Water

- ☐ Collect and analyze samples according to the site's federal or state storm-water permit if the permit requires the facility to do so.
- ☐ Implement a sampling program and best management practices (BMPs) to monitor surface water quality and identify and control the contaminants in storm water run-off from a waste management unit.

Monitoring Performing Action Items (cont.)

- ☐ Perform regular maintenance inspections of surface-water protection measures.
- ☐ Sample a representative storm and collect samples at the outfall point.
- ☐ Coordinate with a qualified laboratory to ensure the quality of sample analysis.
- ☐ Do not collect samples under hazardous conditions.

Soil Monitoring

- ☐ Determine the number and location of samples needed to adequately characterize soil according to the variability of the soil at a site.
- ☐ Follow established soil sampling procedures to obtain meaningful results.
- ☐ Use qualified laboratories to analyze samples.
- ☐ Determine baseline soil conditions by sampling prior to waste application.
- ☐ Collect and analyze samples at regular intervals to detect contaminant problems.

Air Monitoring

- ☐ Use the Industrial Waste Air Model to evaluate risks from VOC emissions.
- ☐ Use an alternative emissions model if the Industrial Waste Air Model indicates a problem with VOC emission or is not appropriate for a site.
- ☐ Consult with an air modeling professional, state and local agencies, and EPA before implementing an air monitoring program or choosing an alternative emissions model.

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Site Characterization

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Part V
Ensuring Long-Term Protection

Chapter 10
Taking Corrective Action

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Taking Corrective Action

Monitor the performance of a waste management unit and take appropriate steps to remediate any contamination. Locate and characterize source of contamination. Identify and evaluate potential corrective measures. Select and implement corrective measures to achieve attainment of cleanup standard. Work closely with the state and community representatives.

Effective operation of a waste management unit requires checking the performance of the waste management system components. When components are not operating effectively or when a problem develops, corrective action may need to be initiated to cleanup and protect human health and the environment. Corrective action involves identifying exposure pathways of concern, selecting the best corrective measure to achieve the appropriate cleanup standard, and consulting with state and community representatives prior to beginning any extensive corrective action program.

This chapter will help address the following questions:

- What steps are associated with corrective action?
- What information should be collected during investigations?
- What factors should be considered in selecting an appropriate corrective measure?
- What is involved in implementing the selected remedy?

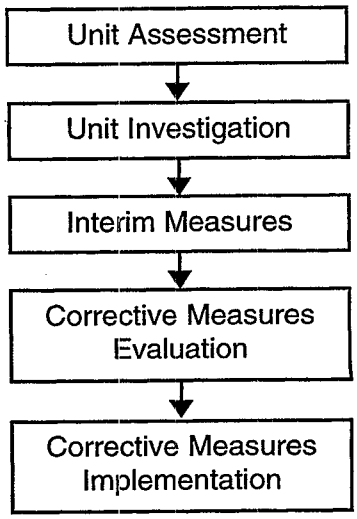
I. Corrective Action Process

The purpose of a corrective action program is to assess the nature and extent of the releases of waste or constituents; to evaluate unit characteristics; and to identify, evaluate, and implement an appropriate corrective measure or measures to protect human health and the environment. The overall goal of any corrective action should be to perform a technically and economically feasible risk-reduction, designed to achieve a cleanup standard at a specified point on the facility property. Using the ground-water pathway as an example, corrective action for new units should have as a goal a reduction of constituent concentration levels to the ground-water protection standards, that is the maximum contaminant levels (MCLs) or health based levels, at the monitoring point.

A corrective action program generally has the components outlined below and in Figure 1. The detail required in each of these components varies depending on the unit and its complexity. Only conduct those tasks appropriate for a site, and coordinate with the state during all phases of corrective action.

- Perform a unit assessment to locate the actual or potential source(s) of the release(s) of contaminants based on the use of existing information.
- Perform a unit investigation to characterize the nature and extent of contamination from the unit and any contamination that may be migrating beyond the facility boundary; identify areas and populations threatened by releases from the unit; and determine short- and long-term threats of releases from the unit to human health and/or the environment.
- Identify, evaluate, and implement interim measures, if needed. Interim measures are short-term actions taken to protect human health and the environment while unit assessment or unit investigations are being performed or before a corrective measure is selected.
- Identify, evaluate, and implement corrective measure(s) to abate the further spread of contaminants, control the source of contamination, and to remediate releases from the unit.
- Design a program to monitor the maintenance and performance of any interim or final corrective measure(s) to ensure that human health and the environment are being protected.

Figure 1
Corrective Action Process



A. Unit Assessment

Often the first activity in the corrective action process is the unit assessment. A unit assessment identifies potential and actual releases from the unit and makes preliminary determinations about release pathways, the need for corrective action, and interim measures. If appropriate, evaluate the possibility of addressing multiple units as the corrective action process proceeds. Table 1 identifies a number of factors to consider during a unit assessment.

As a beginning step, review all available site information regarding unit characteristics, waste characteristics, contaminant migration pathways, evidence of release, and exposure potential. Conduct a visual site inspection of the unit to confirm available information and to note any visual evidence of releases. If necessary, perform sampling to confirm or disprove suspected releases before performing an extensive unit investigation.

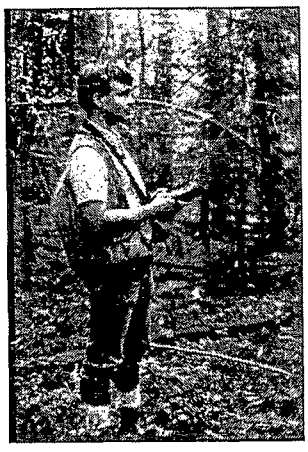


Table 1
Factors To Consider in Conducting a Unit Assessment

Unit/Site Characteristics	Chemical Characteristics	Migration Pathways	Evidence of Release	Exposure Potential
Contamination parameters —Concentrations —Depth and location of contamination Physical parameters —Geology —Depth to ground water —Flow characteristics —Climate Historical information —History of unit —Knowledge of waste generation practices	Type of waste placed in the unit Volatization parameters Toxicological characteristics Physical and chemical properties Chemical class Soil sorption/ degradation parameters	Facility's geological setting Facility's hydogeological setting Atmospheric conditions Topographic characteristics	Prior inspection reports Citizen complaints Monitoring data Visual evidence such as discolored soil, seepage, discolored surface water or run-off Other physical evidence such as fish kills, worker illness, or odors Sampling data	Proximity to affected population Proximity to sensitive environments Likelihood of migration to potential receptors

Additional information on performing unit assessments can be found in *RCRA Facility Assessment Guidance* (U.S. EPA 1986).

B. Unit Investigation

Perform a unit investigation after a release has been confirmed. The purpose of the investigation is to gather enough data to fully characterize the nature, extent, and rate of migration of contaminants to determine and support the selection of the appropriate response action. Tailor unit investigations to specific conditions and circumstances at the unit and focus on releases and potential pathways. 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 such as monitoring data, data which can be gathered from outside information sources 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.

Detailed knowledge of the source characteristics is valuable in identifying monitoring constituents and indicator parameters, possible release pathways, monitoring procedures, and also in linking releases to a particular unit. Waste and unit characteristics will also provide information for determining release rates and for determining the nature and scope of any corrective measures which may be applied. Refer to the characterizing waste chapter for information on how to characterize a waste.

Unit investigations 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, such as sample numbers, locations, procedures, and methods, are readily accessible and accurately maintained.

Guidance on Performing Unit Investigations

Additional guidance on performing unit inspections can be found in the following EPA documents:

- *RCRA Facility Investigation Guidance Volume 1: Development of an RFI Work Plan and General Considerations for RCRA Facility Investigations* (U.S. EPA 1989)
- *RCRA Facility Investigation Guidance Volume 2: Soil, Ground Water, and Sub-Surface Gas Releases* (U.S. EPA 1989)
- *RCRA Facility Investigation Guidance Volume 3: Air and Surface Water Releases* (U.S. EPA 1989)
- *RCRA Facility Investigation Guidance Volume 4: Case Study Examples* (U.S. EPA 1989)
- *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (U.S. EPA 1988)
- *Draft Practical Guide for Assessing and Remediating Contaminated Sites* (U.S. EPA 1989)
- *Site Characterization for Subsurface Remediation* (U.S. EPA 1991)

1. Specific Considerations for Ground-Water Investigations

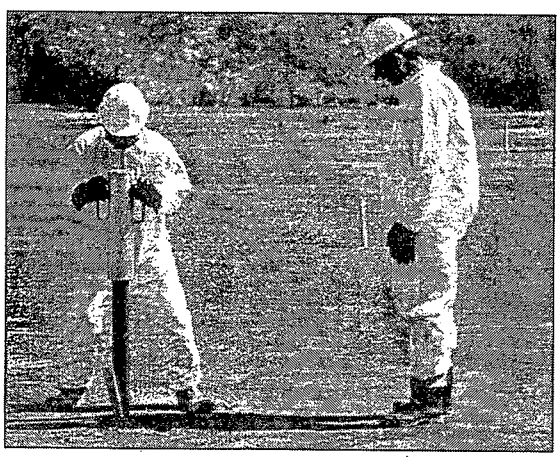
To facilitate ground-water investigations consider the following parameters:

- Ability of the waste to be dissolved or to appear as a distinct phase;
- Degradability of the waste and its decomposition products;
- Geologic and hydrologic factors which affect the release pathway; and
- Regional and site-specific ground-water flow regimes to determine the potential magnitude of the release 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. Also address the potential for the transfer of contaminants in ground

water to other environmental media such as discharge to surface water and volatilization to the atmosphere.

Use an existing ground-water monitoring program to determine the nature, extent, and rate of contaminant release from the unit(s) to the ground water. 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, characterize the release through a subsequent monitoring phase(s). Subsequent characterization involves determining the detailed constituent composition and concentrations and the horizontal and vertical 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 and modeling techniques.



2. Specific Considerations for Soil Investigations

When performing soil investigations, consider the following parameters:

- Ability of the waste to be dissolved by infiltrating precipitation;
- Waste's affinity for soil particles;
- Waste's degradability and its decomposition products;
- Surface features such as topography, erosion potential, land-use capability, and vegetation;
- Stratigraphic/hydrologic features such as soil profile, particle size distribution, hydraulic conductivity, pH, porosity, and cation exchange capacity; and
- Meteorological factors such as temperature, precipitation, run-off, and evapotranspiration.

Relevant physical and chemical soil properties should be measured and related to waste properties to determine potential mobility of the contaminants in the soil. Also, consider the potential for transfer of contaminants in soil to other environmental media such as overland run-off to surface water, leaching to ground water, and volatilization to the atmosphere. In addition, 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. Non-point sources may include airborne particulate contamination originating from a land application unit and widespread leachate seeps from a landfill.

Table 2 presents important mechanisms of contaminant release to soils for various unit types. This information can be used to identify areas for initial soil monitoring.

3. Specific Considerations for Surface-Water Investigations

When conducting surface-water investigations, consider the following parameters:

- The release mechanism such as overtopping of an impoundment;

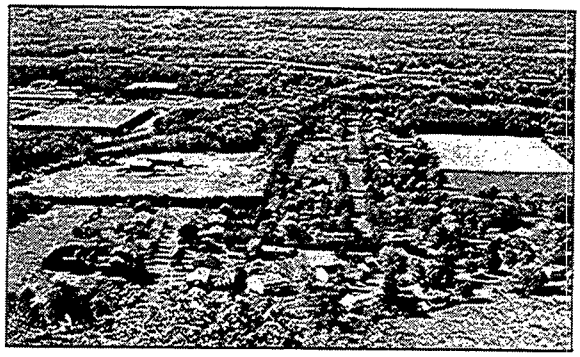
Table 2
Potential Release Mechanisms for Various Unit Types

Unit Type	Release Mechanism
Surface impoundment	Loading and unloading areas Releases from overtopping Seepage
Landfill	Migration of releases outside the unit's run-off collection and containment systems Migration of releases outside the containment area from loading and unloading operations Leakage through dikes or unlined portions to surrounding soils
Waste pile	Migration or releases outside the unit's run-off collection and containment system Migration of releases outside the containment area from loading and unloading operations Seepage through underlying soils
Land application unit	Migration of run-off outside the application area Passage of leachate into the soil horizon

- The nature of the source area such as point or non-point;
- Waste type and degradability;
- Climatic factors such as history of floods;
- Hydrologic factors such as stream flow conditions; and
- Fate and transport factors such as the ability for a contaminant to accumulate in stream bottom sediments.

Also, address the potential for the transfer of contaminants in surface water to other environmental media such as soil contamination as a result of flooding of a contaminated creek on the facility property.

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 for greater efficiency.



4. Specific Consideration for Air Release Investigations

The intent of the air release investigation is to determine actual or potential effects at a nearby receptor. Characterizing air releases may involve emission modeling to estimate unit-specific emission rates, air monitoring to determine concentrations at a nearby receptor, emission monitoring at the source to determine emission rates, and dispersion modeling to estimate concentrations at a nearby receptor. Refer to the monitoring performance chapter for more information on air monitoring and to the protecting air chapter for more information on air modeling.

As in all of the other media-specific investigations, the first step is to collect, review, and evaluate available waste, unit, environmental setting, and release data. Evaluation of these data may, at this point, clearly indicate the need for corrective measures or that no further action is required. For example, the source may involve a large, active storage surface impoundment containing volatile constituents 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 or monitoring database indicates that the air release can be considered insignificant and therefore, further studies are not warranted. In many cases, however, further release characterization may be necessary.

C. Interim Measures

Many cleanup programs recognize the need for interim measures while site characterization is underway or before a final remedy is selected. Typically, interim measures are used to control or abate ongoing risks before final remedy selection. Examples of interim measures for various types of waste management units and various release types are listed in Appendix I. More information is available through the *Interim Measures Guidance - Interim Final* (U.S. EPA, 1988) and *RCRA Corrective Action Stabilization Technologies* (U.S. EPA, 1992). Interim measures may be separate from the comprehensive corrective action plan, but should be consistent with and integrated with any longer term corrective measure. To the extent possible, interim measures should not seriously complicate the ultimate physical management of wastes or constituents, nor should they present or exacerbate a health or environmental threat.

D. Evaluating Potential Corrective Measures

The corrective measure or measures selected should meet the corrective action goals, such as a state or local cleanup standard, and control or remove the source of contamination to reduce or eliminate further releases. Most corrective measures fall into one of three technology categories — containment technologies, extraction or removal technologies, or treatment technologies. Consider the performance objectives of the corrective measures in terms of source reduction, cleanup goals, and cleanup timeframe. These measures may include the repair or upgrade of existing unit components, such as liner systems, leachate

Potential Corrective Measures

Additional guidance on potential corrective measures is available from the following documents:

- *Corrective Action: Technologies and Applications* (U.S. EPA 1989)
- *Handbook: Stabilization Technologies for RCRA Corrective Actions* (U.S. EPA 1991)
- *RCRA Corrective Action Stabilization Technologies* (U.S. EPA 1992)
- *Pump and Treat Ground-Water Remediation: A Guide for Decision Makers and Practitioners* (U.S. EPA 1996)
- *Handbook: Remediation of Contaminated Sediments* (U.S. EPA 1991)
- *Abstracts of Remediation Case Studies* (U.S. EPA 1995)
- *Bioremediation Resource Guide* (U.S. EPA 1993)
- *Groundwater Treatment Technology Resource Guide* (U.S.EPA 1994)
- *Physical/Chemical Treatment Technology Resource Guide* (U.S.EPA 1994)
- *Soil Vapor Extraction Treatment Technology Resource Guide* (U.S.EPA 1994)

collection systems, or covers. Base corrective measure(s) selection on the following considerations and contact the state and community representatives before finalizing the selection:

- The ability to meet cleanup standards;
- The appropriateness and effectiveness of the treatment technology in relation to the waste and site characterizations;
- The long- and short-term effectiveness including economical and technical feasibility and protectiveness of the remedy;
- The effectiveness of the remedy in controlling the source to reduce further releases;
- The ease of implementing the remedy; and
- The degree to which local community concerns have been addressed.

1. Meeting Cleanup Standards

Work with the state and community representatives to establish risk-based cleanup standards for the media of concern (ground water, surface water, soil, air) before identifying potential corrective measures. For example, if there is a statistically significant increase of constituent concentrations over background in the ground water, cleanup standards would include reducing contaminant concentrations to the MCL or health-based level at the point of monitoring.

Several approaches have been developed to identify appropriate cleanup standards. One of the more recent approaches is the Risk-Based Corrective Action (RBCA) standard developed by some states and the American Society for Testing and Materials (ASTM) Committee. The RBCA standard provides guidance on how to integrate ecological and human health risk-based decision-making into the traditional corrective action process described above. RBCA is a decision-making process for the assessment and response to chemical releases. This standard is applicable to all types of chemical release sites, which may vary greatly in terms of their complexity, physical and chemical characteristics, and the risk they pose to human health and the environment. RBCA uses a tiered approach that begins with simple analyses and moves to more complex evaluations when necessary.

The foundation of the RBCA process is that technical policy decisions are identified in the front-end of the process to ensure that data collected are of sufficient quantity and quality to answer questions posed at each tier of the investigation. The RBCA standard is not intended to replace existing regulatory programs, but rather to provide an enhancement to these programs. The RBCA process allows for a three-tiered approach as described below. More information on RBCA is available from ASTM's *Draft Standard Guide for Risk-Based Corrective Action*, and a 1997 draft report prepared by the Louisiana Department of Environmental Quality, *Proposed Louisiana Department of Environmental Quality Risk-Based Corrective Action Program.* Consult with the state and community representatives to determine the appropriateness of a RBCA approach.

Tier 1 Evaluation

A Tier 1 evaluation classifies a site according to the urgency for corrective action using broad measures of release and exposure. This tier is used to identify the source(s) of the chemical release, obvious environmental impacts, potential receptors, and significant exposure pathways. During a Tier 1 evaluation, site-specific contaminant concentrations are compared against a standard table of risk-based screening levels (RBSLs) that have been developed using conservative, nonsite-specific exposure assumptions. If site contaminant concentrations are found to be above the RBSLs, then corrective action or further evaluation would be considered. Continued monitoring may be the only requirement if site-specific contaminant concentrations are below the RBSLs. Hence, at the end of the Tier 1 evaluation, initial corrective action responses are selected while additional analysis is conducted to determine final remedial action, if necessary. The standard includes an exposure scenario evaluation flowchart to help identify appropriate receptors and exposure scenarios based on current and projected reasonable land use scenarios, and appropriate response actions.

Site conditions should also be compared to relevant ecological screening criteria (RESC) applicable to the site which might include qualitative or quantitative benchmarks, comparison of site conditions to local biological and environmental conditions, or considerations related to the exposed habitat areas.

Tier 2 Evaluation

The user may decide to conduct a Tier 2 evaluation after selecting and implementing the appropriate initial response action to the Tier 1 evaluation. The purpose of this tier is to determine site-specific target levels (SSTLs) and appropriate points of compliance when it is determined that Tier 1 RBSLs are not appropriate. While a Tier 2 evaluation is based on similar screening levels as those used in the Tier 1 evaluation, some of the generic assumptions used in the earlier evaluation are replaced with site-specific measurements to develop the SSTLs. The intent of Tier 2 is to incorporate the concept that measured levels of contamination may decline over the distance from source to receptor. Thus, simple environmental fate and transport modeling is used to predict attenuation over that distance. If site-specific contaminant concentrations are above the SSTLs, corrective action is needed and further analysis may be required.

Tier 3 Evaluation

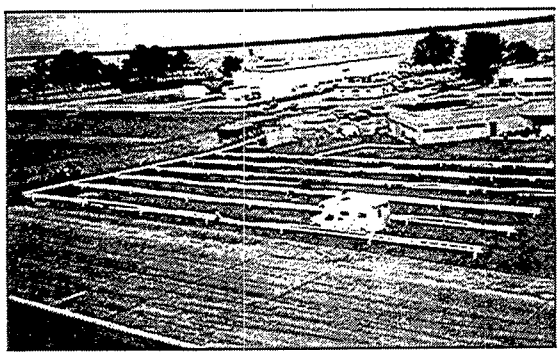
A Tier 3 evaluation involves the same steps as those taken during the Tier 1 and Tier 2 evaluations, except that a significant increase in effort is employed to refine and better

define the scope of the contamination. Actual levels of contamination are compared to SSTLs that are developed for this Tier. The Tier 3 SSTLs differ from Tier 2 SSTLs in the level of sophistication used to develop site-specific measures of environmental fate and transport of contaminants. Where simplified, site-specific measures of environmental fate and transport are used in the Tier 2 evaluation, much more sophisticated models will be used in this Tier. These models may rely on probabilistic approaches and on alternative toxicity and biodegradability data.

2. Evaluating Treatment Technologies

In nearly every phase of the corrective action process, some information about treatment technologies is needed. Many documents exist that describe candidate technologies in detail and give their respective applicability and limitations. Below are descriptions and examples of the three major treatment technology categories.

Containment technologies are used to stop the further spread or migration of contaminants. Some examples of common containment techniques for constituents in land-based units include waste stabilization, solidification, and capping. Capping and other surface-water diversion techniques, for instance, can control infiltration of rainwater to the contaminated medium. Typical ways to contain contaminated ground-water plumes include ground-water pumping, subsurface drains, and barrier or slurry walls. These ground-water containment technologies control the migration of contaminants in the ground-water plume and prevent further dissolution of contaminants by water entering the unit. Each of these ground-water containment technologies is briefly described in Appendix II.



Extraction or removal technologies physically remove constituents from a site. Extraction techniques may remove the constituent of concern only, or the contaminated media itself. For example, vapor extraction may just remove the constituent vapors from the soil, while excavation would remove all of the contaminated soil. Extraction technologies include excavation, pumping, product recovery, vapor extraction or recovery, and soil washing.

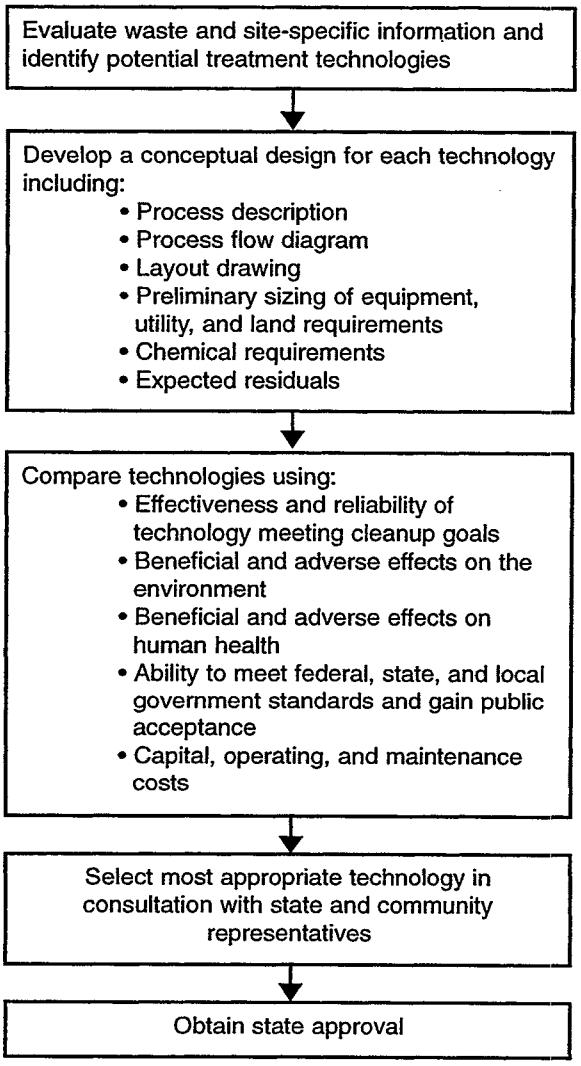
Treatment or destruction technologies render constituents less harmful through biological, chemical, and thermal techniques. Some examples are ground-water treatment, pH adjustment, oxidation and reduction, bioremediation, and incineration. A broader perspective on ground-water, chemical, biological, thermal, and stabilization treatment technologies is presented in Appendix III.

In selecting a treatment technology or set of technologies, it is important to consider the information obtained from the waste and site characterization. For example, the waste characterization should tell the location of the waste and in what phases the waste should be expected to be found, such as sorbed to soil particles. Waste characterization information also allows for the assessment of the leaching characteristics of the waste, its ability to be degraded, and its tendency to react with chemicals. The site characterization information will reveal important information about subsurface flow conditions and other

[1]U.S. EPA, 1991. *Site Characterization for Subsurface Remediations*

Figure 2

Screening Process for Selecting Appropriate Treatment Technologies



physical characteristics (such as organic carbon content). Use the information from the waste and site characterization to select the appropriate treatment technology. In some cases, a treatment train, a series of technologies combined together, will be appropriate.[1] A screening process for selecting an appropriate technology is presented in Figure 2. This step-by-step approach will help ensure that technologies that may be applicable at a site are not overlooked. In addition, the rationale for the elimination of specific technologies will be available to justify decisions to interested parties.

Additional information regarding the use and development of innovative treatment technologies is available from the Federal Remediation Technologies Roundtable's web site at **<http://Solaris.frtr.gov>**. In cooperation with the Federal Remediation Technologies Roundtable, the Army Environmental Center has developed the document *Remediation Technologies Screening Matrix and Reference Guide, Version 3.0.* This guide contains a screening matrix for evaluating treatment technologies. A copy of this matrix is attached as Appendix IV.

3. Evaluating the Long- and Short-Term Effectiveness of the Remedy

To evaluate the long- and short-term effectiveness of the remedy, analyze the risks associated with the remedy as those risks pertain to the construction and implementation of the corrective measure. Because waste characteristics vary from site to site, the effect of a treatment technology with a particular waste may be unknown. Consider, therefore, performing a treatability study to evaluate the effectiveness of one or more potential remedies. Spending the time and money up-front to better assess the effectiveness of a technology on a waste can save significant time and money later in the process. To judge the technical certainty that the remedy will attain the corrective action goal, also consider reviewing case studies where similar technologies have been applied.

Invest a reasonable amount of effort to estimate and quantify risks, based on exposure pathways, estimates of exposure levels, and duration of exposure at a site. It is also

Treatability Studies

The four general types of treatability studies are laboratory-scale, bench-scale, pilot-scale, and field-scale.

- **Laboratory-scale** studies are small scale screening studies that generate qualitative information concerning the general validity of a treatment approach.
- **Bench-scale** studies are intermediate studies conducted in the laboratory. Bench scale studies are intended to answer specific, design, operation, and cost questions, and are more detailed than laboratory studies.
- **Pilot-scale** studies are large scale experiments intended to provide quantative cost and design data. They simulate anticipated full-scale operational configurations as closely as possible.
- **Field-scale** studies are large scale studies intended to monitor the performance of treatment systems under real world conditions at close to full scale operations

More information on treatability studies can be found in *A Guide for Conducting Treatability Studies Under CERCLA* (U.S. EPA, 1992).

important to analyze the time to complete the corrective measure, because it directly impacts the cost of the remedy. Carefully evaluate the long-term costs of the remedial alternatives and the long-term financial condition of the facility. Consider including quality control measures in the implementation schedule to assess the progress of the corrective measure. It is also important to determine the degree to which the remedy complies with all applicable state laws.

4. Evaluating the Effectiveness of Reducing or Eliminating the Source of Contamination

There are two major components of source control that should be evaluated. First, if source control consists of the removal, redisposal, or treatment of wastes and the residual materials, such as contaminated soils, the volume of wastes and residual materials should be quantified and the potential to cause further contamination evaluated. Second, engineering controls intended to upgrade or repair deficient conditions at a waste management unit should be quantified in terms of anticipated effectiveness according to current and future conditions. This evaluation should determine what is technically and financially practicable. Health considerations and the potential for unacceptable exposure(s) to both workers and the public may affect an evaluation.

5. Evaluating the Ease of Implementation

The ease of implementing the proposed corrective measure will affect its schedule. To evaluate the ease of implementation of a specific corrective measure, consider the availability of technical expertise, the construction of equipment or technology, the ability to properly manage, dispose, or treat wastes generated by the corrective measure, and the likelihood of obtaining local permits and public acceptance for the remedy. Consider also the potential for contamination to transfer from one media to another as part of the overall feasibility of the remedy. Cross-media impacts should be addressed as part of the implementation phase. Develop a corrective measure schedule identifying the start and end points of the permitting phase, the construction and startup period, the time when full-scale treatment will be initiated and the

duration of the treatment period, and the implementation and completion of source control measures.

6. Measuring the Degree to Which Community Concerns are Met

Prior to selecting the corrective measure(s), hold a public meeting to discuss the results of the corrective action assessment and to identify proposed remedies. Consider notifying adjacent property owners via mail of any identified contamination and proposed remedies. Identify any public concerns that have been expressed, via written public comments or from public meetings, about the facility's contamination and ensure that these concerns are adequately addressed by the corrective measures being evaluated. The best remedy selected and implemented will be one that is agreed upon by the state or local regulatory agency, the public, and the facility owner. Review the information presented in the building partnerships chapter before selecting any final remedies.

E. Implementing Corrective Measures

Implementation of the corrective measures encompass all activities necessary to initiate and continue remediation. During the evaluation and assessment of the nature and extent of the contamination, decide whether no further assessment is necessary, whether institutional controls are necessary to protect human health and the environment, whether monitoring and site maintenance is necessary, and whether no further action and closure are appropriate actions for the unit.

Citizen Guides to Treatment Technologies

EPA's Technology Innovation Office has developed a series of fact sheets that explain, in basic terms, the operation and application of innovative treatment technologies for remediating sites. The fact sheets address issues associated with innovative treatment technologies as a whole, bioremediation, chemical dehalogenation, in situ soil flushing, natural attenuation, phytoremediation, soil vapor extraction and air sparging, soil washing, solvent extraction, thermal desorption, and the use of treatment walls. A copy of *A Citizen's Guide to Innovative Treatment Technologies* is attached as Appendix V.

English and Spanish versions of the fact sheets can be downloaded from the Internet at **<http://clu-in.com/citguide>**.

1. Institutional Controls

Institutional controls are those controls that can be utilized by responsible parties and regulatory agencies in remedial programs where, as part of the program, certain levels of contamination will remain on site in the soil or ground water. Institutional controls can also be considered in situations where there is an immediate threat to human health. Institutional controls may vary in both form and content. Agencies and landowners can invoke various authorities and enforcement mechanisms, both public and private, to implement one or more of the controls. A state could adopt a statutory mandate, for example, requiring the use of deed restrictions as a way of enforcing use restrictions and posting signs. Commonly used institutional controls include the following:

- Deed restrictions, or restrictive covenants;
- Use restrictions (including all restriction areas);

Selecting a Corrective Action Specialist

Once it has been determined that corrective measures are necessary, determine if in-house expertise is adequate or if an outside consultant is necessary.

If a consultant is needed, determine if the prospective company has the technical competence to do the work needed. A poor design for a recovery system, unacceptable field procedures, lack of familiarity with state requirements, or an inadequate investigation may unnecessarily cost thousands of dollars and still not complete the cleanup.

Some of the most important information to consider in selecting a consultant is whether the company has experience performing site investigations and remediations at similar sites, is familiar with state regulations, has staff trained in the use of field screening instruments, has experience in monitoring well design and installations, has established quality assurance and quality control procedures, and can provide references.

- Access controls;
- Notices, including record notice, actual notice, and notice to government authorities;
- Registry act requirements;
- Transfer act requirements; and
- Contractual obligations.

A brief description of these institutional controls is presented in Appendix VI.

2. Monitoring and Site Maintenance

In many cases, monitoring may need to be conducted to demonstrate the effectiveness of the implemented corrective measures. Consult with the state to determine the amount of time that monitoring should be conducted. Some corrective measures, such as capping, hydraulic control, and other physical barriers, may require long-term maintenance to ensure integrity and continued performance. Upon completion and verification of cleanup goals reinstitute the original or modified ground-water monitoring program if the unit is still in active use.

3. No Further Action and Site Closure

When the corrective action goals have been achieved, and monitoring and site maintenance are no longer necessary to ensure that this condition persists, reinstitute the original or modified ground-water monitoring program if the unit is still in active use. It may be necessary, however, to ensure that any selected institutional controls remain in place. Refer to the chapter on performing closure and post-closure care for additional information.

Corrective Action Action Items

Consider the following when developing a corrective action program for nonhazardous industrial solid waste management units:

- ☐ Locate the source(s) of the release(s) of contaminants and determine the extent of the contamination.
- ☐ Consult with the state, community representatives, and qualified remedial experts when developing a corrective action program.
- ☐ Identify and evaluate all potential corrective measures including interim measures.
- ☐ Select and implement corrective measures based on the effectiveness and protectiveness of the remedy, the certainty that the remedy will achieve established goals, the ease of implementing the remedy, and the degree that the remedy meets local community concerns and all applicable state laws.
- ☐ Design a program to monitor the maintenance and performance of corrective measures to ensure that human health and the environment are being protected.

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Part 5
Ensuring Long-Term Protection

Chapter 11
Performing Closure and Post-Closure Care

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Performing Closure and Post-Closure Care

Providing closure and post-closure care is an integral part of a unit's overall design and operation, helping to reduce or eliminate potential threats and the need for future corrective action at the site. Planning and accomplishing the goals of closure and post-closure care require adequate funding be set aside to cover the planned costs of such activities.

The overall goal of closure is to minimize or eliminate potential threats and the need for future corrective action at the site. If removing the wastes, containment devices, and any contaminated subsoils from a unit, the unit should be returned to an acceptable risk level, so that the unit is not a current or future threat to human health and the environment. If wastes will be left in place at closure, the unit should be closed in a manner to reduce and control current or future threats to human health and the environment. Also, avoid future disruptions to final cover systems and monitoring devices.

This chapter will help address the following questions:

- How do I develop a closure plan?
- What factors should I consider when choosing a closure method?
- What are the components of a final cover?
- What costs are associated with post-closure care?

For post-closure care, the overall goal is to minimize the infiltration of water into a unit by providing maintenance of the final cover until such time as it is determined that care is no longer necessary. Also, during post-closure care closed units should be monitored to verify and document that unacceptable releases are not occurring.

I. Closure Plans

A well-conceived closure plan is the primary resource document for the final stage in the life of a waste management unit. The purpose of a closure plan is to consider all aspects of the closure scenario. It should be comprehensive so that staff who will implement it years after its writing will clearly understand the activities it specifies. It also needs to be sufficiently detailed in order to calculate the costs of closure and post-closure care for purposes of determining how much funding needs to be set aside for those activities.

What should I consider when developing a closure plan?

Tailor a closure plan to account for the unique characteristics of the unit, the waste managed in the unit, and anticipated future land use. Each unit will have different closure activities. Closing a surface impoundment, for example, involves removal of remaining liquids and solidifying sludges prior to placing a final cover on the unit.

Consider the following information when developing a closure plan:

- Overall goals and objectives of closure;
- Future land use;
- Type of waste management unit;
- Types, amount, and physical state of waste in the unit;
- Constituents associated with the wastes;
- Whether wastes will be removed or left in place at closure;
- Schedule (overall and interim);
- Costs to implement closure;
- Steps to monitor progress of closure actions, including inspections, maintenance activities, and necessary monitoring (e.g., ground-water and leachate monitoring) where appropriate;
- Revisions to health and safety plan, as necessary;
- Contingency plans;
- Description of waste treatment or stabilization (if applicable);
- Final cover information (if applicable);
- Waste removal information (if applicable); and
- Parameters to assess performance of the unit throughout the post-closure period.

The plan should address the types of waste that have been or are expected to be deposited in the management unit and the constituents that can reasonably be associated with those wastes. The types of expected wastes will affect both the design of the final cover and the types of activities that should be undertaken during the post-closure care period. Biodegradable waste, for example, may cause a final cover to subside due to decomposition and may also require gas management.

The closure plan should provide other information that will address the closure strategy. If, for instance, a final cover is planned, then the closure plan will need to consider seasonal precipitation that could influence the performance of both the cover and the monitoring system. Information concerning freeze cycles and the depth of frost permeation will provide supporting information with which to assess the adequacy of the cover design. Similarly, arid conditions should be addressed to support a decision to use a particular cover material, such as cobbles.

The closure plan should address the closure schedule, stating the dates when waste will initially be placed in a unit, when closure will begin, and when closure is expected to be completed. Consider starting closure when the unit has reached capacity or has received the last expected waste for disposal. For units containing inorganic wastes, complete closure as soon as possible after the last expected waste has been received. A period of 180 days is a good general guide for completing closure, but the actual time frame will be dictated by site-specific conditions. For units receiving organic wastes, more time may be needed for the wastes to stabilize prior to completing closure. Similarly, other site-specific conditions, such as precipitation or winter weather, may also cause delay in completing closure. For these situations, complete closure as soon as feasible. Consult with the state

agency to determine if requirements exist for closure schedules.

Even within a waste management unit, some areas will be closed on different schedules, with certain areas in partial closure, while other areas continue to operate. The schedules and partial closure activities (such as intermediate cover) should be considered in the closure plan. Although the processes for closing such areas may not be different than those for closing the unit as a whole, it is still more efficient to integrate partial closure activities into the closure plan.

If the closure plan calls for the stabilization, solidification, or other treatment of wastes in the unit before the installation of a final cover, the plan should describe those activities in detail. Waste stabilization, solidification, or other treatment has four goals:

- Remove liquids, which are ill-suited to supporting the final cover;
- Decrease the surface area over which the transfer or escape of contaminants can occur;
- Limit the solubility of leachable constituents in the waste; and
- Reduce toxicity of the waste.

For closure strategies that will use engineering controls, such as final covers, the plan should provide detailed specifications, including descriptions of the cover materials in each layer and their permeability as well as any drainage and/or gas migration control measures included in the operation of the final cover. Also identify measures to verify the continued integrity of the final cover and the proper operation of the gas migration and/or drainage control strategies.

If wastes will be removed at closure, the closure plan should estimate volumes of waste and contaminated subsoil and the extent of contaminated devices to be removed during closure. It should further state waste removal procedures, establish performance goals, and address any state or local requirements for closure by waste removal. The plan should identify numeric clean-up standards and existing background concentrations of constituents. It also should discuss the sampling plan for determining the effectiveness of closure activities. Finally, it should describe the provisions made for the disposal of removed wastes and other materials.

The closure plan should also provide a detailed description of the monitoring that will be conducted to assess the performance of the waste management unit throughout the post-closure period. These measurements include monitoring leachate volume and characteristics to ensure that a cover is minimizing infiltration. It is important to include appropriate ground-water quality standards with which to compare ground-water monitoring reports. The performance measures section of the plan establishes, prior to completing closure, the parameters that will describe successful closure of the unit. If limits on these parameters are exceeded, it will provide an early warning that the final cover system is not functioning as designed and that measure should be undertaken to identify and correct problems.

II. Selecting a Closure Method

Factors to consider in deciding whether to perform closure by means of waste removal or through the use of a final cover include the following:

- **Feasibility.** Is closure by waste removal feasible? For example, if the waste volumes are large and underlying soil and ground water are contaminated, closure by total waste removal may not be possible. If the

unit is contaminated, consult the chapter on taking corrective action to identify activities to address the contamination. In some cases, even in situations where contamination is a concern, partial removal of the waste may be useful to remove the source of ground-water contamination.

- **Cost-effectiveness.** Compare the costs of removing waste, containment devices, and contaminated soils, plus subsequent disposal costs at another facility, to the costs of installing a final cover and providing post-closure care.

- **Long-term protection.** Will the final cover control, minimize, or eliminate, to the extent necessary to protect human health and the environment, post-closure escape of waste constituents or contaminated run-off to ground or surface waters?

- **Availability of alternate site.** Is an alternate site available for final disposal or treatment of removed waste? Consult with the state agency to determine whether alternate disposal sites are appropriate.

III. Closure by Use of Final Cover Systems

You may elect to close a waste management unit by means of a final cover system. This approach is common for landfill units and some surface impoundment units where some waste is left in place. The choice of final cover materials and design should be the result of a careful review and consideration of all site-specific conditions that will affect the performance of the cover system. If you are not knowledgeable about the engineering properties of cover materials, seek the advice of professionals or representatives of state and local environmental protection agencies.

This section will discuss the more important technical issues that should be considered when selecting cover materials and designing a cover system. It will also discuss the various potential components of final cover systems, discussing the types of materials that can be used in their design and some of the advantages and disadvantages of each. Throughout the section, the interaction between the various components as they function within the system will be discussed.

A. Purpose and Goal of Final Cover Systems

The principal goals of final cover systems are to:

- Protect human health and the environment by reducing or eliminating potential risk of contaminant release;
- Minimize infiltration of precipitation into the waste management unit to minimize generation of leachates within the unit by promoting surface drainage and maximizing run-off;
- Minimize risk by controlling gas migration, and by providing physical separation between waste and humans, plants, and animals; and
- Minimize long-term maintenance needs.

For optimal performance, the final cover system should be designed to minimize permeability, surface ponding, and the erosion of cover material. To avoid the accumulation of leachate within a unit, the cover system should be no more permeable than the liner system. For example, if a unit's bottom liner system is composed of a low-permeability material, such as compacted clay or a geomembrane, then the cover should also be composed of a low-permeability material unless an evaluation of site-specific conditions shows an equivalent reduction in infiltration.

If the cover system is more permeable than the liner, leachate will accumulate in the unit, since infiltration through the cover will exceed leachate exfiltration through the liner system. This buildup of liquids within a unit is often referred to as the "bathtub effect." In addition, since many units can potentially generate gas, cover systems should be designed to control gas migration. It is essential to ensure proper quality assurance and quality control during construction and installation of the final cover so that the final cover performs in accordance with its design. For general information on quality assurance during construction of the final cover, consult the construction quality assurance section of the chapter on designing and installing liners. Recommendations for the type of final cover system to use will depend on the type of liner and the gas and liquids management strategy employed in a unit.

B. Technical Considerations for Selecting Cover Materials

Several environmental and engineering concerns can affect cover materials and should be considered in the choice of those materials.

How can climate affect a final cover?

Freeze and thaw effects can lead to the development of microfractures in low permeability soil layers. These effects also can cause the realignment of interstitial fines (silts and clays), thereby increasing the hydraulic conductivity of the final cover. As a result, determine the maximum depth of frost penetration at a site and design covers accordingly (in other words, ensure barrier layers are below the maximum frost penetration depth).

Information regarding the maximum frost penetration depth for a particular area can be obtained from the Natural Resource Conservation Service with the U.S. Department of Agriculture, local utilities, construction companies, local universities, or state agencies. Figure 1 illustrates the regional depth of frost penetration. Ensure that vegetation layers are thick enough to ensure that any geomembrane and the low permeability soil layers in the final cover are placed below the maximum frost penetration depth.

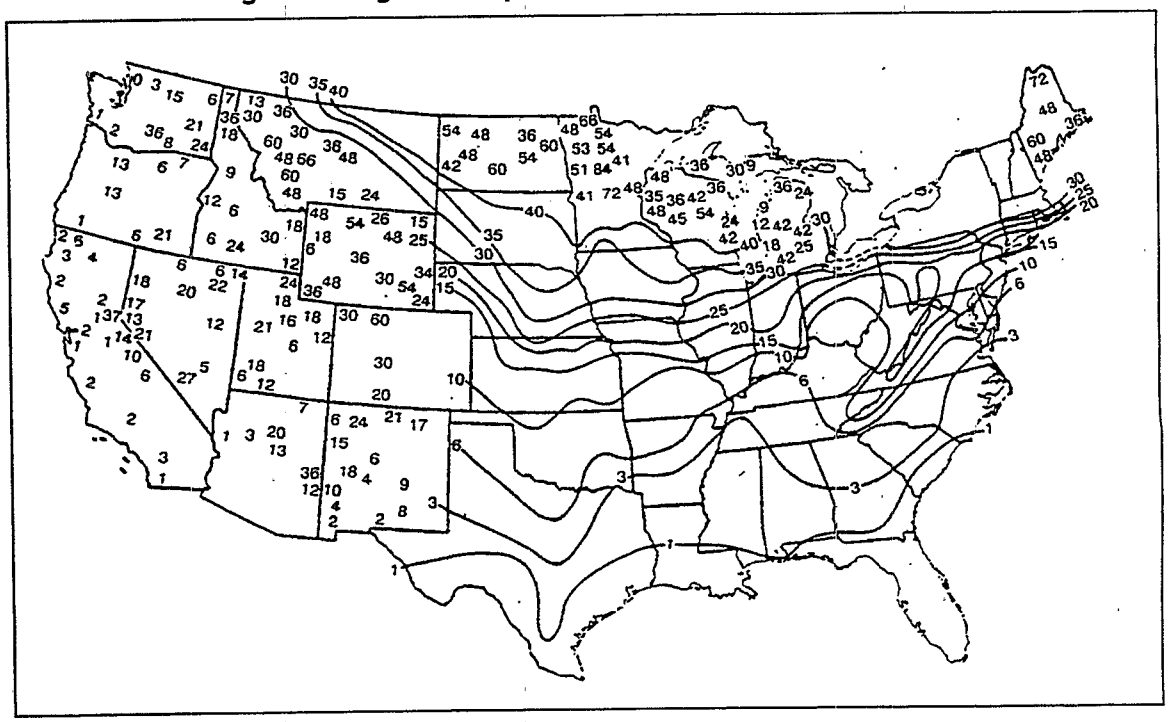
How can settlement and subsidence affect a final cover?

When waste consolidates, settlement and subsidence can result. Excessive settlement and subsidence can significantly impair the integrity of the final cover system by causing ponding of water on the surface, fracturing of low permeability infiltration layers, and failure of geomembranes. The degree and rate of waste settlement are difficult to estimate; however many industrial solid wastes decompose at such a slow rate that settlement is minimal.

How can erosion affect the performance of a final cover?

Erosion can adversely affect the performance of the final cover of a unit by causing rills that require maintenance and repair. Extreme erosion may lead to the exposure of the infiltration layer, initiate or contribute to sliding failures, or expose the waste. Anticipated erosion due to surface-water runoff for a given design criteria may be approximated using the USDA Universal Soil Loss Equation (U.S. EPA 1989a). By evaluating erosion loss, you may be able to optimize the final cover design to reduce maintenance through selection of the best available soil materials. A vegetative cover not only

Figure 1. Regional Depth of Frost Penetration in Inches



Source: U.S. EPA. 1989a. Seminar publication: Requirements for hazardous waste landfill design, construction and closure.

improves the appearance of a unit, but it also controls erosion of the final cover. The vegetation components of the erosion layer should have the following characteristics:

- Locally adapted perennial plants that are resistant to various climatic changes reasonably expected to occur at the site;
- Roots that will not disrupt the low-permeability layer;
- The ability to thrive in low-nutrient soil with minimum nutrient addition; and
- The ability to survive and function with little or no maintenance.

Why are interfacial and internal friction properties for cover components important?

Adequate friction between cover components, such as geomembrane barrier layers and soil drainage layers, as well as between any geosynthetic components, is required to prevent extensive slippage or interfacial shear. Water and ice may affect the potential for cover components to slip. Sudden sliding can tear geomembranes or cause sloughing of earthen materials. Internal shear may also be a concern for composite or geosynthetic clay liner materials. Measures to improve stability include using flatter slopes or textured geosynthetic membranes, geogrids designed to resist slipping forces, or otherwise reinforcing the cover soil.

Can dry soil materials affect a final cover?

Desiccation, the natural drying of soil materials, may have an adverse affect on the soil layers, compromising the final cover. Although this process is most commonly associated with layers of low permeability soil, such as clay, it can cause problems with other soil types as well. Desiccation causes cracks in the soil surface extending downward. Cover layers are not very thick, and therefore, these cracks can extend through an entire layer, radically changing its hydraulic conductivity or permeability. Care should be taken to detect desiccation at an early stage in time to mitigate its damage. Also, the tendency for final covers to become dry makes root penetration even more of a problem in that plants respond to drought by extending their root systems downward.

Can plants and animals have an effect on a final cover?

When selecting the plant species to include in the vegetative cover of a waste management unit, consider the potential for root systems to grow through surface cover layers and penetrate underlying barrier layers. Such penetration will form preferential pathways for water infiltration and compromise the integrity of the final cover system. Similarly, the presence of burrowing animals should be foreseen when designing the final cover system. Such animals may burrow in the surface layers and can potentially breach the underlying barrier layer. Strategies for mitigating the effects described here are discussed below in the context of protection layers composed of gravel or cobbles.

Is it necessary to stabilize wastes?

Before installing a final cover, liquid or semi-liquid wastes may need to be stabilized or solidified. Stabilization or solidification may be necessary to allow equipment on the unit to install the final cover and/or to ensure adequate support, or bearing capacity, for the final cover. With proper bulk cover technique, it may be feasible to place the cover over a homogeneous gel-like semi-liquid waste. When selecting a stabilization or solidification process, consider the effectiveness of the process and its compatibility with the wastes. Performance specifications for stabilization or solidification processes include leachability, free-liquid content, physical stability, bearing capacity, reactivity, ignitability, biodegradability, strength, permeability, and durability of the stabilized and solidified waste. Consider seeking professional assistance to properly stabilize or solidify waste prior to closure.

Where solidification is not practical, consider construction of a specialized lighter weight cover system over unstable wastes. This involves using geogrids, geotextiles, geonets, geosynthetic clay liners, and geomembranes, in conjunction with each other. For more detail on this practice, consult the paper by Robert P. Grefe, *Closure of Papermill Sludge Lagoons Using Geosynthetics and Subsequent Performance*, and the Geosynthetic Research Institute Proceedings, *Landfill Closures: Geosynthetics Interface Friction and New Developments*, cited in the Resources section.

How can I stabilize wastes?

Many stabilization and solidification processes require the mixing of waste with other materials, such as clay, lime, and ash. These processes include either sorbents or encapsulating agents. Sorbents are nonreactive

and nonbiodegradable materials that soak up free liquids to form a solid or near-solid mass. Encapsulating agents enclose wastes to form an impermeable mass. The following are examples of some commonly used types of waste stabilization and solidification methods.

- **Cement-based techniques.** Portland cement can use moisture from the waste (sludge) for cement hydration. The end product has high strength, good durability, and retains waste effectively.
- **Fly ash or lime techniques.** A combination of pozzolanic fly ash, lime, and moisture can form compounds that have cement-like properties.
- **Thermoplastic techniques.** Asphalt, tar, polyolefins, and epoxies may be mixed with waste, forming a semirigid solid after cooling.
- **Organic polymer processes.** This technique involves adding and mixing monomer with a sludge, followed by adding a polymerizing catalyst. This technique entraps the solid particles.

After evaluating and selecting a stabilization or solidification process, conduct pilot-scale tests to address issues such as safety, mix ratios, mix times, and pumping problems. Testing will help assess the potential for an increase in waste volume. It will also help to plan the production phase, train operators, and devise construction specifications.

When conducting full-scale treatment operations, options exist for adding and mixing materials. These options may include in-situ mixing and mobile plant mixing. In-situ mixing is the simplest technique, using common construction equipment, such as backhoes, excavators, and dump trucks. In-situ mixing is most suitable where large amounts of materials are added to stabilize or solidify the waste. The existing waste management area, such as a surface impoundment, can be used as the mixing area. The in-situ mixing process is open to the atmosphere, so environmental and safety issues, such as odor, dust, and vapor generation, should be taken into consideration. For mobile plant mixing, wastes are removed from the unit, mechanically mixed with treatment materials in a portable processing vessel, and deposited back into the unit. Mobile plant mixing is generally used for treating sludges and other wastes with a high liquid content.

C. Components of a Final Cover

Cover systems can be designed in a variety of ways to accomplish closure goals. This flexibility allows a final cover design system to integrate site-specific technical considerations that may affect performance. This section discusses the potential components or layers of a final cover system, their functions, and appropriate materials for each layer. Since the materials used in cover systems are the same as those used in liner systems, refer to the chapter on designing and installing liners for a more detailed discussion of the engineering properties of the various materials. Table 1 presents the types of layers and typical materials that may exist in a final cover. The minimum appropriate thicknesses of each of the five types of layers depends upon many factors including site drainage, erosion potential, slopes, types of vegetative cover, type of soil, and climate.

What function does the surface layer serve?

The role of the surface layer in the final cover system is to promote the growth of native, nonwoody plant species, minimize erosion, restore the aesthetics of the site, and

Table 1
Types of layers in Final Cover Systems

Layer	Type of Layer	Typical Materials
1	Surface (Erosion, Vegetative Cover) Layer	Topsoil, Geosynthetic Erosion Control Layer, Cobbles
2	Protection Layer	Soil, Recycled or Reused Waste Materials, Cobbles
3	Drainage Layer	Sand and Gravel; Geonet or Geocomposite; Chipped or Shredded Tires
4	Barrier (Infiltration) Layer	Compacted Clay, Geomembrane, Geosynthetic Clay Liner
5	Foundation/Gas Collection Layer	Sand or Gravel, Soil, Geonet or Geotextile, Recycled or Reused Waste Material

protect the barrier layer. The surface layer should be thick enough so that the root systems of the plants do not penetrate the underlying barrier layer. The vegetation on the surface layer should be resistant to drought and temperature extremes, able to survive and function with little maintenance, and also be able to maximize evapotranspiration, which will limit water infiltration to the barrier layer. Consult with agriculture or soil conservation experts concerning appropriate cover vegetation. Finally, the surface layer should be thick enough to withstand long-term erosion and to prevent desiccation and freeze/thaw effects of the barrier layer. The recommended thickness for the surface layer is at least 12 inches. Consult with the state agency to determine the appropriate minimum thickness in cold climates to protect against freeze-thaw effects.

What types of materials can be used in the surface layer?

Topsoil has been by far the most commonly used material for surface layers. The principal advantages of using topsoil in the surface layer include its general availability and its suitability for sustaining vegetation. When topsoil is used as a surface layer, the roots of plants will reinforce the soil, reduce the rate of erosion, decrease run-off, and remove water from the soil through evapotranspiration. If topsoil is to be used in the surface layer, the soil should have sufficient water-holding capacity to sustain plant growth. There are some concerns with regard to using topsoil. For example, topsoil requires ongoing maintenance, especially during periods of drought or heavy rainfall. Prolonged drought can lead to cracking in the soil, creating preferential pathways for water infiltration. Heavy rainfall can lead to erosion causing rills or gullies, especially on newly-seeded or steeply sloping covers. If the topsoil does not have sufficient water holding capacity, it may not adequately support surface plant growth, and evapotranspiration may excessively dry the soils. In this case, irrigation may be required to restore the water balance within the soil structure. Topsoil is also vulnerable to penetration by burrowing animals.

Geosynthetic erosion control material can be used as a cover above the topsoil to limit erosion prior to the establishment of a mature vegetative cover. The geosynthetic material can include embedded seeds to promote plant growth, while minimizing soil run-off. It can be anchored or reinforced to add stability on steeply sloped covers. Geosynthetic material, however, does not enhance the water-holding capacity of the soil. In arid or semi-arid areas, therefore, the soil may still be prone to wind and water erosion if its water-holding capacity is insufficient.

Cobbles may be a suitable material for the surface layer in arid areas or on steep slopes which might hinder the establishment of vegetation. If they are large enough they will provide protection from wind and water erosion without washout. Cobbles can also protect the underlying barrier layer from intrusion by burrowing animals, but cobbles may not be available locally, and their use does not protect the underlying barrier layer from water infiltration. Because cobbles create a porous surface through which water can percolate, they do not ordinarily support vegetation. Wind-blown soil material can fill voids between cobbles, and plants may establish themselves in these materials. This plant material should be removed, as its roots are likely to extend into the underlying barrier layer in search of water.

What function does the protection or biotic barrier layer serve?

A protection or biotic barrier layer may be added below the surface layer, but above the drainage layer, to protect the latter from intrusion by plant roots or burrowing animals. This layer adds depth to the surface layer, increasing its water storage capacity and protecting underlying layers from freezing and erosion. In many cases, the protection layer and the surface layer are combined to form a single cover layer.

What types of materials can be used in the protection layer?

Soil will generally be the most suitable material for this layer, except in cases where special design requirements exist for the protection layer. The advantages and disadvantages of using soil in the protection layer are the same as those stated above in the discussion of the surface layer topsoil. Factors impacting the thickness and type of soil to use as a protection layer include freeze and thaw properties and the interaction between the soil and drainage layers. Other types of materials that may be used in the protection layer include cobbles with a geotextile filter, gravel and rock, and recycled or reused waste.

Cobbles with a geotextile filter can form a good barrier against penetration by plant roots and burrowing animals in arid sites. The primary disadvantage is that cobbles have no water storage capacity and allow water percolation into underlying layers.

Gravel and rock are similar to cobbles since they can form a good barrier against penetration by plant roots and burrowing animals. Again, this use is usually only considered for arid sites, because gravel and rocks have no

water storage capacity and allow water percolation into underlying layers.

Recycled or reused waste materials such as fly ash and bottom ash may be used in the protection layer, when available. Check with the state agency to verify that use of these materials is allowable. The advantages of using these materials in the protection layer are that they store water that has infiltrated past the surface layer, which can then be returned to the surface through evapotranspiration, and that they offer protection against burrowing animals and penetration by roots. If planning to use waste material in the protection layer, consider its impact on surface run-off at the unit's perimeter. Design controls to ensure run-off does not contribute to surface-water contamination. Consult the chapter on protecting surface water for more details on designing run-off controls.

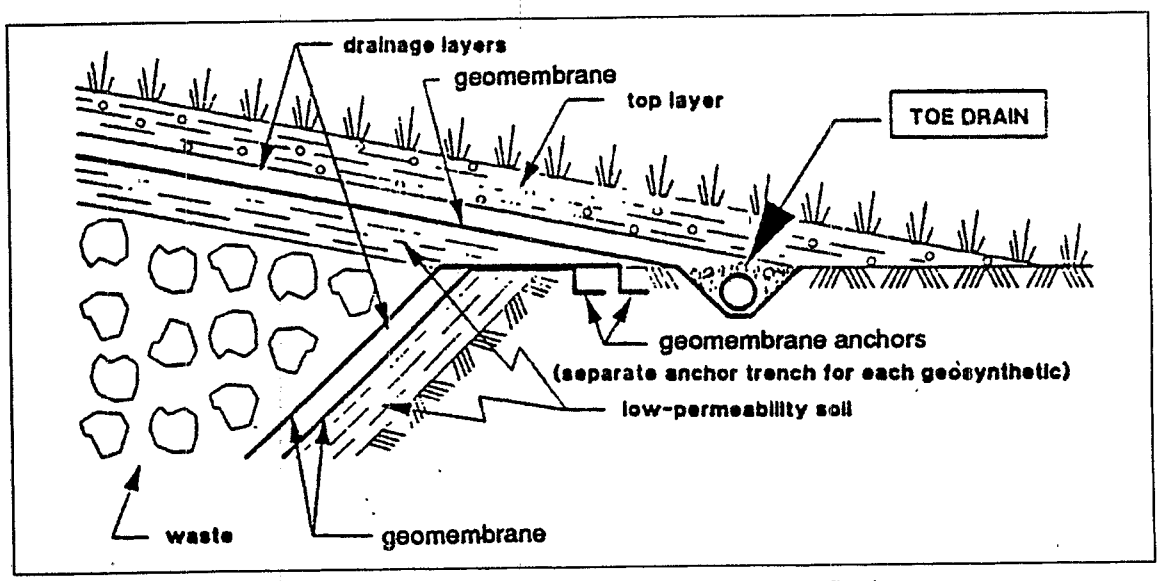
What function does the drainage layer serve?

A drainage layer may be placed below the surface layer, but above the barrier layer, to direct infiltrating water to drainage systems at the toe of the cover (see Figure 2). For drainage layers, the thickness will depend on the level of performance being designed and the properties of available materials. For example, some geonet composites, with a minimal thickness of less than 1 inch, may have a transmissivity equal to a much thicker layer of aggregate or sand. The recommended thickness of the low permeability soil drainage layer is 12 inches with at least a 3 percent slope at the bottom of the layer. Based on standard practice, the drainage layer should have a hydraulic conductivity in the range of 10^{-2} to 10^{-3} cm/sec. Water infiltration control through a drainage layer improves slope stability by reducing the duration of surface and protection layer saturation. In this role, the drainage layer works with vegetation to remove infiltrating water from the cover and protect the underlying barrier layer. If this layer drains the overlying soils too well, it could lead to the need for irrigation of the surface layer to avoid desiccation. Another consideration for design of drainage layers is that the water should discharge freely from the layer at the base of the cover. If outlets at the base become plugged or are not of adequate capacity, the toe of the slope may become saturated and potentially unstable. In addition, when designing the drainage layer, consider using flexible corrugated piping in conjunction with either the sand and gravel or the gravel with geotextile filter material to facilitate the movement of water to the unit perimeter.

What materials can be used in the drainage layer?

Sand and gravel are a common set of materials used in the drainage layer. The principal consideration in their use is the conductivity required by the overall design. There may be cases in which the design requires the drainage of a large amount of water from the surface layer, and the hydraulic properties of the sand and gravel layer may be insufficient to meet these requirements. The advantages of using sand and gravel in the drainage layer include the ability to protect the underlying barrier layer from intrusion, puncture, and temperature extremes. The principal disadvantage to these materials is that they are subject to intrusion from the overlying protective layer that may alter their hydraulic conductivity. Similarly, fines in the sand and gravel can migrate downslope, undermining the stability of the cover slope. A graded filter or a geotextile filter can be used to separate and protect the sand

Figure 2. Drainage Layer Configuration



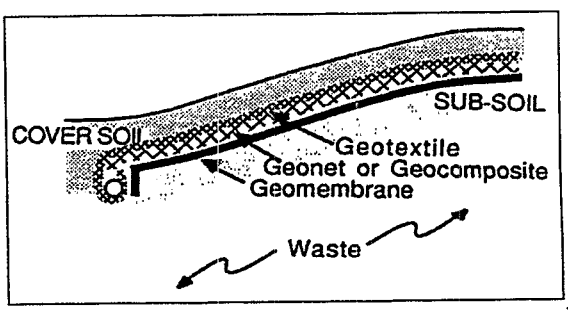
Source: U.S. EPA. 1991. Design and construction of RCRA/CERCLA final covers

and gravel from intrusion by the overlying protection layer.

Gravel with a geotextile filter is also a widely-used design, whose applicability may be limited by the local availability of materials. The gravel promotes drainage of water from the overlying layers, while the geotextile filter prevents the clogging of granular drainage layers. Again, be aware of the possibility that a gravel drainage layer may drain overlying soils so well that irrigation of the surface layer may become necessary. The principal advantage to a gravel/geotextile drainage layer is the engineering community's considerable body of knowledge regarding their use as drainage materials. Other advantages include their ability to protect underlying layers from intrusion, puncture, temperature extremes, and their common availability. The geotextile filter provides a cushion layer between the gravel and the overlying protection layer.

Geonet with geotextile filter materials can be used to form an effective drainage layer directly above a compacted clay or geomembrane liner (see Figure 3). They may be a suitable alternative in cases where other materials, such as sand and gravel, are not locally available. The principal advantage is that lightweight equipment can be used during installation, reducing the risk of damaging the underlying barrier layer.

Figure 3.
Geonet with Geotextile Filter Design for Drainage Layer



Source: U.S. EPA. 1991. Design and construction of RCRA/CERCLA final covers.

The disadvantages associated with these materials are that they provide little protection for the barrier layer against extreme temperature changes, and there can be slippage between the geocomposite interfaces with geomembranes, geotextiles, or low permeability soil barrier materials. Furthermore, problems can arise in the horizontal seaming of the geotextile drainage layer on long slopes.

Chipped or shredded tires are an additional option for drainage layer materials. These have been used for bottom drainage layers in the past and may be suitable for cover drainage layers as well. Consult with the state agency to determine whether this option is an acceptable practice.

What function does the barrier layer serve?

The barrier layer is the most critical component of the cover system because it prevents water infiltration into the waste. It also indirectly promotes the storage and drainage of water from the overlying protection and surface layers, as well as preventing the upward movement of gases. This layer will be the least permeable component of the final cover system. Typically, the hydraulic conductivity of a barrier layer is between 10^{-9} to 10^{-7} cm/sec.

What types of materials can be used in the barrier layer?

Single compacted clay liners (CCLs) are the most common material used as barrier layers in final cover systems. CCL popularity arises largely because of the local availability of materials and the engineering community's extensive experience with their use. Drying and subsidence are the primary difficulties posed by CCLs. When the clay dries, cracks appear and provide preferential pathways along which water may enter the waste, promoting leachate formation, waste decomposition, and gas formation. Dry waste material and gas formation within the unit contribute to drying from below, while a range of climatological conditions, including drought, can affect CCLs from above. Even with extremely thick surface and protection layers, CCLs may still undergo some desiccation.

Clay liners are also vulnerable to subsidence within the waste unit. This problem can first manifest itself during liner construction. As the clay is compacted with machinery, the waste may not provide a stable, even foundation for the compaction process. This will make it difficult to create the evenly measured lifts comprising the liner. As waste settles over time, depressions can form along the top of the CCL. These depressions put differential stresses on the liner, causing cracks which compromise its integrity. For instance, a depression of only 5 to 11 inches across a 6-foot area may be sufficient to crack the liner materials.

Single geomembrane liners are sheets of a plastic polymer combined with other ingredients to form an effective barrier to water infiltration. Such liners are simple and straightforward to install, but they are relatively fragile and can be easily punctured during installation or by movement in surface layer materials. The principal advantage of a geomembrane is that it provides a relatively impermeable barrier with materials that are generally available. It is not damaged by temperature extremes and therefore does not require a thick surface layer. The geomembrane is more flexible than clay and not as vulnerable to cracking as a result of subsidence within the unit. The principal disadvantage is that it provides a point of potential slippage at the interface with the cover soils. Such slippage can tear the geomembrane, even if it is anchored.

Single geosynthetic clay liners (GCLs) are composed of bentonite clay supported by geotextiles or geomembranes held together with stitching or adhesives. These liners are relatively easy to install and have some self-healing capacity for minor punctures. They are easily repaired by patching. The main disadvantages include low shear strength, low bearing capacity, vulnerability to puncture due to relative thinness, and potential for

slippage at interfaces with under- and overlying soil materials. When dry, their permeability to gas makes GCLs unsuitable as a barrier layer for wastes that produce gas, unless the clay will be maintained in a wet state for the entire post-closure period.

Geomembrane with compacted clay liners can be used to mitigate the shortcomings of each material when used alone. In this composite liner, the geomembrane acts to protect the clay from desiccation, while providing increased tolerance to differential settlement within the waste. The clay acts to protect the geomembrane from punctures and tearing. Both act as an effective barrier to water infiltration. The principal disadvantage is slippage between the geomembrane and surface layer materials.

Geomembrane with geosynthetic clay liners can also be used as a barrier layer. As with geomembrane and CCL combinations, each component serves to mitigate the weakness of the other. The geosynthetic material is less vulnerable than its clay counterpart to cracking and has a moderate capacity to self-heal. The geomembrane combined with the GCL is a more flexible cover and is less vulnerable to differential stresses from waste settlement. Neither component is readily affected by extreme temperature changes, and both work together to form an effective barrier layer. For more information on the properties of geosynthetic clay liners, including their hydration after installation, refer to the chapter on designing and installing liners. The potential disadvantage is slippage between the upper and lower surfaces of the geomembrane and some types of GCL and other surface layer materials. The geomembrane is still vulnerable to puncture, so placement of cover soils is important to minimize such damage.

What function does the gas collection layer serve?

The role of the gas collection layer is to control the migration of gases to collection vents. This collection layer is a permeable layer that is placed above the foundation layer. It is often used in cases where the foundation layer itself is not the gas collection layer.

What types of materials can be used in the gas collection layer?

Sand and gravel are the most common materials used for gas collection layers. With these materials, a filter may be needed to prevent infiltration of materials from the barrier layer. Geotextile drains and filters also can make suitable gas collection layers. In many cases, these may be the most cost-effective alternatives. The same disadvantages exist with these materials in the gas collection layer as in other layers, such as slippage and continuity of flow.

D. Capillary-Break Final Covers

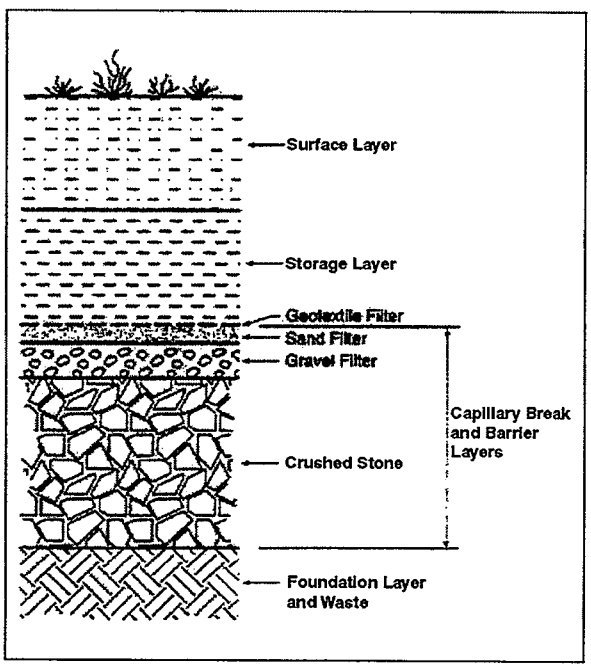
The capillary-break (CB) approach is an alternative design for a final cover system (see Figure 4). This system relies on the fact that for adjacent layers of fine- and coarse-textured soil to be in water-potential equilibrium, the coarse-grained soil (such as crushed stone) will tend to have a much lower water content than the fine-grained soil (such as sand). Furthermore, the conductivity of water through a soil decreases exponentially with its water content, or stated another way, as a soil becomes more dry, its tendency to stay dry increases. Therefore, as long as the strata in a capillary break remain unsaturated (remain above the water table), the overlying fine-textured soil will retain nearly all the water and the coarse soil will behave

as a barrier to water percolation due to its dryness. Since this phenomenon breaks down if the coarse layer becomes saturated, this alternative cover system is most appropriate for semiarid and desert environments.

What types of materials are used in capillary-break covers?

The CB cover system typically consists of five layers: surface, storage, capillary-break, barrier, and foundation. The surface, barrier, and foundation layers play the same role in the cover system as described above. The storage layer consists of fine material, such as silty sand. The capillary-break, or coarse, layer consists of granular materials, such as gravel and/or coarse sand. A fabric filter is often placed between the coarse and fine layers.

Figure 4. Example of a Capillary-Break Final Cover System



Adapted from
<www.hanford.gov/eis/hraeis/eisdoc/graphics/fige-1.gif>

E. The Hydrologic Evaluation of Landfill Performance (HELP) Model

The relative performance of various cover designs can be evaluated with the Hydrologic Evaluation of Landfill Performance (HELP) model, developed by the U.S. Army Corps of Engineers Waterway Experiment Station for EPA (U.S. EPA 1988). The HELP model was designed specifically to support permit writers and engineers in evaluating alternative landfill designs but it can also be used to evaluate various final cover designs.

The HELP model integrates run-off, percolation, and subsurface-water flow actions into one model. The HELP model can be used to estimate the flow of water across and through a final cover. To achieve this, the HELP model uses precipitation and other climatological information to partition rainfall and snow melt into surface run-off, evaporation, and downward infiltration through the barrier layer to the waste. The HELP model essentially divides a waste management unit into layers, each defined in terms of soil type, which is related to the hydraulic conductivity of each. Users fill in data collection sheets that request specific information on the layers and climate, and this information is input to the model. In performing its calculations, the model will take into account the reported engineering properties of each layer, such as slope, hydraulic conductivity, and rates of evapotranspiration, to estimate the amount of precipitation that may enter the waste unit through the final cover. To use the HELP model properly, refer to the HELP Model User's Guide and documentation (U.S. EPA. 1994b, U.S. EPA. 1994c). The HELP model, User's Guide, and supporting documentation may be obtained by calling the National Technical Information Service (NTIS) at 800 553-6847.

Table 2
Types of Recommended Final Cover Systems

Type of Bottom Liner	Recommended Cover System Layers (From top layer down)	Thickness (In inches)	Hydraulic Conductivity (In cm/sec)
Double Liner	Surface Layer	12	not applicable
	Drainage Layer	12[a]	$1x10^{-2}$ to $1x10^{-3}$
	Geomembrane	30mil (PVC) 60mil (HDPE)	-
	Clay Layer	18	less than $1x10^{-5}$
Composite Liner	Surface Layer	12	not applicable
	Drainage Layer	12[a]	$1x10^{-2}$ to $1x10^{-3}$
	Geomembrane	30mil (PVC) 60mil (HDPE)	-
	Clay Layer	18	less than $1x10^{-5}$
Single Clay Liner	Surface Layer	12	not applicable
	Drainage Layer	12[a]	$1x10^{-2}$ to $1x10^{-3}$
	Clay Layer	18	less than $1x10^{-7}$
Single Clay Liner in an Arid Area	Cobble Layer	2-4	not applicble
	Drainage Layer	12[a]	$1x10^{-2}$ to $1x10^{-3}$
	Clay Layer	18	less than $1x10^{-7}$
Single Synthetic Liner	Surface Layer	12	not applicable
	Drainage Layer	12[a]	$1x10^{-2}$ to $1x10^{-3}$
	Geomembrane	30mil (PVC) 60mil (HDPE)	-
	Clay Layer	18	less than $1x10^{-5}$
Natural Soil Liner	Earthen Material	24[b]	No more permeable than base soil

[a]This recommended thickness is for low permeability soil material with at least a 3 percent slope at the bottom of the layer. Some geonet composites, with a minimal thickness of less than 1 inch, may have a transmissivity equal to a much thicker layer of aggregate or sand.

[b]Thickness may need to be increased to address freeze/thaw conditions.

F. Recommended Cover Systems

Figures 5 through 9 present recommended minimum final cover systems. The recommended final cover systems correspond to a waste management unit's bottom liner system. A unit with a single geomembrane bottom liner system, for example, should include, at a minimum, a single geomembrane in its final cover system unless an evaluation of site-specific conditions shows an equivalent reduction in infiltration. Table 2 above summarizes the recommended final cover systems based on the unit's bottom liner system. While the recommended minimum final cover systems

Figure 5. Final Cover System for a Unit With a Double or Composite Liner

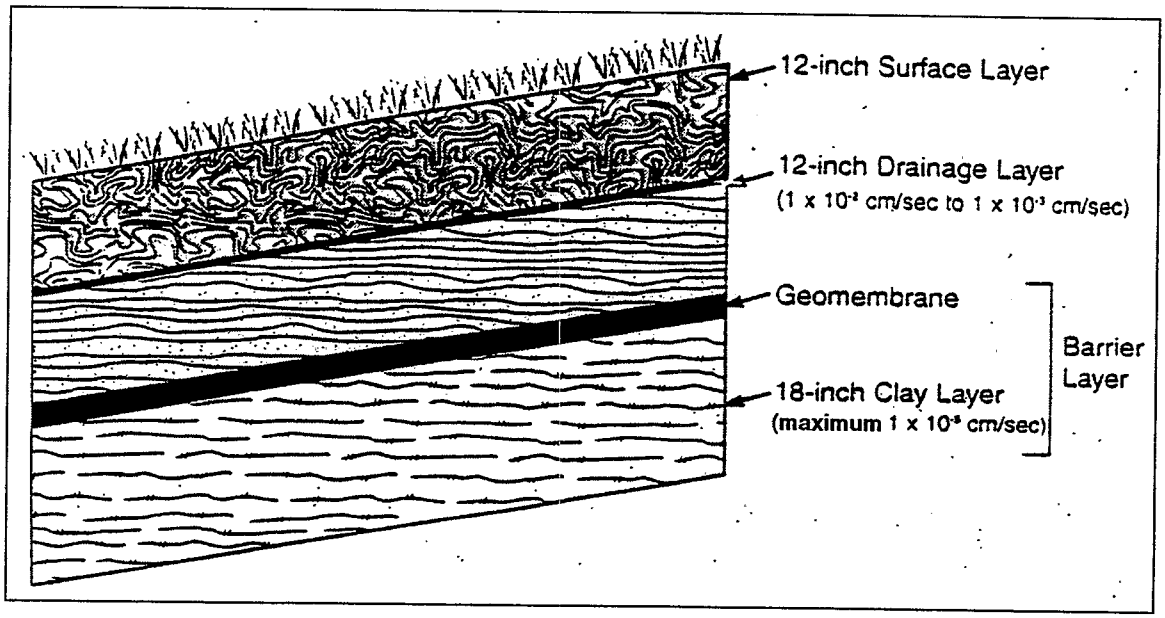


Figure 6. Final Cover System for a Unit With a Single Layer Clay Liner

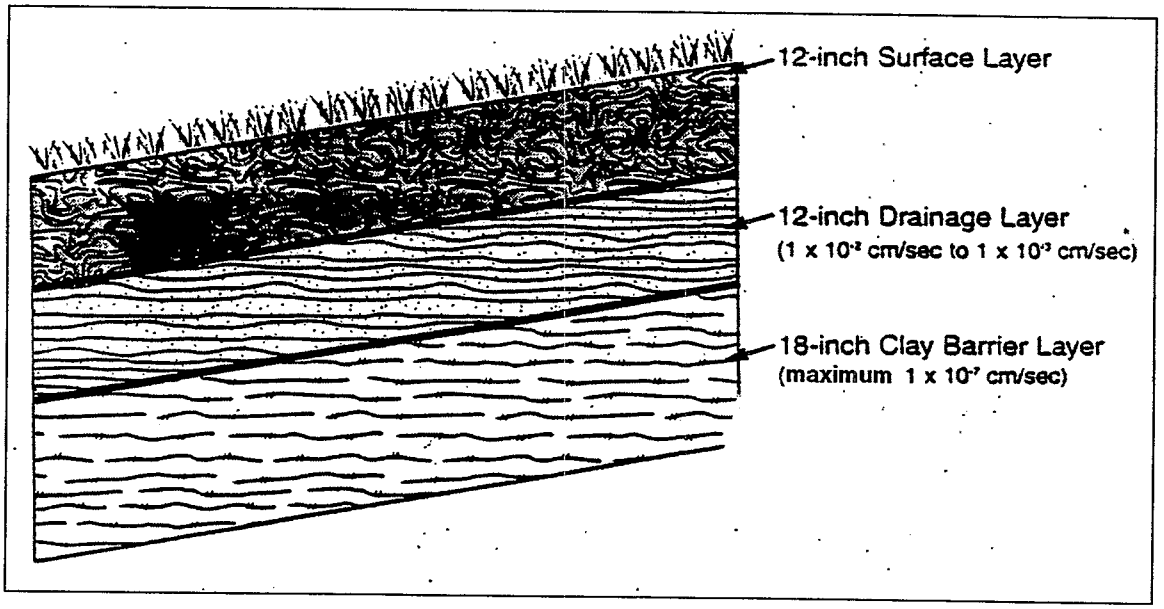


Figure 7. Final Cover System for a Unit With a Single Clay Liner in an Arid Area

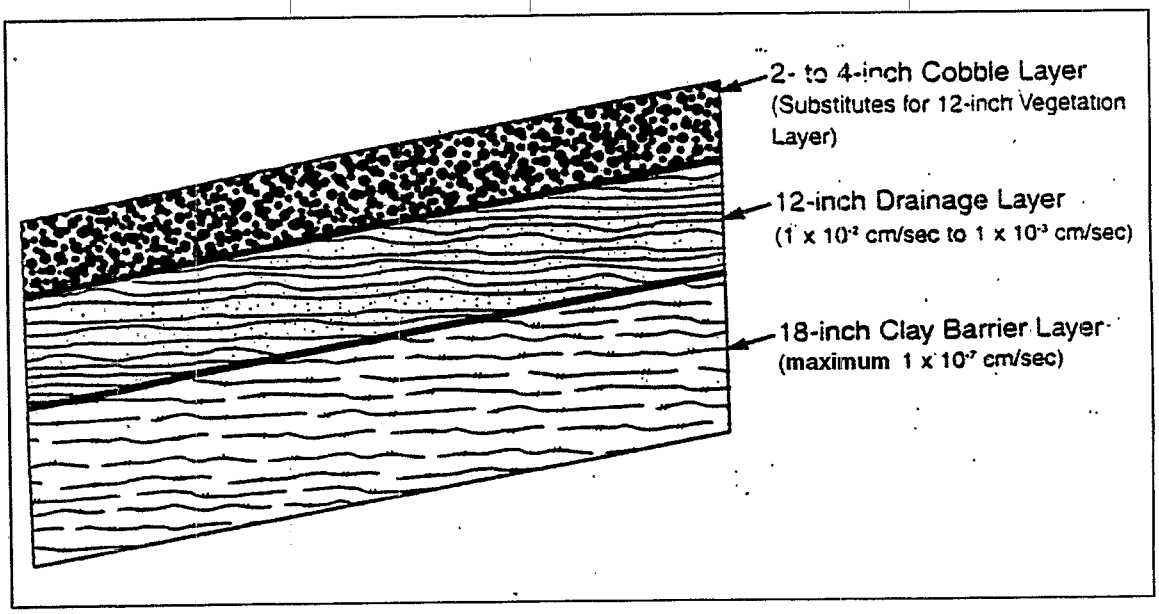


Figure 8. Final Cover System for a Unit With a Single Synthetic Liner

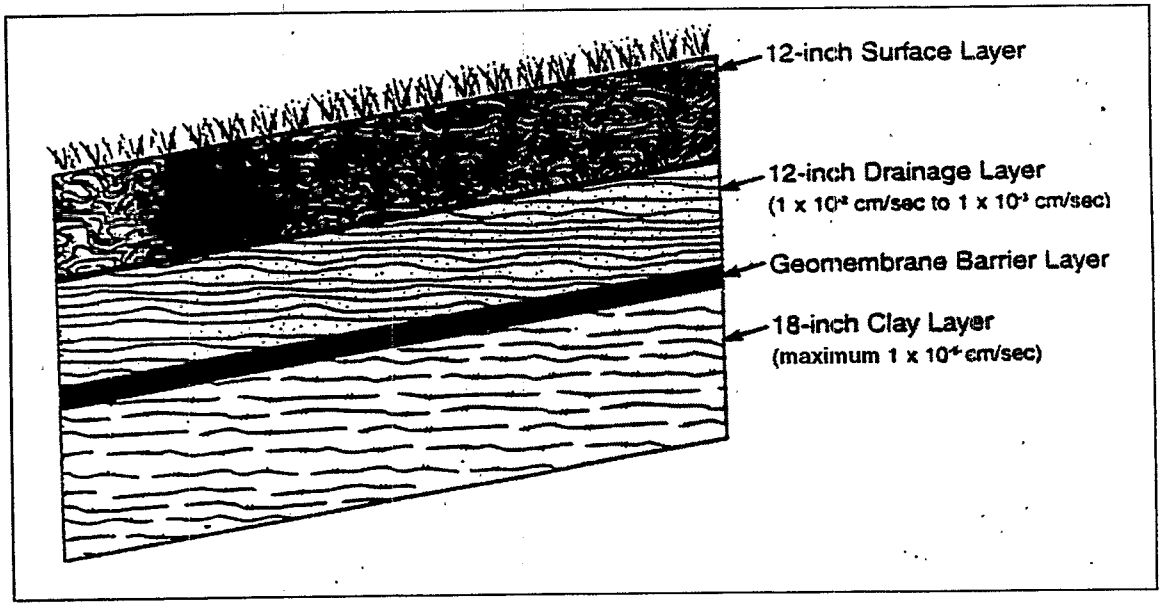
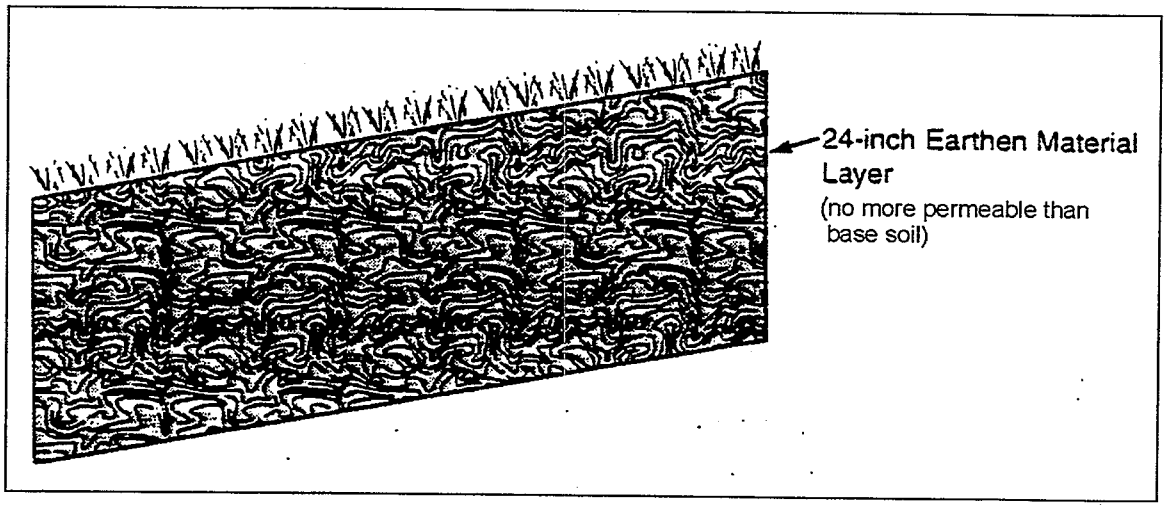


Figure 9. Final Cover System for a Unit With a Natural Soil Liner



include closure layer component thicknesses and hydraulic conductivity, the cover systems can be modified to address site-specific conditions. In addition, consider whether to include a protection layer or a gas collection layer.

IV. Closure by Waste Removal

Closure by waste removal is a term that describes the removal and decontamination of all waste, waste residues, contaminated ground water, soils, and containment devices. This approach is common for waste piles and some surface impoundments.

Removal and decontamination are complete when the constituent concentrations throughout the unit and any areas affected by releases from the unit do not exceed numeric cleanup levels. Check with the state agency to see if it has established any numeric cleanup levels or methods for establishing site-specific levels. In the absence of state cleanup levels, metals and organics should be removed to either statistically equivalent background levels or to maximum contaminant levels (MCLs) or health-based numbers (HBNs).[1]

Metals and organics may have different cleanup levels, but they both need to be based on either local background levels or on health-based guidelines. Future land use considerations may also be important in determining the appropriate level of cleanup. One tool that can be used to help evaluate whether waste removal is appropriate at the site is the risk-based corrective action (RBCA) process described in the chapter on taking corrective action. The RBCA process provides guidance on integrating ecological and human health risk-based decision-making into the traditional corrective action process.

A. Establishing Baseline Conditions

As a good management practice, establish the baseline conditions for a waste management unit. Baseline conditions are the background constituent concentrations at a site prior to waste placement operations. Identifying the types of contaminants that may be present, provides an indication of the potential contamination resulting from the operation of a unit and the level of effort and resources that may be required to reach closure.

[1]Access the Integrated Risk Information System (IRIS), a database of human health effects that may result from exposure to environmental contaminants, to learn about the regulatory and technical basis for MCLs at **<www.epa.gov/ngispgm3/iris/Regulatory.html>**. Call the EPA Risk Information Hotline at 513 569-7254 for more information.

Naturally-occurring elevated background levels that are higher than targeted closure levels may be encountered. In such cases, consult with the state agency to determine whether these elevated background levels are a more appropriate targeted cleanup level. The identification of potential contaminants will also provide a guideline for selecting sampling parameters. In the event that constituents other than those initially identified are discovered through subsequent soil and water sampling, this may indicate that contaminants are migrating from another source.

In some cases, waste contaminants may have been present at the site before a waste management unit was constructed or migrated to the site from another unrelated source. In these situations, closure may still proceed, provided that any contamination originating from the closing unit is removed to appropriate cleanup levels. Determine whether additional remediation is required under other federal or state laws, such as the Resource Conservation and Recovery Act (RCRA) or the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or state cleanup laws.

How should I establish baseline conditions?

Initial soil and ground-water sampling around, within, and below a unit will serve to identify baseline conditions. Sampling can detect contaminant levels that exceed background levels or federal, state, or local health-based benchmarks. Contact local environmental protection officials for guidance on the number and type of samples that should be taken. If the initial round of sampling does not reveal any contaminant levels that exceed benchmarks, proceed with the removal of waste and the restoration of the unit. If the sampling does reveal contamination that exceeds the benchmarks, consider ways to remediate the site in compliance with federal, state, or local requirements.

B. Removal Procedures

Proper removal procedures are vital to the long-term, post-closure care of a unit and surrounding land. Properly removing waste, can minimize the need for further maintenance, thereby saving time and money and facilitating reuse of the land. Perform closure by waste removal in a manner that prevents the escape of waste constituents to the soil, surface water, ground water, and atmosphere. After removing the waste, remove all equipment, bases, liners, soils, and any other materials containing waste or waste residues. Finally, the land should be returned to the appearance and condition of surrounding land areas to the extent possible consistent with the closure and post-closure plans.

Should I have a plan for waste removal procedures?

The waste removal process should be fully described in a closure plan. The removal process description should address estimates of the volumes and types of waste and contaminated equipment or structures to be removed during closure. It should also include the types of equipment to be used, the removal pattern, and the management of loading areas. The closure plan should also detail actions to be taken to minimize and/or prevent emissions of waste during closure activities. For example, if activities during closure include loading and transporting waste in trucks, the closure plan should describe the steps that will be taken to minimize air emissions from windblown dust. Proper quality assurance and quality control during the waste removal process will help ensure that the removal proceeds in accordance with the

waste removal plan. A key component of the waste removal procedure is the consideration of proper disposal of any wastes or contaminated materials.

C. Disposal of Removed Wastes

When a unit is closed by removing waste, waste residues, contaminated ground water, soils, and containment devices, ensure that disposal of these materials is in compliance with state law. If the composition of the waste can not be determined using process knowledge, test it using procedures such as those described in the chapter on characterizing waste. Then consult with the state agency to determine what requirements apply to waste of that kind.

D. Final Sampling and Analysis

The purpose of final sampling and analysis is to ensure that target cleanup levels have been achieved. While initial sampling is intended to establish baseline levels of contaminants, final sampling is used more as a safeguard to make sure levels have not changed. It is important to conduct a final sampling, in addition to the initial sampling, because removal actions can increase the contaminant levels at the site, and sometimes contamination is overlooked in the initial baseline sampling event.

Is it necessary to develop a sampling and analysis plan?

Because of the importance of accurate sampling, develop a sampling and analysis plan to ensure correct sampling procedures. This plan should include information on selection of sampling locations, sampling protocols, methods, quality assurance and quality control procedures, and procedures for analysis of samples and reporting results. The plan should also address the selection of analytical constituents, based on current and historic operations at the facility and closing unit, and the initial review of the wastes present in the unit. Consult with qualified professionals and the state agency to develop the plan and conduct and analyze sampling activities.

Guidance for sample collection, preservation, preparation, and analysis can be found in the following standard testing methods:

- Test Methods for Evaluating Solid Waste, Physical Chemical Methods, Third Edition, U.S. EPA, SW-846
- Methods for Chemical Analysis of Water and Wastes, U.S. EPA, EPA600-4-79-020;
- Standard Methods for the Examination of Water and Wastewater, American Society for Testing Materials (ASTM), American Public Health Association, American Water Works Association, and Water Pollution Control Federation; and
- The ASTM Standard Test Methods for Analysis of Water and Wastes.

How should the sampling data be used?

The results of this sampling event should be compared to the results of the baseline event, and any discrepancies should be noted. The results can be compared to performance measures established at the beginning of the closure process with state or local regulators. Closure plans incorporating waste removal should include a sampling and analysis plan for the initial and final sampling and analysis efforts. The plan should specify procedures to ensure that sample collection, handling, and analysis will result in data of sufficient quality to plan and evaluate closure

activities. The sampling and analysis plan should be designed to define the nature and extent of contamination at/or released from the closing unit. The level of detail in the sampling and analysis plan should be commensurate with the complexity of conditions at the closing unit.

V. Post-Closure Care Considerations When Final Cover Is Used

For units that will close with a final cover, consider the following factors:

- Routine maintenance of the unit's systems, including the final cover, leachate collection and removal systems, surface-water controls, and gas and ground-water monitoring systems where appropriate;
- The names and telephone numbers of facility personnel for emergencies;
- Mechanisms to ensure the integrity of the final cover system, such as posted signs or notifications on deeds;
- The anticipated uses of the property during the post-closure period;
- The length of the post-closure care period;
- Costs to implement post-closure care; and
- Conditions that will cause post-closure care to be extended or shortened.

A. Maintenance

After the final cover is installed, some maintenance and repair will be necessary to keep the cover in good working condition. Maintenance may include mowing the vegetative cover periodically and reseeding, if necessary. Repair the cover when erosion or subsidence occurs. Maintaining healthy vegetation will ensure the stability of slopes, reduce surface erosion, and reduce leachate production by increasing evapotranspiration. A regular schedule for site inspections of maintenance activities during the post-closure period, as well as prompt repair of any problems found at inspection, may help ensure the proper performance of the cover system. Maintenance of the proper thickness of surface and drainage layers will ensure long-term minimization of liquids and protection of geomembranes, if present.

What maintenance and repair activities should I conduct after the final cover has been installed?

In the case of damage to the final cover, determine the cause of damage, so that proper repair measures may be taken to prevent recurrence. For example, if the damage is due to erosion, potential causes may include the length and steepness of slopes, insufficient vegetation growth due to poor planting, or uneven settlement of the waste. Sedimentation basins and drainage swales should be inspected after major storms and repaired or cleaned, as necessary.

Components of the leachate collection and removal system, such as leachate collection pipes, manholes, tanks, and pumps should also receive regular inspection and maintenance. If possible, flush and pressure-clean the collection systems on a regular basis to

reduce sediment accumulation and to prevent clogging caused by biological growth. The manholes, tanks, and pumps should be visually inspected at least annually, and valves and manual controls should be exercised even more frequently, because leachate can corrode metallic parts. Repairs will help prevent future problems, such as leachate overflow from a tank due to pump failure.

Inspect and repair gas and ground-water monitoring wells during the post-closure period. Proper operation of monitoring wells is essential to determine whether releases from a closed waste management unit are occurring. For example, ground-water monitoring wells should be inspected to ensure that they have not been damaged by vehicular traffic or vandalism. Physical scraping or swabbing may be necessary to remove biological clogging or encrustation from calcium carbonate deposits from well screens.

B. Monitoring During Post-Closure Care

Post-closure care monitoring should include the leachate collection system, surface-water controls, the ground-water monitoring system where appropriate, and gas controls where appropriate. Post-closure monitoring will serve as your main source of information about the integrity of the final cover and liners.

What should I consider when monitoring post-closure leachate, ground water, and gas?

The quantity of leachate generated should be monitored, as this is a good indicator of the performance of the closure system. If the closure system is effective, the amount of leachate generated should decrease over time. In addition, the concentration of contaminants in leachate should, in time, reach an equilibrium. An abrupt decline in the contaminant concentration could mean that the cover has failed, and surface water has entered the waste and diluted the leachate.

To ensure leachate has not contaminated ground-water supplies, sample ground water regularly. Regular ground-water monitoring detects changes, or the lack thereof, in the quality of ground water. For a more detailed discussion, consult the chapter on monitoring performance.

As no cover system is impermeable to gas migration, if gas production is a concern at the unit install gas monitoring wells around the perimeter of the unit to detect laterally moving gas. If geomembranes are used in a cover, more gas may escape laterally than vertically. Gas collection systems can also become clogged and stop performing properly. Therefore, periodically check gas vents and flush and pressure-clean those vents not working properly.

C. Recommended Length of the Post-Closure Care Period

The overall goal of post-closure care is to provide care until wastes no longer present a threat to the environment. Threats to the environment during the post-closure care period can be evaluated using leachate and ground-water monitoring data to determine whether there is a potential for migration of waste constituents at levels that might threaten human health and the environment. Ground-water monitoring data can be compared to drinking water standards or health-based criteria to determine whether a threat exists.

Leachate volumes and constituent concentrations may also be used to show that the

unit does not pose a threat to human health and the environment. The threats posed by constituent concentrations in leachate should be evaluated based on potential release of leachate to ground water and surface waters. Consequently, consider doing post-closure care maintenance for some period of time. Individual post-closure care periods may be long or short depending on the type of waste being managed, the waste management unit, and a variety of site-specific characteristics. Contact the state agency to determine what post-closure period the state agency recommends. In the absence of any state guidance on the appropriate length of the post-closure period, consider a minimum of 30 years.

D. Closure and Post-Closure Cost Considerations

The facility manager of a closed industrial unit, is responsible for that unit. To ensure long-term protection of the environment, account for the costs of closure and post-closure care when making initial plans. There are guidance documents available to help plan for the costs associated with closing a unit. For example, estimating guides by the R.S. Means Co. provide up-to-date costs for most construction-related work, such as moving soil, cost of material and labor for installing piping. Appendix I also presents an example of a closure/post-closure cost estimate form. Appendix II contains some sample cost estimating worksheets to assist in determining the cost of closure.[2] Also consider obtaining financial assurance mechanisms so that the necessary funds will be available to complete closure and post-closure care activities if necessary. Financial assurance fosters long-range financial planning and encourages internalization of the future costs associated with waste management units. It also promotes proper design and operating practices, because the costs for closure and post-closure care are often less for units operated in an environmentally protective manner. Check with the state agency to determine whether financial assurance is required and what types of financial assurance mechanisms may be acceptable.

The amount of necessary financial assurance is based on site-specific estimates of the costs of closure and post-closure care. The estimates should reflect the costs that a third party would incur in conducting closure and post-closure activities. This recommendation ensures adequate funds will be available to hire a third party to carry out necessary activities. Consider updating the cost estimates annually to account for inflation and whenever changes are made to the closure and post-closure plans. For financial assurance purposes, if a state does not have a regulation or guidance regarding the length of the post-closure care period, 30 years should be used as a planning tool for developing closure and post-closure cost estimates.

Financial assurance mechanisms do not force anyone to immediately provide full funding for closure and post-closure care. Rather, they ensure future availability of such funds. For example, trust funds may be built up gradually during the operating life of a waste management unit. By having an extended "pay-in" period for trust funds, the burden of funding closure and post-closure care will be spread out over the economic life of the unit. Alternatively, use a corporate financial test or third-party alternatives, such as surety bonds, letters of credit, insurance, or guarantees.

[2]These worksheets were generated from CostPro©: Closure and Post-Closure Cost Estimating Software. CostPro© is available for a fee from Tetra Tech EM Inc.. Contact Steve Jeffords at 404 225-5514, or 285 Peach Tree Center Avenue, Suite 900, Atlanta, GA, 30303.

What costs can I expect to be associated with the closure of a unit?

The cost of constructing a final cover or achieving closure by waste removal will depend on site-specific activities. Consider developing written cost estimates before closure procedures begin. For closure by means of a final cover, the cost of constructing the final cover will depend on the complexity of the cover profile, final slope contours of the cover, whether the entire unit will be closed (or partial closures), and other site-specific factors. For example, the components of the final cover system, such as a gas vent layer or biotic layer, will affect costs. In addition, closure cost estimates would also include final cover vegetation, run-on and run-off control systems, leachate collection and removal systems, ground-water monitoring wells, gas monitoring systems and controls, and access controls, such as fences or signs. Closure costs may also include costs for construction quality assurance costs, engineering fees, accounting and banking fees, insurance, permit fees, legal fees, and, where appropriate, contingencies for cost overruns, reworks, emergencies, and unforeseen expenses.

For closure by means of waste removal, closure costs would include the costs of removal procedures, decontamination procedures, and sampling and analysis. Closure costs should also consider the costs for equipment to remove all waste, transport it to another waste management unit, and properly dispose of it. In addition, fugitive dust emission controls, such as dust suppression practices, may need to be included as a closure cost.

What costs can I expect to be associated with post-closure care?

After a waste management unit is closed, conduct monitoring and maintenance to ensure that the closed unit remains secure and stable. Consider the costs to conduct post-closure care and monitoring for at least 30 years (in the absence of a state regulation or guidance). If a unit is successfully closed by means of waste removal, no post-closure care costs would be expected. Post-closure care costs should include both annual costs, such as monitoring, and periodic costs, such as cap or monitoring well replacement.

For units closed by means of a final cover, consider the costs for a maintenance program for the final cover and associated vegetation. This program may include repair of damaged or stressed vegetation, and maintenance of side slopes. Costs to maintain the run-on and run-off control systems, leachate collection and removal systems, and ground-water and gas monitoring wells should also be expected. In addition, sampling and analysis costs may need to be factored into the post-closure cost estimates.

Post-closure costs should be updated annually as a record of actual unit costs is developed. Some costs, such as erosion control and ground-water sampling, may be reduced over time as the vegetation on the cover matures and a meaningful amount of monitoring data is accumulated. Due to site-specific conditions, a shorter or longer post-closure period may be determined to be appropriate.

How can I obtain long-term financial assurance for my unit?

Some of the different forms of financial assurance mechanisms include prepayment,

surety, insurance, guarantee, corporate guarantees, and financial tests. Prepayment is a method whereby cash, liquid assets, certificates of deposit, or government securities are deposited into a fund controlled by a trustee, escrow agent, or state agency. The prepayment amount should be such that the principal plus accumulated earnings over the projected life of the waste management unit would be sufficient to pay closure and post-closure care costs. Surety, insurance, and guarantee are methods to arrange for a third party to guarantee payment for closure and post-closure activities if necessary. A financial test is an accounting ratio, net worth, bond rating, or combination of these standards that measures the financial strength of a firm. By passing a financial test, it is determined that one has the financial strength to pay for closure and post-closure costs.

A more detailed list of examples of financial assurance mechanisms may be found in Appendix III. These mechanisms may be used individually or in combination. This guidance, however, does not recommend specific acceptable financial assurance mechanisms.

Action Items for Performing Closure and Post-Closure

Consider the following while developing closure and post-closure care activities for industrial waste management units.

- ☐ Develop a closure and post-closure plan, specifying the activities, unit type, waste type, and schedule of the closure.
- ☐ If using a final cover to accomplish closure:
  - — Include the specifications for the final cover in the closure plan;
  - — Determine whether the waste will need stabilization or solidification prior to constructing the final cover;
  - — Address site-specific factors that may affect cover performance;
  - — Select the appropriate materials to use for each layer of the final cover;
  - — Evaluate the effectiveness of the final cover design using an appropriate methodology or modeling program;
  - — Establish a maintenance plan for the cover system;
  - — Establish a program for monitoring leachate collection, ground-water quality, and gas generation during the post-closure period; and
  - — Ensure proper quality assurance and quality control during final cover installation and post-closure monitoring.
- ☐ If accomplishing closure by waste removal:
  - — Include estimates of the waste volume and contaminated equipment to be removed during closure;
  - — Establish baseline conditions and check to see if the state requires numeric cleanup levels;
  - — Develop removal procedures;
  - — Develop a sampling and analysis plan; and
  - — Ensure proper quality assurance and quality control during sampling and

Action Items for Performing Closure and Post-Closure (cont.)

- ☐ Determine what post-closure activities will be appropriate at the site.
- ☐ Estimate the costs of closure and post-closure care activities and consider financial assurance mechanisms to help plan for these future costs.

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Glossary

24-hour, 25-year storm event — a rainfall event of 24 hours duration and of such a magnitude that it has a 4 percent statistical likelihood of occurring in any given year.

acceptance and conformance testing — methods used to evaluate the performance of geomembranes. While the specific ASTM test methods vary depending on geomembrane type, recommended acceptance and conformance testing for geomembranes includes evaluation of thickness, tensile strength and elongation, and puncture and tear resistance testing, as appropriate.

access controls — measures, such as fences or security guards, used to restrict entry to a site.

active gas control systems — mechanical means, such as a vacuum or pump, to forcibly remove gas from a waste management unit.

adsorption — the process by which molecules of gas, liquid, or dissolved solids adhere to the surface of other particles, such as activated carbon or clay.

aerobic processes — a biochemical process or condition occurring in the presence of oxygen.

agronomic rate — in land application, a waste application rate designed to provide the amount of nitrogen needed by a crop or vegetation to attain a desired yield, while minimizing the amount of nitrogen that will pass below the root zone of the crop or vegetation to ground water.

anaerobic processes — a biological process that reduces organic matter to compounds such as methane and carbon dioxide in an oxygen-free environment.

anchor trench — a long, narrow ditch along the perimeter of a unit cell in which the edges of a geomembrane are buried or secured.

annular seal — impermeable material used to prevent infiltration of surface water and contaminants into the space between the borehole wall and the groundwater well casing.

attenuation — the process by which a compound is reduced in concentration over time through chemical, physical and biological processes such as adsorption, degradation, dilution, and transformation.

Atterberg limits — a soil's plastic limit (percent moisture at which soil transitions from solid to plastic) and its liquid limit (percent moisture at which soil transitions from plastic to liquid); useful in characterizing soil plasticity when designing liners with clay soils.

barrier (infiltration) — in a final cover system, a layer preventing water infiltration into the waste, indirectly promoting the storage and drainage of water from the overlying protection and surface layers, and preventing the upward movement of gases.

Glossary (cont.)

barrier walls	low permeability partitions used to direct uncontaminated groundwater flow around a disposal site or to prevent contaminated material from migrating from a site.
bathtub effect	the buildup of leachate within a unit that occurs when the cover system is more permeable than the liner. Leachate accumulates due to the infiltration rate through the cover system exceeding the exfiltration rate through the liner system.
bench-scale treatability study	a study used to evaluate the effectiveness of one or more potential treatment remedies. It establishes the validity of a technology and generates data indicating the remedy's potential to meet performance goals.
berm	a raised flow diversion structure made from compacted earth or rock fill and used to buttress a slope and prevent run-on from entering a waste management unit.
best management practices (BMPs)	measures used to reduce or eliminate contaminant releases to the environment. BMPs can take the form of a process, activity, or physical structure.
bioaccumulation	the uptake and concentration of substances, such as waste constituents, by exposed organisms. This phenomenon has the potential to cause high concentrations especially in the tissues of higher predators.
biochemical oxygen demand (BOD)	the amount of oxygen consumed in the biological processes that break down organic matter (typically measured in mg oxygen per L waste or leachate).
biodegradable organic	significant component of waste used in land application. Carbon-based matter material derived from biological organisms; eventually decomposed by microbes into nontoxic products often useful as plant nutrients. (Compare to **synthetic organic molecules**.)
biological treatment	a process relying primarily on oxidative or reductive mechanisms initiated by microorganisms to stabilize or de-toxify a waste or leachate. Biological treatment can rely either on aerobic or anaerobic processes.
blanks	samples of ground water, air, or other media, collected to determine background contaminants in the field; used for comparison purposes when analyzing monitoring data.
borrow pit	a location where soils are excavated for use as fill or for compaction into liners.
buffer zone	an area between waste management units and other nearby properties,

Glossary (cont.)

such as schools. Buffer zones provide time and space to shield surrounding properties from ongoing activities and disruptions associated with waste management activities.

calcium carbonate equivalent (CCE) — a measure of a waste's ability to neutralize soil acidity—its buffering capacity—compared to pure calcium carbonate.

capillary-break (CB) approach — an alternative design for a final cover system that exploits the relative differences in porosity between soil types to inhibit water infiltration.

carbon to nitrogen ratio — in land application, the ratio of the relative quantities of these two elements in a waste. Carbon is associated with the biodegradable organic matter in a waste, and the carbon to nitrogen ratio reflects the level of inorganic nitrogen available in the soil for plant growth.

cation exchange capacity — the ability of a soil to take up and give off positively charged ions—a process which affects the movement of metals in soil.

chain-of-custody — a document tracking possession of samples from the time of collection record through laboratory analysis. A chain-of-custody record generally includes the date and time of collection, signatures of those involved in the chain of possession, time and dates of possession, and other notations to allow tracking of samples.

chemical oxygen demand (COD) — a measure of the oxygen equivalent of the organic matter in a waste or leachate that is susceptible to oxidation by a strong chemical oxidant such as chromate. COD is used to determine the degree of contamination of a waste or leachate that is not readily biodegradable (see **biochemical oxygen demand**.)

chemical seaming — the use of solvents, cement, or an adhesive to join panels or rolls of a liner. Chemical seaming processes include chemical fusion and adhesive seaming.

chemical treatment — a class of processes in which chemicals are added to wastes or to contaminated media to reduce toxicity, mobility, or volume.

closure — termination of the active life of a waste management unit accompanied by one of the following measures: (1) use of engineered controls, such as a final cover, and post-closure care activities to maintain and monitor the controls; or (2) removal of waste and contaminated containment devices and soils.

Glossary (cont.)

closure plan — a document describing the procedure envisioned for the termination of a waste management unit's active life. Topics addressed often include future land use, whether wastes will be removed or left in place at closure, closure schedule, steps to monitor progress of closure actions, contingency plans, and final cover information.

collection and sedimentation basin — an area that retains runoff long enough to allow solids/particles that are suspended in and being transported by surface water to settle out by gravity.

compacted clay liner (CCL) — a hydraulic barrier layer composed of natural mineral materials (natural soils), bentonite-soil blends, and other materials placed and compressed in layers called lifts.

construction quality assurance (CQA) — a planned series of observations and tests of unit components, such as liners, as they are being built. CQA is designed to ensure that the components meet specifications. CQA testing, often referred to as acceptance inspection, provides a measure of final product quality and its conformance with project plans and specifications.

construction quality control (CQC) — an ongoing process of measuring and controlling the characteristics of unit components, such as liners, in order to meet manufacturer's or project specifications. CQC inspections are typically performed by the contractor to provide an in-process measure of construction quality and conformance with the project plans and specifications, thereby allowing the contractor to correct the construction process if the quality of the product is not meeting the specifications and plans.

control charts — a statistical method of evaluating ground-water monitoring data using historical data for comparison purposes. Appropriate only for initially uncontaminated wells.

corrective action — the process of taking appropriate steps to remediate any contamination.

critical habitat — areas which are occupied by endangered or threatened species and which contain physical or biological features essential to the proliferation of the species.

daily cover — a level of soil and/or other materials applied at the end of a day after waste has been placed, spread, and compacted. Covering the waste helps control nuisance factors, such as the escape of odors, dust, and airborne emissions, and can limit disease vectors.

deed restriction — a notation on a property's deed or title placing limits and conditions on the use and conveyance of the property.

Glossary (cont.)

design storm event — a storm of an intensity, volume, and duration predicted to recur once in a given number of years, whose effects you are designing a system or structure to withstand. (See **24-hour, 25-year storm event**.)

destructive testing — the removal of a sample from a liner seam or sheet to perform tests to assess quality.

dilution/attenuation factor (DAF) — DAFs are used to measure the difference in the concentration of waste-constituents found in the leachate released from a waste management unit at the source and the same leachate subsequently arriving at a receptor well. DAF is defined as the ratio of the leachate concentration at the source to the receptor well concentration.

direct-push sampling — a method of sampling ground water by hydraulically pressing and/or vibrating a probe to the desired depth and retrieving a ground-water sample through the probe. The probe is removed for reuse after the desired volume of ground water is extracted.

diversion dike — a raised land feature built to channel or control the flow of run-on and run-off water around and within a waste management unit.

downgradient well — a ground-water monitoring installation built to detect contaminant plumes from a waste management unit. In the absence of specific state requirements, monitoring points should be no more than 150 meters downgradient from a waste management unit boundary and placed in potential contamination migration pathways.

drainage layer — in a final cover system, a stratum that directs infiltrating water to drainage systems at the toe of the cover. The drainage layer may be placed below the surface or protection layer, but above the barrier layer.

electrical conductivity (EC) — the ability of a sample to carry an electrical charge. Used in land application to estimate the total dissolved solids content of a soil or waste.

emergency response — procedures to address major types of waste management unit emergencies: accidents, spills, and fires/explosions.

environmental justice — the practice of identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of waste management programs, policies, and activities on minority and low-income populations.

environmental stress cracks — imperfections or failures in a liner caused by environmental factors before the liner is stressed to its stated maximum strength.

Glossary (cont.)

EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP)	EPACMTP is a ground-water fate and transport model. It simulates subsurface fate and transport of contaminants leaching from the bottom of a waste management unit and predicts concentrations of those contaminants in a downstream receptor well.
erosion layer	(see **surface layer**.)
expansive soils	soils that may lose their ability to support a foundation when subjected to certain natural events, such as heavy rain, or human-caused events, such as explosions.
fate and transport	a methodology which examines numerous waste and site characteristics to determine how waste constituents move through the environment, how they are degraded or changed, and where they end up.
fault	a failure that occurs in a geologic material, such as rock, when tectonic, volcanic, or other stresses exceed the material's ability to withstand them.
field study	in land application, a scientific investigation of waste, soil, and plant interaction conducted under natural environmental conditions. (Compare to **greenhouse study**.)
filter pack	in a ground-water monitoring well, a quantity of chemically inert material such as quartz sand, that prevents material from surrounding geological formations from entering the well intake and helps stabilize the adjacent formation. May be necessary in boreholes that are oversized with regard to the casing and well intake diameter.
final cover	a system of multiple layers of soil; engineered controls, such as liners; and/or other materials placed atop a closed waste management unit. Typically improves aesthetics, prevents erosion, blocks roots and burrowing animals, collects and drains incoming water, provides a barrier between waste and the environment, and collects gas generated within the unit.
financial assurance mechanism	a funding instrument, such as a bond or trust, that provides or guarantees sufficient financial resources for the closure and post-closure care of a unit in the event the owner or operator is unable to pay.
fines	silt and clay-sized particles.
100-year floodplain	a relatively flat, lowland area adjoining inland and coastal waters that is susceptible to inundation during a 100-year flood. A 100-year flood is a large magnitude occurrence with a 1 percent chance of recurring in any given year.

Glossary (cont.)

foundation/gas collection layer	in a final cover system, a stratum of permeable material such as sand or gravel that controls the migration of gases to collection vents and supports overlying strata.
freeboard	depth (capacity) intended to remain unused above the expected highest liquid level in a liquid storage facility, such as a surface impoundment.
freeze-thaw cycles	climatic changes in which water enters a small crack in a material, expands upon freezing, and thereby expands the crack; the process then repeats itself and the crack progressively grows. It may increase the hydraulic conductivity of low permeability soil layers or damage geomembranes in final covers.
fugitive dust control	dust suppression at a waste management unit through measures such as control watering or chemical dust suppression.
fugitive emission	solid particulate matter, excluding particulate matter emitted from exhaust stacks, that become airborne directly or indirectly as a result of human activity.
gabion	a structure formed from crushed rock encased in wire mesh and used to check erosion and sediment transport.
gas migration	the lateral and/or vertical movement of gas through a waste management unit or its cover systems; may convey methane or other dangerous gases to other sites or buildings if gas monitoring is not implemented.
geogrid	plastic material manufactured into an open, lattice-like sheet configuration and typically used as reinforcement; designed with apertures or openings sized to allow strike through of surrounding rock and soil.
geomembrane	a synthetic sheet composed of one or more plastic polymers with ingredients such as carbon black, pigments, fillers, plasticizers, processing aids, cross-linking chemicals, anti-degradants, and biocides. Geomembranes are used as hydraulic barriers in liner and cover systems.
geophysical monitoring	measurement of changes in the geophysical characteristics of subsurface soils, and in some cases, in the ground water itself, to determine potential changes in ground-water quality.
geosynthetic clay liner (GCLs)	a factory-manufactured, hydraulic barrier typically consisting of bentonite clay (or other very low permeability materials), supported by geotextiles and/or geomembranes held together by needling, stitching, or chemical adhesives.

Glossary (cont.)

geotextile a woven, nonwoven, or knitted synthetic fabric used as a filter to prevent the passing of fine-grained material such as silt or clay. A geotextile may be placed on top of a drainage layer to prevent the layer from becoming clogged with fine material.

gravel soil particles unable to pass through the openings of a U.S. Number 4 sieve, which has 4.76 mm (0.2 in.) openings.

greenhouse study in land application, a scientific investigation of waste, soil, and plant interaction conducted under controlled indoor conditions. (Compare to **field study**.)

ground-water monitoring well a borehole in soil outfitted with components typically including a casing, an intake, a filter pack, and annular and surface seals; used to collect ground water from one or more soil layers for sampling and analysis.

ground-water monitoring program The objectives of a ground-water monitoring program are to measure the effectiveness of a waste management unit's design; to detect changes, or the lack thereof, in the quality of ground water caused by the presence of a waste management unit; and to provide data to accurately determine the nature and extent of any contamination that may occur.

ground-water pump-and-treat a ground-water remediation technology in which contaminated water is pumped to the surface for treatment.

ground-water specialist a scientist or engineer who has received a baccalaureate or post-graduate degree in the natural sciences or engineering and has sufficient training and experience in ground-water hydrology and related fields as may be demonstrated by State registration, professional certifications, or completion of accredited university programs that enable that individual to make sound professional judgements regarding ground-water monitoring, contaminant fate and transport, and corrective action.

health-based number (HBN) a concentration limit for a waste constituent. The HBN is derived from reference doses or reference concentrations that estimate the maximum daily exposure to a waste constituent thru a specific pathway (i.e., ingestion) that would be without appreciable risk of deleterious effects during a lifetime.

hydraulic conductivity the velocity at which a fluid, such as leachate, flows through a material, such as a compacted clay liner.

hydraulic loading capacity in land application, the quantity of liquid or aqueous waste that can be assimilated per unit area by the soil system.

hydraulic overloading in land application, the application of waste in excess of the liquid or water handling capacity of a soil; can result in ponding, anaerobic waste degradation, and odors.

Glossary (cont.)

hydrogeologic characterization study and quantification of a site's subsurface features to determine ground-water flow rate and direction; necessary for an effective ground-water monitoring program.

Hydrologic Evaluation of Landfill Performance (HELP) an EPA model that evaluates the relative performance of various final cover designs, estimates the flow of water across and through a final cover, and determines leachate generation rates.

infiltration the entry of precipitation, ground water, waste, or other liquid into a soil layer or other stratum.

in-situ soil geological material already present at a site; known as an in-situ liner when used as a barrier layer in place of imported soil or synthetic materials.

institutional control a measure that can be used by responsible parties and regulatory agencies to prevent use of or access to a site in a remedial program where, as part of the program, certain levels of contamination will remain on site in the soil or ground water. Can also be considered in situations where there is an immediate threat to human health; may include deed restrictions, restrictive covenants, use restrictions, access controls; notices; registry act requirements, transfer act requirements, and contractual obligations.

interfacial shear the friction or stress between components, such as a compacted clay liner and a geomembrane, that occurs on side slopes of waste management units. When the interfacial shear is inadequate, a weak plane may form on which sliding may occur. The shift in components can compromise liner and cover performance, negatively affecting unit stability.

interim measure in corrective action, a step taken to control or abate ongoing risks before final remedy selection.

internal shear a stress that can lead to tearing of liner or cover components when overlying or underlying pressure upon a liner or cover exceeds its ability to withstand this stress.

ISO 14000 procedures voluntary set of standards for good environmental practices developed by the International Standards Organization (ISO), also known as Environmental Management Standards (EMS).

karst terrain areas containing soluble bedrock, such as limestone or dolomite, that have been dissolved and eroded by water, leaving characteristic physiographic features including sinkholes, sinking streams, caves, large springs, and blind valleys.

land application (see **land application unit**.)

Glossary (cont.)

land application unit — a waste management unit in which waste (such as sludge or wastewater) is spread onto or incorporated into the land to amend the soil and/or treat or dispose of the waste.

landfills — a waste management unit in which waste is compacted in engineered cells for permanent disposal, usually covered daily.

leachate — liquid (usually water) that has percolated through waste and taken some of the waste or its constituents into solution.

leachate concentration — the concentration (usually in mg/L) of a particular waste constituent in the leachate.

leachate collection and removal system — a system of porous media, pipes, and pumps that collect and convey leachate out of a unit and/or control the depth of leachate above a liner.

leachate testing — used to characterize waste constituents and their concentrations, and to estimate the potential amount and/or rate of the release of waste constituents under worst case environmental conditions.

leak detection system (LDS) — also known as a **secondary leachate collection and removal system**; a redundant leachate collection and removal system to detect and capture leachate that escapes or bypasses the primary system. Sudden increases in leachate captured by an LDS can indicate failure of a primary leachate collection and removal system.

lifts — layers of compacted natural mineral materials (natural soils), bentonite-soil blends, and other materials that compose a liner or other compacted stratum.

liner — a hydraulic barrier, such as compacted clay or a geomembrane, used to restrict the downward or lateral escape of waste, waste constituents, and leachate. Liners accomplish this by physically impeding the flow of leachate and/or by absorbing or attenuating pollutants.

in-situ soil. geological material already present at a site; known as an in-situ liner when used as a barrier layer in place of imported soil or synthetic materials.

single liner. a hydraulic barrier consisting of one soil layer, one geomembrane, or any other individual barrier without a second barrier to impede contaminants that might breach it.

composite liner. a liner consisting of both a geomembrane and a compacted clay layer (or a geosynthetic clay liner).

Glossary (cont.)

double liner. a hydraulic barrier between a waste management unit and the natural environment, consisting of primary (top) and secondary (bottom) levels. Each level may consist of compacted clay, a geomembrane, or a composite (consisting of a geomembrane and a compacted clay layer or GCL).

liquefaction occurs when vibrating motions caused by an earthquake turn saturated sand grains in the soil into a viscous fluid, diminishing the bearing capacity of the soil and possibly leading to foundation and slope failures.

lithology the description of geological materials on the basis of their physical and chemical characteristics.

lower explosive limit (LEL) the minimum percentage of a gas by volume in the air that is necessary for an explosion. This level is 5 percent for methane.

lysimeter a device used to measure the quantity or rate of water movement through or from a block of soil or other material. It collects soil-pore liquids by applying a vacuum that exceeds the soil moisture tension; usually a buried chamber made from wide perforated pipe.

material balances used to calculate all input and output streams, such as the annual quantities of chemicals transported to a facility and stored, used, or produced at a facility, and released or transported from a facility as a commercial product or by-product or a waste. Material balances can assist in determining concentrations of waste constituents where analytical test data are limited.

Maximum Achievable Control Technology (MACT) standards national standards that regulate major sources of hazardous air pollutants. Each MACT standard specifies particular operations, processes, and/or wastes that are covered. If a facility is covered by a MACT standard, it must be permitted under Title V.

maximum contaminant level (MCL) the maximum permissible level of a contaminant in water delivered to any user of a public water system.

molding water content for natural soils, the degree of saturation of the soil liner at the time of compaction; influences the engineering properties, such as hydraulic conductivity, of the compacted material.

Monte Carlo analysis an iterative process involving the random selection of model parameter values from specified frequency distributions, followed by simulation of the system and output of predicted values. The distribution of the output values can be used to determine the probability of occurrence of any particular value given the uncertainty in the parameters. In this guidance, used to predict a statistical distribution of exposures and risks for a given site.

Glossary (cont.)

National Ambient Air Quality Standards (NAAQS)	airborne emission limits set by EPA as authorized by the Clean Air Act. EPA has designated NAAQS for the following criteria pollutants: ozone, sulfur dioxide, nitrogen dioxide, lead, particulate matter, and carbon monoxide.
National Emission Standards for Hazardous Air Pollutants (NESHAP)	national standards regulating 188 hazardous air pollutants listed in Section 112(b) of the Clean Air Act Amendments of 1990.
numeric clean-up standard	a state corrective action requirement mandating that a site be cleaned up such that concentrations of a waste constituent do not exceed a set level.
operating plan	a document that specifies methods of running a waste management unit, such as standard waste-handling practices, management and maintenance activities, employee training, and emergency plans; based on comprehensive knowledge of the chemical and physical composition of the waste managed, unit type, operational schedules, and monitoring performed at the unit.
overland flow increased("flood")	land application of liquid waste by irrigation methods; can lead to application surface run-off of waste if not properly managed and, therefore, is regulated by some states and localities.
parametric analysis of variance (ANOVA)	a method of statistical analysis that attempts to determine whether different monitoring wells have significantly different average constituent concentrations.
particulate matter (PM)	a mixture of solid particles and liquid droplets suspended in the atmosphere that can cause a variety of respiratory problems, carry absorbed pollutants far from their source, impair visibility, and stain or damage surfaces, such as buildings or clothes, on which it settles.
passive gas control system	a gas control system using natural pressure and convection mechanisms to system control gas migration and to help vent gas emissions into the atmosphere; may include ditches, trenches, vent walls, perforated pipes surrounded by coarse soil, synthetic membranes, and high moisture, fine-grained soil.
pathogens	potentially disease-causing micro-organisms, such as bacteria, viruses, protozoa, and the eggs of parasitic worms.
peak flow period	the phase of a storm event when flood waters are at their highest level.

Glossary (cont.)

pH A measure of acidity or alkalinity equal to the logarithm of the reciprocal of hydrogen ion (H+) concentration in a medium. pH is represented on a scale of 0 to 14; 7 represents a neutral state; 0 represents the most acid, and 14 the most alkaline.

pH adjustment the neutralization of acids and bases (alkaline substances) and promotion of the formation of precipitates, which can subsequently be removed by conventional settling techniques.

piezometer a well installed to monitor hydraulic head of ground water or to monitor ground-water quality.

pilot-scale treatability study a small study to evaluate the effectiveness of and determine the potential continued development of one or more potential remedies; typically conducted to generate information on quantitative performance, cost, and design issues.

plasticity characteristics parameters describing a material's ability to behave as a moldable material.

plume an elongated and mobile column or band of a contaminant moving through the subsurface.

point of monitoring the location(s) where ground-water is sampled; should be appropriate for site conditions and located at waste management boundary or out to 150 meters downgradient of the waste management unit area.

post-closure care monitoring of a closed waste management unit to verify and document that unacceptable releases from the unit are not occurring. The overall goal is to ensure that waste constituents are contained until such time as containment is no longer necessary.

prediction intervals a statistical method of approximating future sample values from a population or distribution with a specific probability; used with ground-water monitoring data, both for comparison of downgradient wells to upgradient wells (inter-well comparison) and for comparison of current well data to previous data for the same well (intra-well comparison).

process knowledge an understanding of industrial processes used to predict the types of waste generated and to determine the mechanism by which they are generated.

protection layer a stratum in a final cover system that protects the drainage layer from intrusion by plant roots or burrowing animals; located below the surface layer and above the drainage layer.

public involvement dialogue between facility owners and operators and public to share information, identify and address issues and concerns, and provide input into the decision-making process.

Glossary (cont.)

public notice a document, announcement, or information release that publicizes a meeting, decision, operational change, or other information of interest to the public; usually provides the name and address of the facility owner and operator and information about the issue being publicized.

puncture resistance the degree to which a material, such as a liner, will resist rupture by jagged or angular materials which may be placed above or below it.

quality assurance and quality control (QA/QC) procedures in ground-water sampling, steps for collection and handling of ground-water samples to ensure accurate results. In liner construction, steps to ensure that liners are installed according to design and will perform specifications.

rational method a method for calculating the volume of storm water run-off. The rational method approximates the surface water discharge from a watershed using a run-off coefficient, the rainfall intensity, and the drainage area.

receptor a person or other organism that may be exposed to waste constituents, especially an organism whose exposure is addressed by a fate and transport analysis; or, a downgradient ground-water monitoring well that receives ground water which has passed near a waste management unit.

recycling the process of collecting, processing, and reusing waste materials.

redox (oxidation-reduction) potential the capacity of a medium to raise the valence state of molecules (such as metals), add oxygen, or remove hydrogen (oxidation); or to lower the valence state of molecules, remove oxygen, or add hydrogen (reduction).

riprap rock cover used to protect soil in dikes or channels from erosion.

risk-based corrective action (RBCA) an approach to corrective action that integrates the components of traditional corrective action with alternative risk and exposure assessment practices. States and ASTM have developed RBCA as a three stage process.

run-off storm water that flows from a waste management unit to surface waters.

run-on storm water that falls directly on a waste management unit or flows toward the unit from adjoining areas.

saline soil soil with excessive salt concentrations.

sampling parameters for monitoring, those items for which ground water samples will be tested, such as waste constituents reasonably expected to migrate to the ground water and other geochemical indicators of contaminant migration.

seaming process the joining of panels or rolls of a liner using thermal, chemical, or other methods compatible with the properties of the liner material.

Glossary (cont.)

seismic impact zone an area having a 10 percent or greater probability that the maximum horizontal acceleration caused by an earthquake at the site will exceed 0.1g in 250 years. g is a unit of force equal to the force exerted by gravity on a body at rest and used to indicate the force to which a body is subjected when accelerated.

setback the placing of a waste management unit or one of its components some distance from an adjoining property, a geologic feature, or other feature that could affect the unit or be affected by the unit. (Compare to **buffer zone**.)

shear strength for soils, the internal resistance per unit area that a soil mass can offer to resist failure and sliding along any plane inside it; in liner design, indicates the degree to which stability problems and desiccation cracks are likely to occur in liner material (such as clay).

silt fence a barrier consisting of geotextile fabric supported by wooden posts; slows the flow of water and retains sediment as water filters through the geotextile.

slip for soils, to slide downhill in mass movements such as avalanches, landslides, and rock slides; may be caused by inherent properties of the soil or by cutting or filling of slopes during construction.

slippage movement of a geomembrane liner due to a lack of adequate friction between the liner and the soil subgrade or between any geosynthetic components.

sodic soil soil with excessive levels of sodium ions (Na^+) relative to divalent ions, such as calcium ($Ca2^+$) and magnesium ($Mg2^+$).

soil gas sampling collection of gas from soil pores to detect the presence or movement of volatile contaminants and gases, such as carbon dioxide and methane, that are associated with waste degradation.

soil-pore liquids fluids present in spaces between soil particles in the vadose zone; can be collected to determine the type and concentration of contaminants that may be moving within the vadose zone.

soil water content the ratio of the weight of water to the weight of solids in a given volume of soil; usually stated as a percentage and can be greater than 100 percent for very soft clays.

soil water tension a measure of the strength of capillary effects holding water between soil particles; decreases as soil water content increases, so decreases in soil water tension beneath a lined waste management unit may indicate the presence of leachate due to a leaking liner.

solidification processes the conversion of a non-solid waste into a solid, monolithic structure that ideally will not permit liquids to percolate into or leach materials out of the mass; used to immobilize waste constituents.

Glossary (cont.)

soluble salts materials that could dissolve in or are already in solution in a waste. Major soluble salts include calcium, magnesium, sodium, potassium, chloride, sulfate, bicarbonate, and nitrate.

Source Loading and Management Model (SLAMM) an urban nonpoint source water quality model developed by the University of Alabama at Birmingham; useful for designing run-on and run-off controls.

source reduction the prevention or reduction of waste at the point of generation.

spill prevention and response procedures for avoiding accidental releases of waste or other contaminants and promptly addressing any releases that occur.

stabilization process a means of immobilizing waste constituents by binding them into an insoluble matrix or by changing them to insoluble forms.

standard operating procedures established, defined practices for the operation of a waste management unit; useful in maintaining unit safety and protection of human health and the environment; should be recorded in an operating plan to facilitate employees' familiarity.

storm water conveyances pipes, ditches, swales, and other structures or landforms that carry, divert, or direct run-on and/or run-off.

Storm Water Management Model (SWMM) EPA computer model capable of simulating the movement of precipitation and pollutants from the surface through pipe and channel networks, storage treatment units, and finally to surface water; used in the design of run-on and run-off controls.

stratigraphy characterization of the origin, distribution, and succession of geologic strata, such as soil and rock layers.

subsidence lowering of the land surface due to factors such as excessive soil loading, compaction of soil owing to high moisture content, or reduction in waste volume due to degradation; can significantly impair the integrity of the final cover system by causing ponding of water on the surface, fracturing of low permeability infiltration layers, and failure of geomembranes.

sump a low point in a liner system constructed to gravitationally collect leachate from either the primary or secondary leachate collection system.

Glossary (cont.)

surface completion — the part of a ground-water monitoring well constructed at or just above ground level, often consisting of a protective outer casing around the inner well casing, fitted with a locking cap; discourages vandalism and unauthorized entry into the well, prevents damage by contact with vehicles, reduces degradation caused by direct exposure to sunlight, and prevents surface run-off from entering and infiltrating the well.

surface impoundment — a natural or manmade topographic depression, excavation, or diked area designed to hold liquid waste.

surface layer — in a final cover system, a stratum that promotes the growth of native, non-woody plant species, minimizes erosion, restores the aesthetics of the site, and protects the barrier layer.

surface seal — neat cement or concrete surrounding a ground-water monitoring well casing and filling the space between the casing and the borehole at the surface; protects against infiltration of surface water and potential contaminants from the ground surface.

synthetic organic molecules — man-made carbon compounds used in a variety of industrial and agricultural processes, sometimes hazardous, and unlike biodegradable organic matter, not necessarily biodegradable, or if biodegradable, not necessarily broken down into nonhazardous byproducts.

Synthetic Precipitation Leaching Procedure (SPLP) — The SPLP is currently used by several state agencies to evaluate the leaching of TC hazardous constituents from wastes and may be used to assess the risks posed by wastes placed in a landfill and subject to acid rain. The SPLP is designed to determine the mobility of both organic and inorganic analytes present in liquids, soils, and wastes.

tear resistance — the ability of a material, such as a geomembrane, to resist being split due to stresses at installation, high winds, or handling.

tensile behavior — the tendency of a material to elongate under strain.

tensiometer — an instrument that measures soil water tension.

terraces and benches — earthen embankments with flat tops or ridges and channels; used to hold moisture and minimize sediment loadings in run-off.

test pad — in liner design, a small-scale replica of a liner system used to verify that the materials and methods tested will yield a liner that provides the desired hydraulic conductivity.

thermal seaming — the use of heat to join panels or rolls of a liner.

Glossary (cont.)

Title V operating permits established by the Clean Air Act, these permits are required for any facility emitting or having the potential to emit more than 100 tons per year of any air pollutants, as defined by Section 302(g) of the Clean Air Act. Permits are also required for all sources subject to MACT or NSPS standards.

toe the lower endpoint of a slope.

tolerance interval a statistical interval constructed from data designed to contain a portion of a population, such as 95 percent of all sample measurements; used to compare data from a downgradient well to data from an upgradient well.

topography the physical features (configuration) of a surface area including relative elevations and the position of natural and constructed features.

total dissolved solids (TDS) the sum of all ions in solution.

total solids content the sum of suspended and dissolved solids in a liquid waste, usually expressed as a percentage.

Toxicity Characteristic Leaching Procedure (TCLP) The TCLP is most commonly used by EPA and state agencies to evaluate the leaching potential of wastes, and to determine toxicity. The TCLP quantifies the extractability of certain hazardous constituents from solid waste under a defined set of laboratory conditions. It evaluates the leaching of metals, volatile and semi-volatile organic compounds, and pesticides from wastes.

ultraviolet resistance the degree to which a material, such as a geomembrane, can resist degradation and cracking from prolonged exposure to ultraviolet radiation.

unstable area a location susceptible to human-caused or natural events or forces, such as earthquakes, capable of impairing the integrity of a waste management unit.

upgradient well a ground-water monitoring installation built to measure background levels of contamination in ground water at an elevation before it encounters a waste management unit.

upper explosive limit the maximum percentage of a gas by volume in the air that will permit an explosion. This level is 15 percent for methane; at higher percentages, non-explosive burning is still possible.

use restrictions stipulations describing appropriate and inappropriate future uses of a closed site, in an effort to perpetuate the benefits of the remedial action and ensure property use that is consistent with the applied clean-up standard.

vadose zone the soil (or other strata) between the ground surface and the saturated zone; depending on climate, soils, and geology, may be very shallow or as deep as several hundred feet.

Glossary (cont.)

vegetative cover (see **surface layer**.)
layer

volatile organic compounds (VOCs) carbon compounds which tend to evaporate at low to moderate temperatures due to their low vapor pressure.

waste pile a noncontainerized accumulation of solid, nonflowing waste that is used for treatment or storage.

waste reduction waste reduction practices include source reduction, recycling and reuse, and treatment of waste constituents. Waste reduction minimizes the amount of waste that needs to be disposed of in the first place, and limits the environmental impact of those wastes that actually are disposed.

water content (see **soil water content**.)

well casing in a ground-water monitoring well, the pipe or tube lowered into the borehole as the outer wall of the well; supports the sides of the hole and prevents water from entering or leaving the well other than by normal ground-water flow.

well intake (well screen) a perforated segment of a ground-water monitoring well designed to allow ground water to flow freely into the well from an adjacent geological formation while minimizing or eliminating the entrance of fine-grained materials such as clay or sand.

well purging methods procedures for removing stagnant water from a ground-water monitoring well and its filter pack before collecting a sample; employed to ensure collection of samples that accurately represent current ground-water quality.

wellhead protection area (WHPA) the most easily contaminated zone surrounding a wellhead; officially designated for protection in many jurisdictions to prevent public drinking water sources from becoming contaminated.

wetlands areas, such as tidal zones, marshes, and bottomland forests, that are inundated or saturated by surface or ground water at a frequency or duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

working face the area of a waste management unit, especially a landfill, where waste is currently being placed and compacted.

zoning local government classification of land into areas designated for different use categories, such as residential, commercial, industrial, or agricultural; used to protect public health and safety, maintain property values, and manage development.