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DESIGN, PERFORMANCE, AND MONITORING  
OF DREDGED MATERIAL  
CONFINED DISPOSAL FACILITIES IN REGION 5  
Guidance Document

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#### DISCLAIMER

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## ABSTRACT

This guidance document provides design and performance criteria for Confined Disposal Facilities (CDFs) used for long-term containment of dredged materials. Sediment remediation and the implementation of navigational dredging projects require disposal options for dredged materials which are legally permissible, environmentally acceptable, and economically feasible. Contaminated sediments represent a high priority environmental problem, especially in the Great Lakes area. This guidance document presents the regulatory background that influences the dredging and long-term disposal of dredged materials, as well as design and monitoring criteria for CDFs consistent with applicable Federal Regulations, and reflective of the significance and severity of dredged material contamination levels.

Design guidelines are presented in this document that will lead to CDF's providing adequate environmental performance/protection (referred to in this document as AEPP) to the ecosystem adjacent to this CDF. AEPP criteria are developed based on an evaluation of potential contaminant pathways and the impact of such releases on the immediate environment. The fundamental design philosophy used in developing this document was control of contaminant pathways using barriers that are technically and economically feasible for the significant quantities of contaminated dredged sediments that must be safely disposed. Such barriers may, by necessity, generally differ from those commonly used to contain smaller quantities of more highly contaminated materials.

Information within the technical documents is organized as follows:

Section 1	Provides a general overview of contaminated dredged material types, CDF types, and applicable regulations;
Section 2	Reviews the draft EPA/COE dredged material management strategy and develops AEPP criteria for the CDF types;
Section 3	Provides background on dredged material production and sediment remedial activities within Region 5;
Section 4	Reviews the design and performance of existing CDFs and EPA/State remediation projects within Region 5;
Section 5	Defines pathways that allow release of contaminants from CDFs;
Section 6	Provides design recommendations and examples for CDF containment basins;

Section 7	Provides design recommendations and examples for CDF final closures; and
Section 8	Defines operational and monitoring requirements for the post-closure monitoring period.

Appendices are included in this document to provide significant detail on available dredged material remediation technologies, environmental performance requirements, existing Region 5 CDFs, and the use of geosynthetics in sediment containment systems.



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## ACRONYMS

AEPP	Adequate Environmental Performance and Protection
ARAR	Applicable or Relevant and Appropriate Regulation
ARCS	Assessment and Remediation of Contaminated Sediments
ASTM	American Society for Testing and Materials
AVS	Acid Volatile Sulfide
CAA	Clean Air Act
CAD	Contained Aquatic Disposal
CDF	Confined Disposal Facility
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSO	Combined Sewer Overflow
CWA	Clean Water Act
DOE	United States Department of Energy
EEC	European Economic Commission
EIS	Environmental Impact Statement
EP	Extraction Process
EPA	Environmental Protection Agency
EqP	Equilibrium Partitioning
FDA	U.S. Food and Drug Administration
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GAO	General Accounting Office
GLNPO	Great Lakes National Program Office
GLWQA	Great Lakes Water Quality Agreement
HSWA	Hazardous and Solid Waste Amendments (1984)
MCL	Maximum Concentration Level
MPRSA	Marine Protection, Research, and Sanctuaries Act
MSW	Municipal Solid Waste
MTG	Minimum Technology Guidance
NEP	National Estuary Program
NEPA	National Environmental Policy Act
NETAC	National Effluent Toxicity Assessment Center
NMOC	Non-Methane Organic Compounds
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
OERR	Office of Emergency and Remedial Response (Superfund)
OMEP	Office of Marine and Estuarine Protection
QAPP	Quality Assurance Program Plan
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PRP	Potentially Responsible Party
RCRA	Resource Conservation and Recovery Act

RHA	Rivers and Harbors Act
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SLT	Standard Leachate Test
SQC	Sediment Quality Criteria
TBP	Theoretical Bioaccumulation Potential
TCLP	Toxicity Characteristic Leaching Procedure
TIE	Toxicity Identification Evaluation
TSCA	Toxic Substances Control Act
TSS	Total Suspended Solids
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
VOC	Volatile Organic Compound
WQS	Water Quality Standards



## SECTION 1

### INTRODUCTION

Throughout the Great Lakes, about four million cubic yards of sediments are dredged annually to maintain navigation in channels and harbors for commercial, military and recreational users, and as part of environmental projects (EPA, 1990). Sediment is the material that settles to the bottom of a body of water and is primarily composed of soil particles consisting of clays, silts, and sands, organic matter, shells, and can include varying quantities of residuals from industrial discharges polluted by synthetic organic compounds and heavy metals. Many of the waterways are adjacent to urban and industrial areas and the sediments in these areas are often contaminated from various adjacent sources. A listing of industries associated with particular sediment contaminants is presented on Table 1-1. Such contamination is typically historical and much of it predates regulatory control. Additionally, ongoing releases from combined sewer overflows (CSOs) can be locally significant. Sediments are also contaminated by non-point sources such as agricultural run off. A portion of the sediments are so highly contaminated that they require remedial action. About one-half of the total amount of sediments dredged (approximately 2 million cubic yards) are sufficiently contaminated to preclude their unconfined release to the environment. In this document, such materials are referred to as problematic sediments. The disposal of these dredged materials in, and technical guidance for the design of confined disposal facilities (CDFs) is the focus of this document. These contaminated sediments require special consideration during dredging and disposal operations because of potentially adverse impacts on water and air quality and aquatic organisms. Sound planning and design of dredging operations and disposal facilities are necessary to protect the environment, while keeping these activities economically viable. The remaining half of the sediments are generally classified as clean and suitable for unconfined disposal.

The regulatory requirements for the disposal of dredged material are determined by both the type and level of the contaminants associated with the dredged material, as well as the extent to which the contaminants could potentially be released from the sediments to proximal air, ground water or surface water. To date, regulatory concern with most contaminated dredged material disposal projects have been focused primarily on containment of release routes to water, but as decisions need to be made on the proper handling of some of the more contaminated materials remaining in the region, potential contaminant loss pathways like air emission and seepage of free oil-phase organic contamination are being examined more closely. This is reflected in Table 1.2, which depicts several pertinent relationships between the level of sediment contamination, the degree of contaminant partitioning to the water associated with the sediments, in conjunction with three conceptual categories under which sediment disposal can occur and the significant disposal regulations. As depicted on Table 1.2, these three conceptual approaches to dredged material disposal are labeled "beneficial use or open water disposal," "solids retention" and "hydraulic isolation."

Table 1.1  
**Historical Sources of Sediment Contaminants**

November 25, 1992

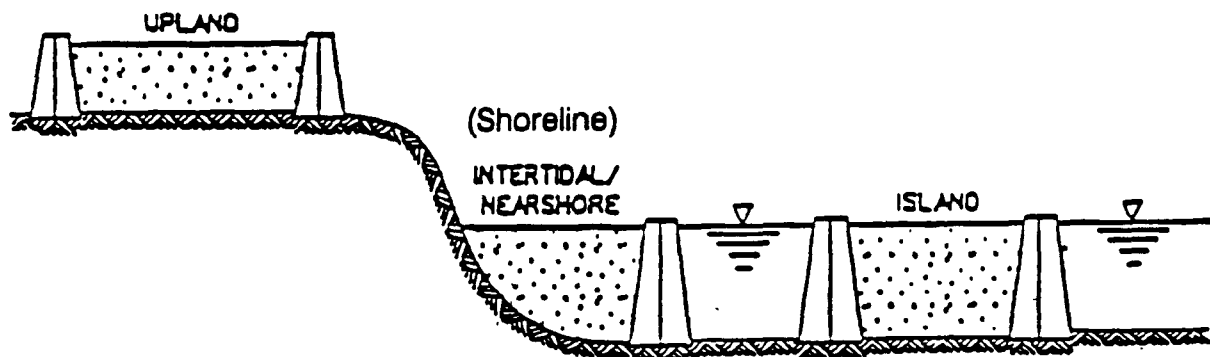
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REFERENCES: 11th edition Merck Index; An Overview of Sediment Quality in U.S., June 1987; Principles of Water Quality Management, 1980; sources of pollution in Wisconsin Storm Water

**Table 1.2 CDF Design Criteria Based on Contaminant Level and Partitioning Potential**

Uncontaminated Sediments		CWA 404 Guidance			Partitioning > State WQS or not Meeting CWA 404		Significant Partitioning		Highly Contaminated Sediments	
Minor Sediment Contamination Minimal Partitioning	PROBLEMATIC SEDIMENTS								RCRA/TSCA Sediments	
	Minor Partitioning		Moderate Partitioning		Extensive Partitioning					
Beneficial Use or Open Water Disposal  Passes 404 Evaluation for Open Water Disposal  CWA 401 Certification for Dredged Material Discharge	Solids Retention Approach		Hybrid Approach		Hydraulic Isolation Approach		Hydraulic Isolation CDF MTG Design (Appendix E)			
	Increasing Degree of Sediment Isolation		Hydraulic Isolation During Sediment Disposal Only		Increasing Degree of Hydraulic Isolation		CWA 401 Certification for Point Discharge			
	Filter Intake CDFs		CWA 401 Certification for Point or Diffuse Discharge		CWA 401 Certification for Point Discharge		CWA 402 Permit for a Point Discharge			
	CWA 401 Certification for Discharge						TSCA "Third Alternative" Design, 40 CFR 761.60(a)(5)			
							Conformance with RCRA-C Minimum Technology Guidance			
		←----- 87 USACE CDF DESIGN MANUAL -----→								
		←----- SHORELINE AND IN-LAKE CDF DESIGNS -----→								
		←----- UPLAND CDF DESIGNS -----→								
		←----- REGION 5 CDF GUIDANCE DESIGNS -----→								
		←----- CWA SECTION 404 AND EPA/USACE FRAMEWORK -----→								
←----- INCREASING DEGREE OF SEDIMENT CONTAMINATION -----→										

The Clean Water Act (CWA) governs the discharge of dredged material into "waters of the United States." If the level of sediment contamination is sufficiently low so that the unconfined release of the sediments into the environment would not have an unacceptably adverse environmental impact and would not result in an exceedance of the applicable State Water Quality Standards (WQS), after consideration of mixing, the sediments could be disposed of at an approved open water disposal site or placed in the environment in an unrestricted manner. An example of such unrestricted or unconfined placement would be the use of dredged material for beach nourishment. As shown on Table 1.2, no discharge of dredged material into US waters is permitted under CWA Section 404 if it causes violations of any applicable State WQS. Therefore State WQS certification under CWA Section 401 is required in order for a dredged material discharge permit to be issued. As discussed further in Section 1.1.3, the State may opt to deny, waive, certify, or certify with conditions which may be similar to CWA Section 402 NPDES permit conditions. Dredged materials which can not meet the CWA standards for open water disposal or beneficial use, i.e. problematic dredged materials, must be segregated from the environment to some extent. Sediments which cannot be released to the environment in an unrestrictive manner are labeled problematic dredged material in Table 1.2. The disposal of problematic dredged materials is the focus of this document.



(adapted from USACE/EPA, 1992)

Figure 1.1 Upland, Shoreline, and Island CDF

The USACE uses confined disposal facilities (CDFs) to contain contaminated sediments which cannot be released without control to the environment and to facilitate settling and disposal of clean sediments at upland sites. As shown on Figure 1.1, CDFs can be located at both upland and in-lake sites. CDF designs reflect the level of isolation which the sediments under consideration warrant. As diagramed on Table 1.2 and as discussed below, CDF designs can be grouped under two headings; CDFs which physically isolated the sediment solids from the adjacent environment (solids

retention) and CDFs which hydraulically isolate the sediments and any derived effluent from the adjacent environment (hydraulic isolation).

Dredged materials typically contain large amounts of water. Depending upon the method used to excavate the materials, dredged materials are typically composed of 50 to 95 % water by weight. The disposal of large quantities of material with a high percentages of both solids and water presents both technical and regulatory challenges unique to dredged materials. Generally, the disposal of wastes which have a high percentage of water is regulated by the CWA while the disposal of waste high in solids is regulated under RCRA. Given the large quantities of water and solids, CDFs commonly incorporate considerations from both regulatory program requirements into their design.

Commonly under the CWA, aqueous wastes are sent through one or more treatment steps. Each treatment step targets a contaminant or group of contaminants with similar chemical or physical properties. Once the concentration of contaminants has been reduced sufficiently to comply with applicable standards, the treated effluent is generally released to the environment as a point source discharge under Section 402 of the CWA or as a dredged material discharge under CWA Section 401. Often dredged material discharges and CDF return waters are sufficiently dilute as to require little or no treatment in order to comply with State WQS after a mixing zone is applied. In contrast, solid wastes under RCRA are disposed of in facilities designed to hydraulically isolate the wastes and derived liquids from the ambient environment. Precipitation, groundwater, or surface waters that breach the facility and come in contact with the waste are termed leachate. RCRA facilities include systems to collect and remove leachate from within the facility to isolate it from the proximal environment. After collection, the leachate is removed from the facility for treatment and disposal. Additionally, both TSCA and RCRA disposal facilities are prohibited from receiving wastes having free liquids.

Most contaminants are tightly bound (sorbed) to the solids which compose the sediments. Consequently, a principal criterion for CDF designs has been the retention of as high a percentage of the dredged material solids as practical. CDFs which retain the contaminated dredged material also retain and isolate most of the contamination from the environment. CDF designs premised upon this approach are included under the portion of Table 1.2 labeled "solids retention." Increasing levels of contaminant concentrations would be reflected in CDFs with an increasing degree of sediment isolation. This is generally reflected in more elaborate CDF designs aimed at the removal of lower concentrations of suspended solids from the water entrained with the sediments during the dredging process. In the absence of significant partitioning of contaminants to the associated free water phase, and given the removal and retention by the CDF of the sediment solids, this approach has been environmentally acceptable.

CDFs can also be designed to include aspects of both the solids retention approach and the hydraulic isolation approach. These are exhibited during different periods of the life of the facility. As depicted on Table 1.2, such composite CDF designs are termed "hybrid" in this document. An

example of a hybrid facility is provided by the Chicago CDF, which is further described in Section 4.1.2. This facility was designed to hydraulically isolate the CDF interior from the adjacent waters during placement of sediments within the CDF. Hydraulic isolation during disposal is accomplished by pumping water from the interior of the CDF at a rate which is greater than or equal to the rate of disposal of dredged materials and associated waters. This eliminates or greatly reduces the increase in head that would normally accompany the filling of the CDF. The water removed from the CDF is treated and then released to the environment via a point discharge. When placement of dredged materials is not occurring, the pumping is stopped and the CDF operates under the conventional solids isolation approach. This allows the physical retention of solids while allowing the drainage of CDF waters to the surrounding environment.

In contrast, should sediments under consideration be releasing, that is partitioning, contaminants of concern to the aqueous phase at a concentration(s) of environmental significance, the solids retention approach may no longer be appropriate. At this point, a CDF design should consider not only the isolation of the sediment solids themselves, but also any associated water. This could include the water entrained with the sediments when dredged as well as any ground water, surface water, or precipitation which found its way into the CDF and came in intimate contact with the contaminated sediment. Under this scenario, the hydraulic isolation of the sediment, as well as any effluent from the proximal environment, may be required. CDF designs premised upon this approach to sediment disposal are included in Table 1.2 under the heading of "hydraulic isolation". As indicated on Table 1.2, the degree of hydraulic isolation required increases with the increasing potential of the contaminants to partition to the aqueous phase.

As the environmental significance of the contaminant partitioning increases, CDF designs must provide a greater degree of hydraulic isolation. A worst-case CDF design, providing a high degree of hydraulic isolation for the dredged materials, is depicted on the right-side of Table 1.2. The design criteria for this worst-case CDF design is based on RCRA Minimum Technology Guidance (MTG) for hazardous waste landfills. An explanation of these design criteria is provided in Appendix E. CDFs conforming with these criteria would perform in a manner similar to RCRA hazardous waste landfills and TSCA chemical waste landfills. In those instances where the dredged materials are highly contaminated and the applicable regulations allow for land disposal, a CDF complying with MTG criteria would provide adequate environmental performance/protection (AEPP) to the ecosystem adjacent to the facility. As discussed below, such a CDF design may also form the basis of an acceptable TSCA sediment disposal application under 40 CFR Part 761.60(a)(5) for the disposal of dredged material contaminated with PCB concentrations equal to or exceeding 50 ppm. This disposal option for PCB contaminated materials is commonly referred to as "the TSCA third alternative."

The partitioning of contaminants to the proximal aqueous phase has a temporal component which the reviewer of a CDF application should be aware of. The release of contaminant to the aqueous phase during the act of dredging or at the time of placement in the CDF are governed by the short term chemical kinetics associated with the dredging process. Laboratory procedures, e.g., the

elutriate and the modified elutriate tests (discussed in Section 2.2.1), used to quantify contaminant releases to water during these events reflect this. In contrast, the contaminant concentration within the pore water fluids of dredged materials after disposal would tend to be significantly higher. These post-disposal pore water contaminant concentrations would be better approximated by long term equilibrium concentrations that would eventually be established between the contaminants associated with the sediments and the adjacent aqueous phase. Such higher post-disposal pore water contaminant concentrations can move advectively through the sediments due to natural hydraulic gradients. Consequently, the CDF design should reflect these higher post-disposal partitioning concentrations in the pore water. Without control, such fluids could migrate from the CDF and impact the proximal environment.

Design guidelines are presented in this document that allow the design of CDFs for problematic dredged materials to provide AEPP to the ecosystem adjacent to this CDF. AEPP criteria are developed based on an evaluation of potential contaminant pathways, the nature and concentration of contaminants associated with the sediments, and the impact of such releases on the immediate environment and to the ecosystem as a whole. The regulatory and design requirements for CDFs are influenced by both the level of contaminants within the dredged material and the degree to which the contaminants partition between the sediment solids and water. These partitioning factors are discussed in Section 2. Satisfactory design, performance, and monitoring of CDFs requires the evaluation of all potential pathways and a clear understanding of the partitioning of the contaminant between the dredged material particles and the impacted waters.

The fundamental design philosophy used in developing this document was control of contaminant pathways using technically effective barriers that are economically feasible for the significant quantities of lightly contaminated dredged materials that must be safely disposed.

## **1.1 Regulation of Dredged Material Disposal Activities**

The basic framework for federal water pollution control regulation was established by the Federal Water Pollution Control Act (FWPCA) established in 1972. In 1977, FWPCA was renamed the Clean Water Act (CWA) and amended to provide regulatory control of toxic water pollutants. Sections 401 and 404 of the 1977 amendments to the CWA provide regulatory authority to USACE, EPA and the States over dredged material disposal activities. In addition, because permitting under Section 404 is a major Federal action under the definitions in the regulations (40 CFR 1508.18) for implementing the National Environmental Policy Act (NEPA), all 404 disposal projects are subject to full disclosure public review of the project planning process. Under NEPA there is a requirement that alternatives be examined as well as requirements to disclose project alternative compliance with other applicable Federal and State environmental laws, including the River and Harbor Act of 1910, the Clean Air Act, the Watershed Protection and Flood Prevention Act, the Toxic Substance Control Act (TSCA), the Resources Conservation and Recovery Act (RCRA), the Fish and Wildlife Coordination Act, the State Historic Preservation Act, the Endangered Species Act, and any

applicable Federal Executive Orders. TSCA and RCRA may be applicable for disposal of problematic dredged materials under certain conditions, discussed in Section 1.2.1.

### **1.1.1 CWA - USACE 404 Program**

Section 404 of the CWA regulates the disposal of dredged or fill material into navigable water by granting the US Army Corps of Engineers (USACE) the authority to designate disposal areas and the authority to control their use. Navigable waters now include all waters which may be susceptible to use in interstate commerce, or the use, degradation, or destruction of which could affect interstate commerce. The CWA regulates the impact of effluent discharge and dredge material disposal activities on navigable waters. As such, the CWA typically addresses the disposal or impact of materials having a high liquid and low solid content. All states within Region 5 are authorized under the CWA and have implemented WQSs that are as strict or stricter than those in the CWA, and these States must certify or waive WQS Certification of all proposed dredged material disposal into the US waters in order to comply with 404 permit requirements.

In approving a discharge site for a 404 permit, the USACE applies guidelines developed jointly by USACE and EPA in a Memorandum or Agreement (55 FR 9211, March 12, 1990) as codified in 40 CFR Part 230. These guidelines require that dredged or fill material should not be discharged into an aquatic ecosystem unless it can be demonstrated that the discharge will not have an unacceptable impact either individually or in combination with other activities that could affect the ecosystem. A primary emphasis of this review is the ability of the disposal operation to be carried out to satisfy the four requirements found in Section 230.10. These requirements are as follows: 230.10(a) The discharge site must represent the least damaging, practical alternative; 230.10(b) Requires compliance with established legal standards (e.g. State Water Quality Certification); 230.10(c) No significant degradation of the aquatic ecosystem; and 230.10(d) All practical means must be made to minimize or mitigate adverse environmental impact. The concept of a "Mixing Zone" in the vicinity of the point of discharge is introduced in 404 (b) (1) guidelines presented in 40 CFR 230 and may also appear in State water quality regulations. This concept allows containment concentrations to exceed State WQS only within a predefined mixing zone that is immediately adjacent to the point of discharge or dredging activity. The mixing zone analysis is being eliminated by many States in favor of WQS limits based on biological concentrating contaminants (BCC). BCC considerations are discussed in Sections 2.2.3 and 2.2.4.

### **1.1.2 CWA - EPA 404 Program Review**

Under CWA 404(c), the EPA Administrator is given authority to veto a Section 404 permit issued by USACE if the administrator determines the discharge of dredged or fill materials into the specified disposal area will have an unacceptable effect on municipal water supplies, shellfish beds, fishery areas, wildlife, or recreational areas. EPA has promulgated regulations that define the environmental restrictions associated with these disposal areas [ 40 CFR Part 231 ].



### **1.1.3 CWA - State 401 Program Review**

As stated above, Section 401 of the CWA provides that an application for a 404 permit must include a certification from the State in which the discharge originates that the discharge will comply with the following sections of the CWA:

- 301-Effluent Limitations
- 302-Water Quality Related Effluent Limitations
- 303-Water Quality Standards and Implementation Plan
- 306-National Standards of Performance
- 307-Toxic and Pretreatment Effluent Standards.

Primary emphasis in this review is maintenance of State WQS beyond the mixing zone at the point of discharge. The State must establish procedures for public notice for all applications for 401 Certification. A 404 permit cannot be granted, and a USACE maintenance project cannot proceed if certification is denied by the State.

### **1.1.4 CWA - State 402 Program Review**

The continuing discharge of rainwater and/or seepage from a CDF is also subject to control under the CWA. Such discharges may be required to adhere to discharge limitations, based on State 401 WQS Certification and authority. Some confusion has occurred in the past because regulations under Section 402, the NPDES program also seem to be appropriate. EPA Region 5 has expressed interest in using Section 402 to regulate certain types of discharges from CDFs, such as rainwater, that are not specifically exempted from Section 404. However, Section 402 has never been used for this purpose, and Section 401 has equivalent power. A State may, when appropriate, issue a 401 Certification letter that could be virtually indistinguishable in content from a typical NPDES permit. However, because most CDF releases, which are usually diffuse and intermittent, do not usually violate State WQS outside of an approved mixing zone, State 401 Certifications may range from simple waiver letters to permit-like letters requiring specific pollution monitoring and limits, ground water monitoring requirements, fish migration timing restrictions, and even plan modifications that may or may not be acceptable to the USACE or the permittee. Any project consisting of problematic sediments or dredged materials is likely to require considerable effort coordinating for an acceptable 401 Certification from the State.

### **1.1.5 Marine Protection Research and Sanctuaries Act (MPRSA)**

Section 102 of MPRSA requires EPA, in consultation with USACE, to develop environmental criteria for all ocean disposal. Section 103 of MPRSA provides that USACE must specifically authorize all ocean disposal of dredged materials. Since Region 5 applications do not involve ocean disposal, the provisions of MPRSA are not applicable to this document.

### **1.1.6 National Environmental Policy Act (NEPA)**

Dredged material disposal activities must comply with applicable NEPA requirements regarding identification and evaluation of alternatives associated with the dredging project. Sections 102(2) and 102(2)(E) of NEPA require the examination of reasonable alternatives to the actions proposed by the lead Federal agency. All alternatives, even those discarded, must be analyzed in an Environmental Assessment (EA) or Environmental Impact Statement (EIS). For Federal dredging projects, the USACE is responsible under NEPA for developing alternatives for the discharge of dredged material. The USACE is also responsible for preparing NEPA documents for Section 404 permit decisions. NEPA does not define performance objectives, but does require the process evaluation procedure.

## **1.2 Contaminated Dredged Materials**

### **1.2.1 Regulation of Contaminated Dredged Materials**

For the purposes of this document, dredged materials are considered contaminated when the ambient or leachable concentration of metals or organic compounds exceed Federal RCRA or TSCA regulatory limits or when contamination exists in high enough concentrations and are sufficiently available to affect human and/or ecosystem health. Contaminated dredged material may threaten human health by direct exposure or when contaminated water or organisms are consumed. Consequently, an acceptable disposal option for such sediments will entail some form of isolation from the ambient environment. Contaminants in sediments can be from point sources (municipal or industrial effluent), non-point sources (e.g. agricultural run-off or airborne sources), and from other sources such as spills or leaks.

RCRA and TSCA regulations provide for the land disposal of contaminated materials in cells that hydraulically isolate the waste material from proximal ground and surface waters. Wastes placed within such landfill cells must not contain free liquids as defined by the paint filter test (EPA Method 9095). RCRA and TSCA land disposal regulations are therefore directed at wastes that are very high in solids and have little or no free liquids. Conversely, CWA regulations, previously discussed in Section 1.1, are directed at the disposal of waters containing very small concentrations of suspended solids and partitioned contaminants. With large portions of both water and solids, environmentally acceptable disposal options for dredged sediments combine aspects common to both of these regulatory perspectives.

In general, the potential for sediments to hold or bind contaminants increases with increasing percentages of fine grained sediments (silts and clays) and organics. Fine grained sediments have a high surface area per unit weight and significant ionic forces that attract and retain many classes of contaminants. The presence of organic matter increases the affinity of sediments for metals and organic contaminants.

Sediment acidity and oxidation/reduction status also affect the mobility and biological availability of contaminants. Strongly acidic (low pH) sediments slow microbial activity and increase the soluble level of toxic metals. Weakly acidic to slightly alkaline sediments result in less mobile metals. The oxidation/reduction potential of a sediment, as measured by the redox potential of the sediment, has a major effect on the capture or release of metals by a sediment. Frequently, the sediment contaminants are chemically stable under the geochemical conditions existing within the in-situ sediments. However, changes in the pH or redox potential of a sediment during dredging or disposal will substantially affect contaminant mobilization. This influences the partitioning of the contaminant between the sediment solids and the pore water. EPA is currently updating equilibrium sediment quality criteria (SQC) that normalize non-ionic organic contaminants to organic carbon and metal contaminants to acid volatile sulfide (AVS). The role of long term equilibrium contaminant partitioning is reflected in the regulatory present scheme previously shown on Table 1.2. Contaminant mobilization mechanisms in dredged materials, SQC, and remediation of contaminated materials are discussed in greater detail in Appendix A.

**Problematic Dredged Material ----** In this document, problematic dredged material are defined as materials which are sufficiently contaminated to preclude their unconfined release to the environment, e.g. open water disposal or beneficial reuse. In Region 5, problematic dredged material are commonly the result of non-point source releases and spills or point-source releases which occurred prior to the effective date of the CWA as well as most other environmental regulations. Because the unrestricted release of problematic dredged materials to the environment is unacceptable, the AEPP disposal criteria for these materials will require containment to some extent. The extent of containment required is dependent upon the nature, concentration, and partitioning potential of the specific contaminants. Provided an acceptable level of suspended solids is achieved in the effluent, the AEPP criteria for the disposal of sediments associated with low levels of tightly sorbed contamination may require only physical isolation of the dredged material. AEPP criteria for the disposal of sediments with higher levels of contaminants that partition to the aqueous phase at concentrations of concern will generally require hydraulic isolation of the dredged material as well as any derived effluent. These two approaches to the disposal of dredged materials have been labeled the "Sediment Retention Approach" and the "Hydraulic Isolation Approach" respectively. As discussed below, the disposal of sufficiently contaminated problematic dredged material can be regulated by RCRA-C and/or TSCA. AEPP criteria for the disposal of such highly contaminated materials which meet the regulatory requirements for land disposal will require a hydraulic isolation design based on RCRA-C MTG as summarized in Appendix E.

**TSCA Dredged Material ----** Enacted in 1976 by Congress in response to the discovery that DDT and other pesticides were impacting waterfowl and that PCBs were present in large numbers of birds and fish, TSCA required EPA to test certain existing chemicals to determine if they posed an unacceptable human health or environmental risk. While the twenty-nine sections of TSCA cover a wide range of considerations, TSCA has become fundamentally associated with the control of PCBs at concentrations equal to or greater than 50 ppm. The use, control and disposal of PCBs under TSCA are covered in 40 CFR Part 761, as issued in 1982. Subpart D specifies that, in general,

PCBs at concentrations equal to or greater than 50 ppm must be disposed of in an incinerator. However, 40 CFR Part 761.60(a)(2) also allows PCBs at concentrations less than 500 ppm to be disposed of in a chemical waste landfill as defined in 761.75. TSCA specifically addresses dredged sediments contaminated with PCB concentrations equal or exceeding 50 ppm in 761.60(a)(5). This section provides three methods of PCB contaminated sediment or sludge disposal: (1) incineration, (2) placement in a TSCA chemical waste landfill, and (3) using a disposal method approved by the Regional Administrator. Application for the "3rd alternative" must demonstrate that disposal in an incinerator or chemical landfill is not reasonable and appropriate, and that the alternate disposal method will provide adequate protection to health and the environment. Performance criteria which could form the basis for the disposal of TSCA regulated sediments are presented in Appendix E. TSCA also allows for the temporary storage of wastes containing PCBs at concentrations equal to or greater than 50 ppm for a time period not to exceed 1 year in an approved storage facility.

A chemical waste landfill under 40 CFR Part 761.75 (TSCA) must satisfy well defined technical liner requirements. These technical liner requirements are based on hydraulic isolation of the PCB contaminated material and include the following:

- (1) As a minimum, the landfill must have 4 feet of in situ natural soils or 3 feet of compacted soils having a hydraulic conductivity equal to or less than  $1 \times 10^{-7}$  cm/sec. A synthetic membrane liner must be used when, in the judgement of the Regional Administrator, the hydrogeologic or geologic conditions at the site require it to achieve an equivalence to these criteria.
- (2) The landfill design must include a leachate collection/monitoring system.
- (3) The bottom of the liner system must be at least fifty feet from the historic high water table. Floodplains, shorelands, and groundwater recharge areas shall be avoided.
- (4) The landfill must be protected from the 100 year flood.
- (5) The landfill site must have low to moderate relief to minimize long-term erosion.
- (6) The landfill must be equipped with a monitoring system that allows both ground and surface water to be monitored.

These regulatory requirements, while not consistent in minor design details with those required by RCRA-C for a hazardous waste landfill, are consistent with the full containment concepts of RCRA. The TSCA chemical landfill requires a greater thickness of vertical buffer between the liner and seasonal high groundwater table. From a dredged material disposal perspective, the 50 foot above the historic high water table requirement would virtually eliminate all CDFs for TSCA waste in Region 5 if not for the 3rd alternative, e.g. disposal method approved by the Regional Administrator.

The conceptual basis for the TSCA regulations is the hydraulic isolation of the waste from surface and ground waters. This is identical to the conceptual basis for RCRA-C and RCRA-D regulations.

**RCRA Subtitle C Sediments ----** As promulgated in 1976 and amended by Hazardous and Solid Waste Amendments (HSWA) in 1984, RCRA-C is a national regulatory mechanism that controls the treatment, storage, and disposal of hazardous waste as defined under 40 CFR 261 and thereby minimizes the present and future threat to human health and the environment. 40 CFR 261 specifies that a waste is hazardous if it is not excluded from regulation as a hazardous waste and it meets any of the following criteria: 1) is named as a hazardous waste and is included in one of three lists under 261, 2) exhibits a hazardous waste characteristic, 3) results from the mixture of a waste with listed hazardous waste, 4) is derived from a listed hazardous waste or exhibits a hazardous waste characteristic, and 5) is an environmental media which contains a listed hazardous waste. The first list under 261 contains hazardous wastes from nonspecific sources (e.g. spent halogenated solvents, such as toluene). The second list identifies hazardous wastes which commonly result from manufacturing or industrial processes (e.g. bottom sediment sludge from the treatment of waste water by wood preservers). The third list contains commercial chemical products or chemical manufacturing intermediates which, when discarded, must be treated as hazardous waste. If a waste is not listed as hazardous, it is still covered by RCRA if it exhibits one of four hazardous waste characteristics: ignitability, corrosivity, reactivity, or toxicity. For example, under the definition provided for toxicity, a solid waste is hazardous if the extract obtained from the sample using the Toxic Characteristic Leaching Procedure (TCLP) test contains a hazardous constituent at or above the regulatory threshold provided for that constituent. To date, most RCRA-C sediment characterization efforts in Region 5 have focused on toxicity as defined by the TCLP test.

Of major potential significance to the disposal of contaminated dredged materials is the land disposal ban enacted by HSWA. These regulatory requirements mandate that hazardous wastes or Subtitle C media must be properly and adequately treated prior to land disposal. Such treatment would include destruction of organic constituents and/or solidification of the metal constituents in the waste such that it will pass a TCLP test. In 1986, EPA banned the land disposal of untreated hazardous wastes containing dioxin and solvents. Next, in 1987, EPA banned the disposal of certain untreated hazardous wastes that had previously been banned by California. Third, EPA published a ranking of all other hazardous wastes based on their hazard or volume. From 1988 to 1990 EPA enacted a ban on the land disposal of these wastes without treatment. By banning the direct land disposal of such hazardous wastes, Congress sought to reduce the rate of hazardous waste production and the long term risks associated with hazardous waste disposal.

The treatment requirements under RCRA-C for contaminated environmental media such as sediment, depend upon the type of RCRA-C contaminant associated with the sediment. Conceptually, sediments can be contaminated with one or more listed hazardous waste or can exhibit one or more hazardous waste characteristics. In practice however, the identification of sediments which require compliance with the RCRA-C regulations for listed waste has been rare. This is due to the RCRA-C exclusions under 40 CFR 261.4(a) for hazardous waste mixed with

domestic sewage and waste released from industrial point source discharges subject to Section 402 of the CWA. An overview of the treatment and disposal regulations for sediments requiring compliance with RCRA-C is provided below.

The treatment and disposal of sediments contaminated with a listed hazardous waste can be handled in one of two ways. Where feasible, such sediments can be treated to the extent that the sediments no longer "contain" the listed waste. The threshold levels for this determination are provided by the EPA Region in which the activities occur. Treatment procedures which reduce the listed RCRA-C wastes from the sediment to concentrations below these thresholds render the sediments nonhazardous. Subsequent disposal of the sediments is then not regulated under RCRA-C. In contrast, if the treated sediments still contain listed hazardous wastes, but meet the treatment standards provided under 40 CFR 268, the disposal of the sediments would continue to be regulated under RCRA-C. Consequently, such treated sediments would need to be dewatered until the sediments pass the paint filter test and subsequently placed in a RCRA-C disposal facility. A similar treatment scenario exists for sediments that exhibit a RCRA-C hazardous waste characteristic.

Similarly, the treatment requirements for dredged sediments which exhibit a RCRA-C hazardous waste characteristic can also be addressed through one of two scenarios. The first option requires treatment of the sediment to the standards provided in 40 CFR 268 (if applicable standards were promulgated) or to levels which would render the sediments noncharacteristic if treatment standards were not promulgated. Once adequately treated, disposal of the sediments would no longer be regulated under RCRA-C. A second option available for characteristic wastes for which treatment standards have not been promulgated would require dewatering of the waste and disposal in a RCRA-C hazardous waste landfill.

RCRA-C differs from TSCA in that many specific requirements for treatment, storage or disposal (TSD) facilities are not codified. Technical requirements for TSDs have been codified in 40 CFR 264 as Minimum Technology Requirements (MTR) and are given in Minimum Technology Guidance (MTG) documents prepared by EPA. Site location requirements are codified with respect to seismic considerations and floodplains ( 40 CFR 264.18 ). RCRA does not contain site restrictions that would eliminate in-lake or near shore TSDs or CDFs. Under Subpart N, the hazardous waste regulations simply specify a liner system designed to prevent any migration of wastes out of the landfill and a leachate collection system immediately above the liner that will prevent the leachate depth from exceeding 30 cm over the liner. These specifications form the basis for the worst-case hydraulic isolation CDF design criteria. These general criteria are presented in Appendix E.

The ground water protection standards of Subtitle C involve the use of EPA approved health based standards for evaluating compliance with approved environmental performance standards. Such standards include the Maximum Contaminant Levels (MCL) established by the CWA. When no MCLs exist, the Reference Doses (RFDs) for threshold constituents, and Carcinogenic Potency Factors (CPFs) for non-threshold constituents are used. CPFs measure the ability of a chemical to

cause cancer assuming a risk level of  $10^{-6}$  for Class A and B carcinogens and  $10^{-5}$  for Class C carcinogens (EPA, 1986).

**RCRA Subtitle D Municipal Solid Wastes (MSW)** ---- As promulgated on October 9, 1991, Subtitle D (40 CFR 258) defined minimum landfill standards for those facilities receiving MSW and for landfills co-disposing sewage sludge with MSW. The Co-disposal Regulations were co-promulgated under the authority of RCRA-D and CWA. Separate regulations are being developed for sewage sludge monofills under CWA Authority. The RCRA-D regulations are the first to clearly establish performance objectives for the landfills. While a default composite liner is provided in Subtitle D, the general performance criteria for a MSW landfill requires that groundwater quality be maintained such that all constituents are at concentrations below their MCLs at a regulatory specified point of compliance adjacent to the landfill.

### **1.2.2 Presumptive Remediation of Contaminated Sediments**

Remediation of dredged material to remove or lower the level of contaminants may involve combining several treatment processes to achieve cleanup objectives. Treated sediments, once cleaned, can be used as beneficial fill material outside of a CDF or as designed components within the CDF. For example, cleaned fine grained sediments could be used to line a CDF. The Assessment and Remediation of Contaminated Sediments (ARCS) program has performed pilot and bench scale demonstrations of selected technologies. A full discussion of these technologies is presented in Appendix A of this document. It should be noted that, at present, these technologies have not been widely implemented at full scale.

The containment of contaminated sediments in CDFs is generally viewed as the most cost effective remediation tool. This is consistent with a parallel trend in Superfund sites where containment of the contaminated soils or wastes has been the selected alternative in a clear majority of existing RODs. This containment policy is expressed in recent revised Remedial Investigation/Feasibility Study (RI/FS) procedures for contaminated municipal solid waste landfills (EPA/540/P-91/001). These revised RI/FS procedures make containment of the waste the presumptive remedy. As with dredging projects, the quantities of contaminated solids and relatively low contamination levels associated with MSW landfills frequently makes current waste remediation technologies prohibitively expensive.

### **1.3 Confined Disposal of Problematic Dredged Materials**

While nationwide CDFs were built to dispose of clean dredged materials, within Region 5, however, all existing CDFs were designed for the disposal of problematic dredged materials. Such facilities are designed to retain dredged solids while allowing the carrier water to be released from the containment area. The general conceptual drawing for this process is shown on Figure 1.2. The principal functional components of the CDF are the containment dikes that hold the dredged materials and a weir, or filter wall, or treatment system that allows the carrier

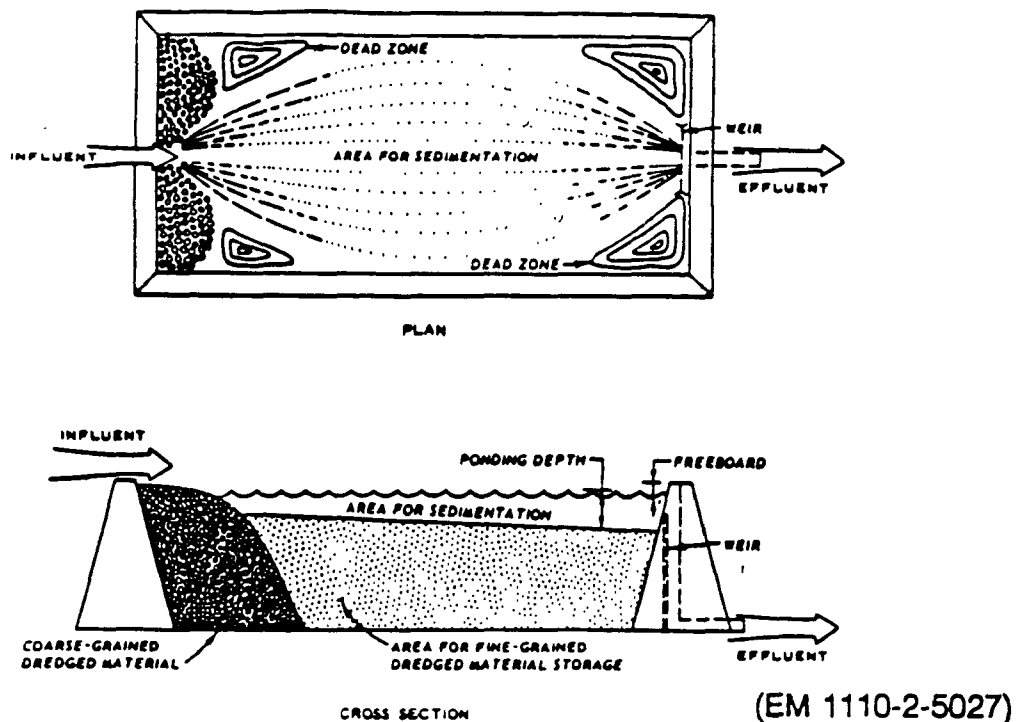


Figure 1.2 Conceptual Diagram of a CDF

water to decant from the CDF. The design of containment dikes is site-specific and must consider the following factors: dike stability with respect to shear strength, settlement, seepage, erosion, and available building materials or construction equipment. A review of specific CDF dike cross sections and component design are presented in Section 4. The influent dredged material may be a slurry if hydraulic dredging processes are used or a water/soil-clod matrix if bucket excavators are used. This dredged material influent and the decanted effluent are normally characterized by the suspended solids concentration, suspended particle size gradation, type of carrier water (fresh or saline), and rate of flow.

The containment basin must be sized to provide an adequate volume to contain the dredged slurry and to provide sufficient retention time for the associated water to allow solids to fall out of suspension. Flocculent may be used to increase the rate at which solids fall out of suspension if the site area is restricted. Weirs are designed such that the water depth above the solids can be maintained constant as the CDF fills with sediment.

The Great Lakes CDFs were designed so that the effluent leaving the CDF has a concentration of suspended solids less than 1 to 2 grams per liter for freshwater conditions (USACE, 1987). Typical effluent requirements in Region 5 are usually in terms of tens of milligrams per liter and are enforced at those CDFs having a measurable point discharge. A more detailed discussion of the USACE procedure for design of CDFs is presented in Section 6.

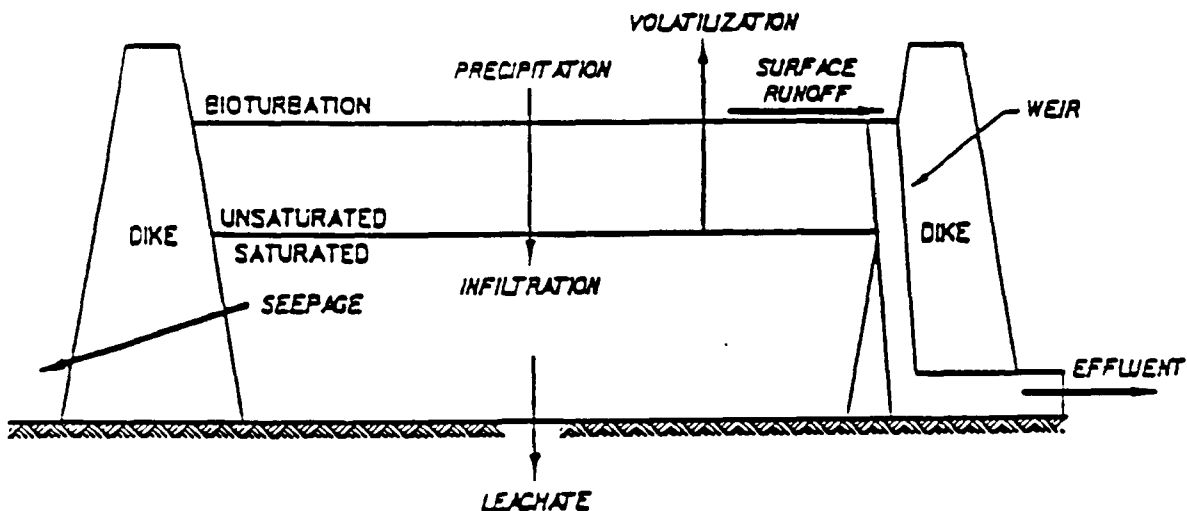


## 1.4 CDF Contaminant Pathways

The design of the CDF must be concerned with potential pathways by which the contaminant can leave the containment system. For an upland or typical island CDF such pathways are shown on Figure 1.3 and include

1. effluent drained through the weir or dikes,
2. leachate drained from the sediments that may move into the ground water,
3. surface water run-off,
4. plant uptake through vegetation growing within the CDF or on its dikes,
5. animal uptake in animals living or nesting within the CDF, and
6. from volatilization or wind borne migration of fine grained soils and bound contaminants into the atmosphere.

The effectiveness of conventional CDFs to limit contaminant pathways is the focus of this document. Performance criteria for the first five pathways are developed in Section 2. Air quality guidance for landfills and CDF type facilities is pending. This pending guidance focuses on non-methane organic compounds (NMOC) and will require evaluating NMOC emissions through the final cover.



(USACE/EPA, 1991)

Figure 1.3 Contaminant Pathways for Upland CDF

## SECTION 2.0

### DEVELOPMENT OF ENVIRONMENTAL PERFORMANCE CRITERIA for CDFs

In 1971, Region 5 of the Environmental Protection Agency (EPA) issued "Criteria for Determining Acceptability of Dredge Spoil Disposal to the National Waters" as a first effort to identify and classify polluted sediments in the nation's waterways for purposes of controlling dredging and disposal operations. These ambient concentration thresholds were published before there was adequate scientific data to define the type, quantity, and partitioning potential of contaminants which are associated with dredged material which impact water and sediment quality at the dredging or disposal site and, thus, become bioavailable. Sediments that failed this evaluation were considered unsuitable for aquatic (open water) disposal and required confined disposal, i.e. placement in a CDF. In 1977, Region 5 began to use sediment pollution criteria defined by the Great Lakes guidelines shown on Table 2.1.

During this same time period the USACE was developing an approach for evaluating the pollution potential and bioavailability of contaminated dredged materials during dredging and disposal operations. Keeley and Engler (1974) discussed the USACE position about establishing regulatory criteria for the disposal of clean and contaminated dredged materials in the oceans and other aquatic bodies such as lakes and rivers. They noted that the criteria for defining environmental protection should:

1. be meaningful and based on the best possible knowledge
2. not precede the current technical state of the art
3. be based upon laboratory procedures that can be performed satisfactorily at routine testing laboratories
4. attainment and implementation not be prohibitively expensive

The first guidelines for the discharge of dredged materials into waters of the United States were issued in 1975 and were quickly followed by interim guidance manuals for discharge into navigable waters (USACE, 1976) and into ocean waters (EPA, 1977). The latter manual is referred to as the "Green Book". In 1991, EPA and USACE jointly published an update of the 1977 Green Book for the discharge of dredged material into ocean waters (EPA/USACE, 1991). This update was intended to address the differences between the regulations governing disposal under CWA and MPRSA and is specifically intended for CWA 404(b)(1) compliance determinations. EPA and USACE are currently drafting a guidance manual for evaluation of material proposed for discharge in inland and near coastal waters. (Inland Testing Manual).

**Table 2.1 EPA Guideline Values for Harbor Sediment Classification**

<u>Compound/Element</u>	<u>Non Polluted</u>	<u>Moderately Polluted</u>	<u>Heavily Polluted</u>
	(expressed in mg/kg, dry weight unless specified)		
Ranking	①	②	③
Volatile Solids (%)	<5	5-8	>8
COD	<40,000	40,000-80,000	>80,000
TKN	<1,000	1,000-2,000	>2,000
Oil and Grease	<1,000	1,000-2,000	>2,000
Lead	<40	40-60	>60
Zinc	<90	90-2000	>200
Ammonia	<75	75-200	>200
Cyanide	<0.10	0.10-0.25	>0.25
Phosphorus	<420	420-650	>650
Iron	<17,000	17,000-25,000	>25,000
Nickel	<20	20-50	>50
Manganese	<300	300-500	>500
Arsenic	<3	3-8	>8
Cadmium	—	—	>6
Chromium	<25	25-75	>75
Barium	<20	20-60	>60
Copper	<25	25-50	>50
Mercury	—	—	≥1
Total PCBs	—	—	≥10

source: Guideline for the Pollutational Classification of Great Lakes Harbor Sediments, U.S. Environmental Protection Agency, Region V, 1977

Because the Green Book applies to ocean and coastal waters it has not been used by Region 5 for the Great Lakes. Region 5 has instead used a case-by-case approach using the 1977 Great Lakes Guidelines (see Table 2.1), International Joint Commission guidelines, and other criteria to make the decision of whether the dredged materials are polluted and thus inappropriate for open water disposal. While the proposed Inland Testing Manual is national in scope, the USACE North Central Division and Region 2, 3 and 5 are also developing a Great Lakes Testing Manual.

Section 2 presents the current joint EPA/USACE sediment management strategy and then evaluates current test procedures used to evaluate the potential contaminant pathways identified in Section 1.4. The section concludes with a review of Region 5 Adequate Environmental Performance and Protection (AEPP) criteria for each potential contaminant pathway.

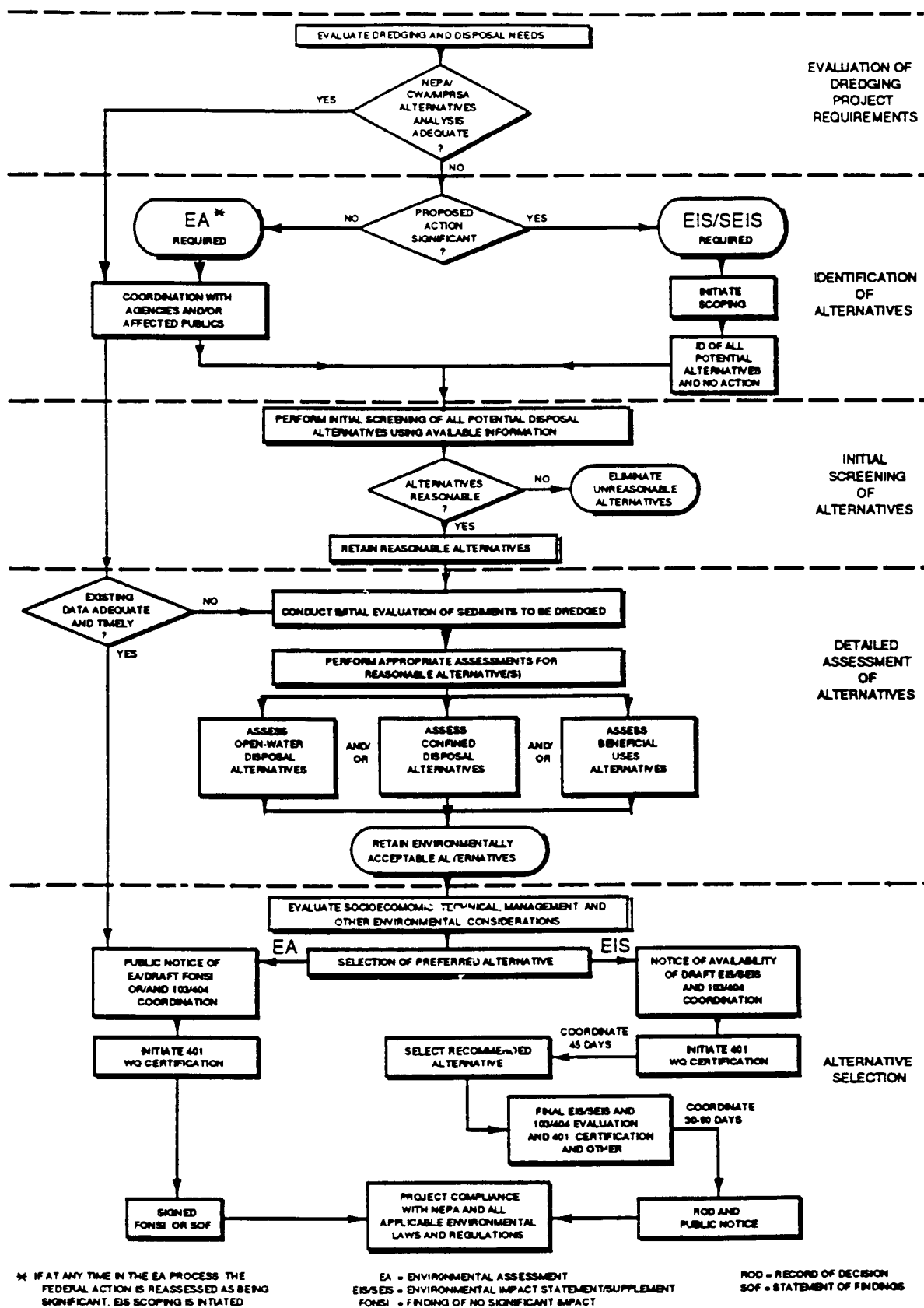
## **2.1 Joint USACE/EPA Technical Framework for Dredged Material Management**

Based on the USACE decision making framework (Francingues et al, 1985) as applied to Commencement Bay, Washington (Peddicord et al. 1986), a joint USACE/EPA guidance document for evaluation of environmentally acceptable dredged material management alternatives was developed (USACE/EPA, 1992). The document is intended to serve as the Technical Framework for USACE and EPA personnel in evaluating the environmental acceptability of dredged material management alternatives. Three dredged material management alternatives are considered in the joint framework: open water disposal, confined (dike) disposal, and beneficial use application. The joint USACE/EPA dredged material management program is summarized in the flowchart on Figure 2.1. This proposed management program is divided into five major elements as follows:

**Evaluation of Dredging Project Requirements ----** The need for the dredging project must be established under NEPA, CWA, and/or MPRSA. Under NEPA, the initial impact assessment for the dredging project relates to the purpose and need for the proposed action in the case of new work and the continued viability in the case of an existing project. The needs determination under CWA or MPRSA is specifically concerned with a justification of the necessity for dredged material disposal in waters of the U.S. or ocean respectively.

**Identification of Alternatives ----** Under NEPA, the environmental impact of disposal options such as CDFs, open water, and beneficial uses must be considered. The NEPA document must discuss all reasonable alternatives even if they are beyond the capability of the applicant or lead agency making the application. Note that NEPA does not specify performance standards but simply requires the evaluation of alternatives.

**Initial Screening of Alternatives ----** Reasonable sediment management alternatives include those that are practical or feasible given environmental, technical, and economic constraints. All potential alternatives are evaluated with respect to the availability of the required and suitable disposal site,



(EPA/USACE, 1991, or EPA/USACE, 1992)

Figure 2.1 Flow Chart Illustrating Framework for Determining Environmental Acceptability of Dredged Material Disposal Alternatives

design limitations, climatic conditions, dredging equipment availability, physical and chemical aspects of the sediments, local interests or concerns, and known environmental regulatory (e.g. endangered species) and economic concerns. The initial screening is based on available sources of sediment contamination information, see Table 2.2.

**Detailed Assessment of Alternatives** ---- Environmental acceptability of a sediment management alternative must include the following:

- a. evaluation of the adequacy and timeliness of existing data,
- b. evaluation of the physical characteristics of the sediments,
- c. evaluation of sediment contamination,
- d. perform appropriate CWA testing and assessments,
- e. evaluation of sediment management/control options.

The last consideration (e.) includes assessment of openwater, confined disposal and beneficial use alternatives. This document herein concerns the assessment of confined disposal options only and is therefore a subset of the detailed assessment of alternatives provided in the USACE/EPA framework.

Specific guidelines are provided in this document for evaluation of the technical feasibility and cost of CDF alternatives. Once a Detailed Assessment of the Alternatives is completed and the CDF alternative has been selected, the flowchart on Figure 2.2 is used for the detailed assessment of the CDF alternative to include testing and related evaluations. This requires a site assessment of all potential CDF locations including an evaluation of physical impacts, site capacity, and possible management options. The primary concern of this flowchart is the short and long-term impact of contaminated dredged material placement into the CDF and the need for additional control measures.

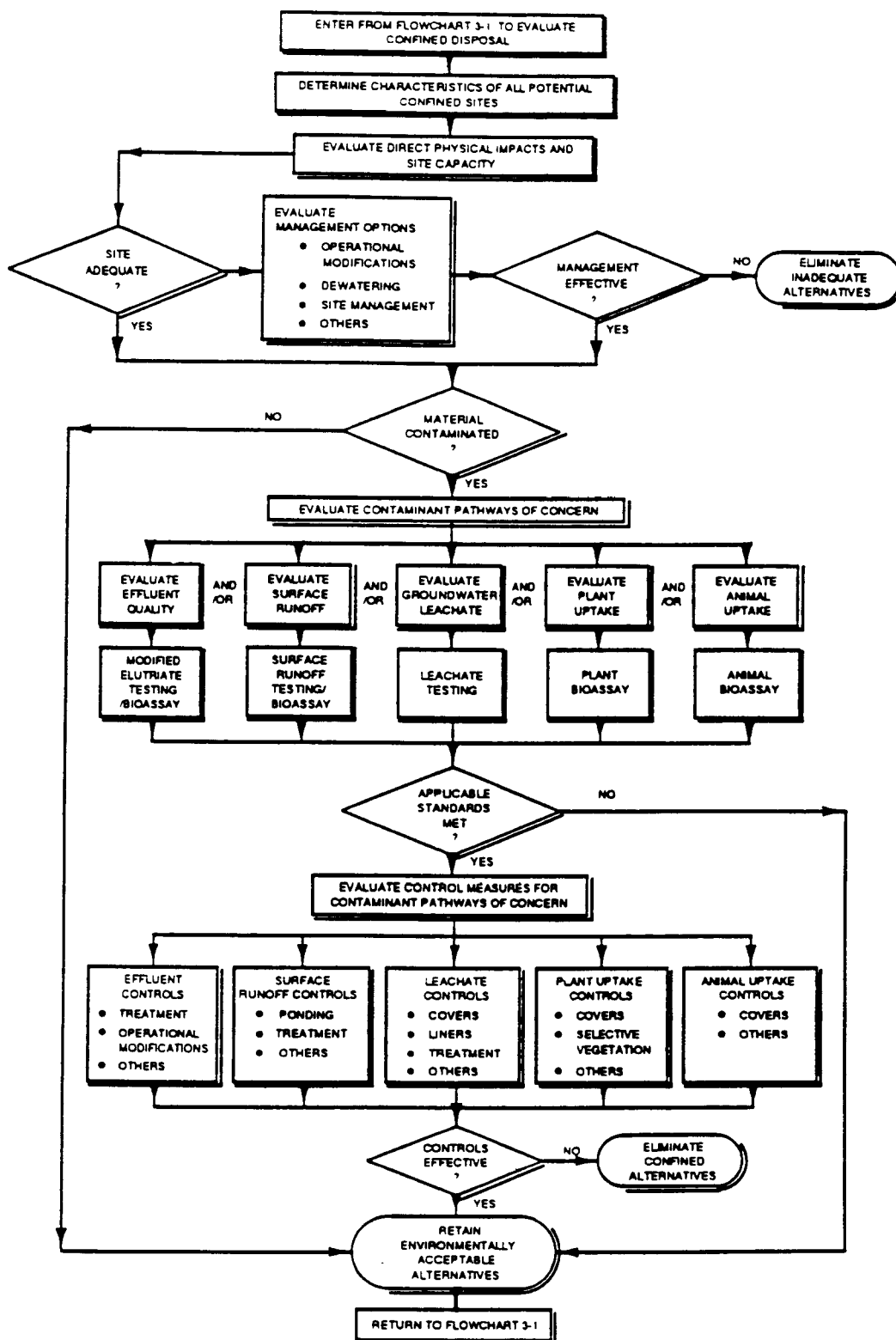
**Alternative Selection** ---- The selection of a preferred/proposed alternative during the NEPA EIS phase is based on environmental acceptability, technical feasibility, costs, and other factors.

## **2.2 Evaluation of Contaminant Pathways**

The evaluation of the impact of the disposal of contaminated dredged materials upon the local environment is based upon a detailed laboratory testing protocol that considers each of the possible contaminant pathways as discussed in Section 1.4. Based on the test results and analysis, the laboratory testing program will determine if additional control measures are required for the proposed CDF. Additional control measures such as liners, covers, and filters are covered in detail in Appendix E and Section 7.

**Table 2.2 Sources of Existing Sediment Contamination Information**  
(draft Inland Testing Manual)

- Available results of prior physical, chemical, and biological tests of the materials proposed to be dumped.
- Available results of prior field characterization studies of the materials proposed to be dumped (e.g., physical characteristics, organic-carbon content, and grain size)
- Available information describing the source(s) of the material to be dumped which would be relevant to the identification of potential contaminants of concern.
- Existing data contained in files of either the EPA or USACE or otherwise available from public or private sources. Examples of sources from which relevant information might be obtained include:
  - Selected Chemical Spill Listing (EPA)
  - Pesticide Spill Reporting System (EPA)
  - Pollution Incident Reporting System (USCG)
  - Identification of In-Place Pollutants and Priorities for Removal (EPA)
  - Hazardous waste sites and management facilities reports (EPA)
  - USACE studies of sediment pollution and sediments
  - Federal STORET, BIOS, CETIS, and ODES databases (EPA)
  - Water and sediment data on major tributaries (USGS)
  - NPDES permit records
  - Fish and Wildlife Service
  - CWA 404(b)(1) evaluations
  - Pertinent and applicable research reports
  - MPRSA 103 Evaluations
  - Port Authorities
  - Colleges/Universities
  - Records of state agencies (e.g., environmental, water survey)
  - Published scientific literature
  - CERCLA/RCRA Facility Files



(EPA/USACE, 1991 or EPA/USACE, 1992)

Figure 2.2 Flow Chart Illustrating Framework for Testing and Evaluation  
For Confined (Dike) Disposal



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## 2.2.1 Effluent Discharge Quality

The large volumes of fluids generated during dredging may contain undesirable levels of dissolved contaminants and suspended fine solids with adsorbed contaminants. The modified elutriate test (Palermo, 1984) is the current method which the USACE uses to predict effluent quality from a CDF (USACE/EPA, 1992). This is a modification of the standard elutriate test used for assessment of aquatic disposal of dredged material.

A review of the standard elutriate test is presented here to aid in understanding the transition represented by the "modified" elutriate test. The USACE has always based its criteria on the change in ambient water quality (dissolved chemical concentrations) that might be expected during dredging and disposal in a CDF. The compliance of a dredged material operation with State Water Quality Standards (WQS) is assessed by the elutriate test which is designed to simulate the dredging/disposal process. A schematic diagram of the original elutriate test (Keeley and Engler) is presented in Figure 2.3 as designed for the disposal of hydraulically dredged material. As noted in the diagram, four volumes of disposal site water and one volume of contaminated dredged material are shaken vigorously in a beaker for 30 minutes to simulate hydraulic dredging and to allow for the exchange of contaminants from the solid phase (adsorbed organics and metals) to the dissolved phase. Also, prior to mixing the water with sediments, the dissolved concentrations of pollutants in the disposal site water are measured and listed as  $X_1$ . After shaking the sediment/water suspension, the mixture is allowed to settle for one hour. The supernatant is then filtered to remove particles and analyzed for the same chemical constituents previously determined and listed as  $X$ . While test simplifies the complex interaction between polluted sediment and water, it has shown that there is little migration from the solid to dissolved phase.

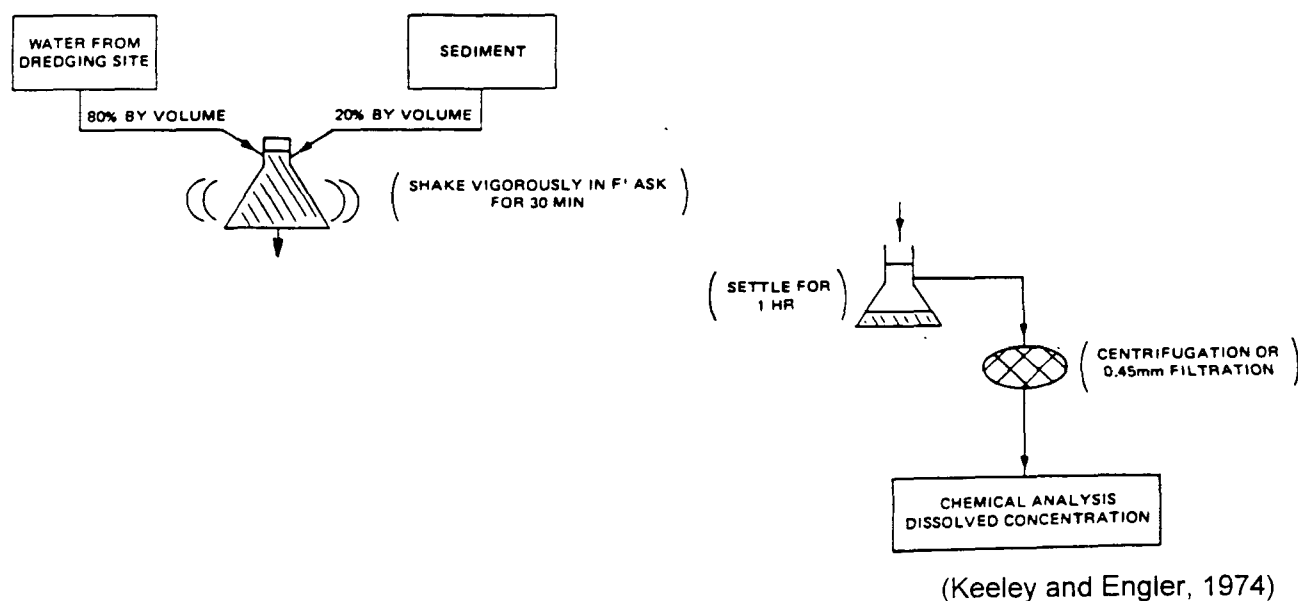
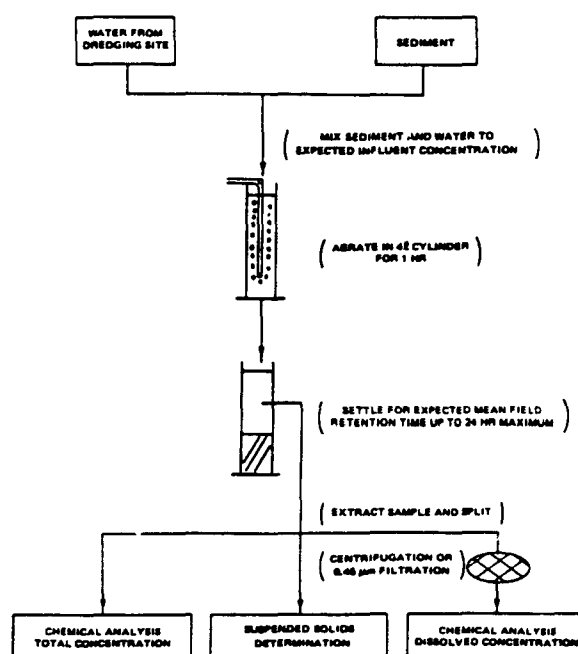


Figure 2.3 Elutriate Test

The modified elutriate test, as summarized in Figure 2.4, was developed by USACE to be a more realistic laboratory simulation of CDF effluent quality during hydraulic disposal of dredged material in open water or within a CDF. The test involves mixing contaminated sediment and water from the dredge site in proportion to the expected CDF influent concentration as influenced by the dredging method. The mixture is then aerated and settled in a column. Modifications to the test can be made to simulate transport and deposition for an estimated CDF retention time (Averett et al, 1988 and Palermo et al, 1988). The unfiltered supernatant (effluent) is subjected to chemical analysis to define the concentration of the contaminants associated with the total suspended solids (TSS). Similarly, a chemical analysis is performed on the filtered water to determine the concentrations of contaminants dissolved in the water. This allows prediction of both the dissolved and the total concentration of contaminants in the effluent.

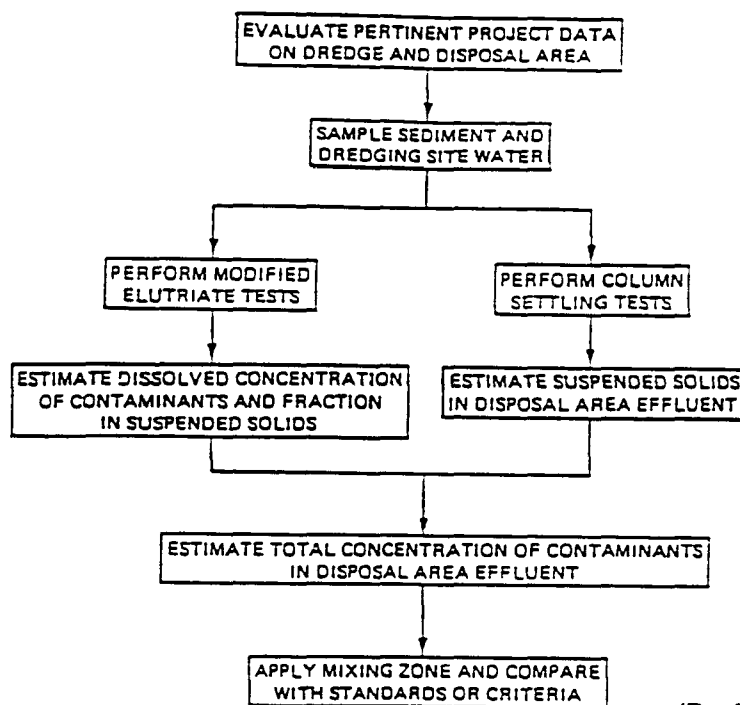


(Palermo, 1989)

Figure 2.4 Modified Elutriate Test

The modified elutriate test is generally used with a parallel column settling test to predict actual effluent TSS as outlined in Figure 2.5. The estimated total concentration of effluent contaminants is compared to State water quality standards, (WQS). If the effluent does not meet the State WQS standards, the USACE can then propose the use of a mixing zone to further dilute the effluent as part of the CDF design.

While the modified elutriate test provides conservative estimates of contaminants within the effluent, the bulk quantities (mass released) of contaminants released from a CDF are highly dependent upon the volume of dredging fluids generated during dredging. The percentage of dredging fluids by



(Draft, Inland Test Manual)

Figure 2.5 Effluent Quality Predictive Technique

weight can range from more than 90% for hydraulic methods, e.g. using a cutterhead dredge, to less than 20% using clam-shell excavations. For a hypothetical annual dredging volume of 200,000 cubic yards of the highly contaminated sediments associated with Indiana Harbor, the USACE(1987b) estimated the quantities of PCBs expected to be released with the effluent for three CDF filling scenarios including hydraulic transfer from scow, direct pumping from dredge site using a matchbox type dredgehead and mechanical placement. The projected annual PCBs released for these three methods relative to a common size CDF are 6.3 kg, 4.2 kg and 0.0027 kg, respectively. Ironically, methods of dredging that minimize contaminant transport at the site of dredging can lead to a maximum potential for contaminant release at the point of discharge from the CDF and ultimately into the local environment. For example, the use of a cutterhead dredge minimizes the generation of turbidity and the potential for contaminant migration at the dredging site. However, the high water to solids effluent produced by the cutterhead hydraulic dredging does produce a potential for contaminant migration in the effluent.

The effluent from a CDF is generated by both the supernatant that remains after the dredged material falls out of suspension and from rainfall run-off coming from dredged material that rises above the water elevation. The quality of the effluent is influenced by type and quantities of pollutants, sediment mineralogy and organic content, and the dissolution kinetics discussed below.

**Organic Contaminants** ---- An alternative approach to evaluate the relationship between sediments and bioavailability of toxic organic contaminants is the equilibrium partitioning (EqP) method. The EqP approach relies on established water quality criteria to assess sediment toxicity. The first basic assumption of the EqP approach is that sediment toxicity is correlated to the concentration of the contaminants in the interstitial water and not to the total sediment concentration. The second basic

assumption is that contaminants partitioned between the interstitial water and the sediment sorbents (i.e. organic carbon) are in equilibrium. Such equilibrium concentrations are significantly larger than developed in the elutriate tests. Therefore, for a given contaminant, if the total sediment concentration, the concentration of sorbent(s), and the partitioning coefficient are known, then the interstitial pore water contaminant concentration can be calculated. Given the third assumption that organic carbon is the significant sorbent, the contaminant concentration can be predicted based on the total organic compound (e.g. TOC normalization).

**Metal Contaminants** ---- Of particular recent interest is research into the relationship between sediment sulfide content and bioavailability of toxic metals. Studies by DiToro et al. (1990), Carlson et al. (1991), and Ankley et al. (1991) have shown that sulfide content of freshwater and marine sediments is a predominant determinant of metal toxicity. This is based on the fact that many toxic metals form insoluble sulfides in anoxic or reduced environments (e.g. cadmium, copper, lead, mercury, nickel, and zinc) and most freshwater and marine sediments have significant sulfide contents. Note that this includes uncontaminated sediments. These researchers examined acid volatile sulfide (AVS) content of sediments, the solid phase sediment sulfides ( $\text{FeS}$  and  $\text{MnS}$ ,  $\text{H}_2\text{S}$ ,  $\text{HS}$ , and  $\text{S}_2^{2-}$ ) that are soluble in cold acid, and the concentration of simultaneously extracted metals (SEM) using the ratio  $[\text{SEM}]/[\text{AVS}]$ . AVS binding of metals reduces their bioavailability by decreasing metal solubility and is a precursor to formation of more insoluble pyritic sulfides (e.g.  $\text{FeS}_2$ ). Formation of pyritic metal sulfides is one mechanism of potential permanent removal of toxic metals. DiToro et al. (1990) measured  $[\text{AVS}]$  of marine sediments in relation to cadmium toxicity to three species of amphipods. They found that  $[\text{AVS}]$  is the sediment phase that determines the LC-50 for cadmium and also that correlations occurred between mortality and interstitial water metal activity. Ankley et al. (1991) studied cadmium and nickel in estuarine sediments in 10-day exposure tests with an amphipod and oligochaete species. In this study, molar  $[\text{SEM} (\text{cadmium and nickel})]/[\text{AVS}]$  ratios greater than one were consistently toxic to the amphipod (*Hyallela azteca*) and ratios of less than one were not. Metal availability was apparent through bioaccumulation in the oligochaete worm (*Lumbriculus variegatus*) when  $[\text{SEM}]/[\text{AVS}]$  ratios exceeded one. Freshwater sediments were spiked with cadmium and tested by a 10-day exposure with the same species of oligochaete worm, and the snail *Helisoma* sp. (Carlson et al., 1991). Here again, toxicity was not observed when the cadmium/AVS ratio was less than or equal to one.

Metal bioavailability is decreased by AVS, which acts as a sink for metals as long as the sediment remains anaerobic and the redox potential is too low to allow for oxidation of sulfides. Decreasing solubility of metal sulfides coincides with an increased AVS affinity for metals, that is  $\text{Mn} < \text{Fe} < \text{Ni} < \text{Zn} < \text{Cd} < \text{Pb} < \text{Cu} < \text{Hg}$  (DiToro et al., 1990). These studies suggest an important sediment and interstitial water metal toxicity assessment technique which may be useful in developing sediment quality criteria. Note that potential effect associated with dredging and dredge material disposal alternatives can significantly impact the beneficial role played by AVS. Ankley et al. (1991)

notes the importance of microbial processes to sediment [AVS], considering this a critical need in future research. General rules of thumb for sediments were:

$[\text{metal}]/[\text{AVS}] < 1$       sediment has little toxicity;

$1 \leq [\text{metal}]/[\text{AVS}] \leq 10$       sediment has little to high toxicity

$[\text{metal}]/[\text{AVS}] > 10$       sediment is highly toxic

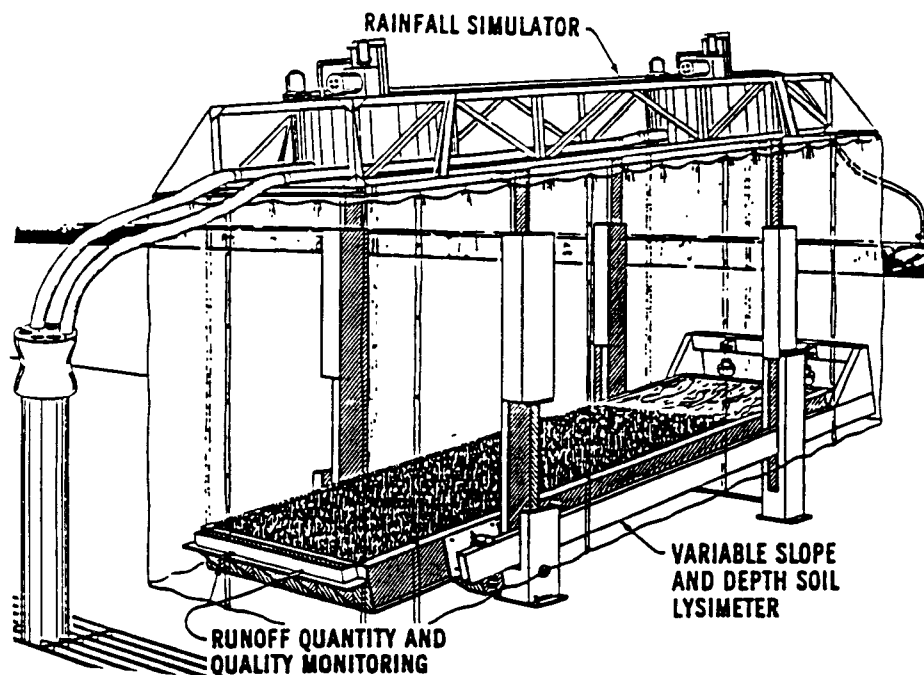
Copper may be an exception to this rule due to its affinity to also bind to organic compounds, and most of this research was performed on marine and lake sediment (i.e. high in Fe and aluminum oxides).

### **2.2.2 Surface Water Run-off Quality**

Concerns regarding surface water run-off from the dredged material in the CDF begin when the elevation of the dredged material exceeds that of the water in the CDF. This concern can be mitigated by an adequate residence time for the supernatant (e.g. water draining from the dredged materials) and run-off waters in the CDF such that the fines settle out and are not carried out of the CDF by the effluent. Final contours of sediment within the CDF can exceed the elevation of perimeter dikes. Thus, there is the long-term potential for sediment and contaminant mobility with the runoff water if the dredged material is not properly managed.

The quality of surface runoff water within a CDF can be expected to vary with time as a result of the changing physicochemical condition of the dredged material. When initially placed in a CDF, the dredged material is saturated, reduced, anaerobic and of neutral to slightly basic pH. However, dredged material placed above the zone of saturation within the CDF are subject to drying. This promotes aerobic microbial degradation or volatilization of organic components, oxidation of some metals and sulfides and changes in pH (usually lower and more acidic depending on the mineral composition of the dredged material). This reduction in pH can increase the solubility of metals and organic contaminants, leading to release of the contaminants (see Appendix A).

A laboratory testing protocol has been developed by the U.S. Army Waterways Experiment Station (WES) to simulate the complex process of rainfall runoff (Lee and Skogerboe, 1983; Lee et al 1991). The WES surface runoff simulator is shown in Figure 2.6. The test protocol requires a large sediment sample from the dredge site to be placed in the soil lysimeter in the saturated reduced state. At various stages of the drying process, rainfall events are applied to the dredge material and surface runoff water samples are collected for analysis of water quality parameters. Rainfall simulations are performed several times over the full range of air drying. These results have been shown to accurately predict surface runoff water quality which can be compared to water quality



(Lee et al. , 1991)

Figure 2.6 Surface Runoff Evaporation Simulator

standards and, thus, determine the need for runoff water treatment or the need to apply control measures to the CDF (e.g. an engineered final cover). This apparatus can also be used to evaluate control measures such as lime treatment, soil covers and plant stabilization. Section 7 presents such design considerations for an engineered final cover.

### 2.2.3 Plant Uptake

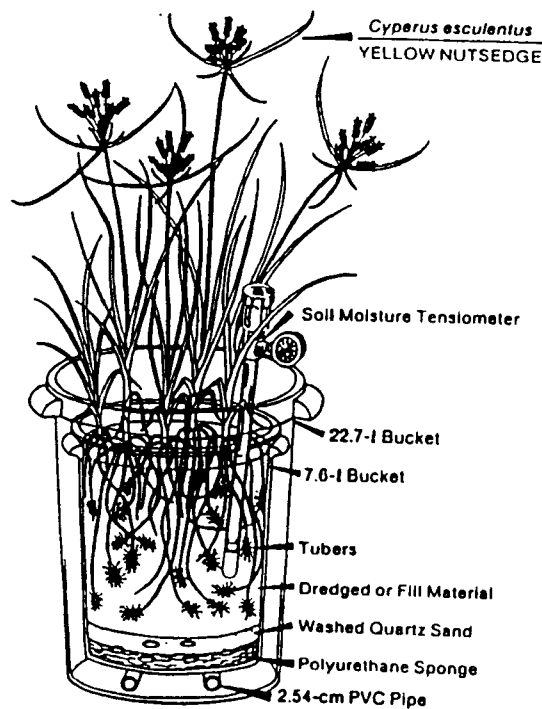
Most dredged sediments contain large amounts of nitrogen and phosphorus which promote vigorous plant growth. As a result, plants are easily established in a CDF following placement of sediments. When contaminated dredged materials are placed in the CDF, there is the potential that contaminants will move into the food chain from bioaccumulation in the plants. A summary of sources and pathways of toxic trace elements to plants is presented on Table 2-3. Organic contaminants typically have large molecules that will not pass through the cell walls of plants, thus limiting the plant uptake of organics. Also, because most contaminated dredged materials contain a suite of pollutants they may interact to affect biological systems.

The USACE has developed a plant bioassay test protocol (Folsom et al, 1981; Lee et al, 1991) which has been applied to freshwater and marine sediments. For freshwater sediments, the test protocol uses *Cyperus Escalantus* (yellow nutsedge) as an index plant. This plant is grown in buckets filled with contaminated sediments from the dredge site under conditions that simulate the CDF environment. Plant growth, phytotoxicity (growth reduction) and bioaccumulation are monitored during the test in the apparatus shown in Figure 2.7. A chemical analysis is performed on plants

**Table 2.3 Sources and Pathways of Toxic Trace Elements to Plants**

	Sb*	As	Be	B	Cd	Cr	Co	Cu	Pb	Hg	Ni	Se	Sn	V
<u>Uptake by roots</u>														
A. Soil or groundwater	x	x	x	x	x	x	x	x	x	x	x	x	x	x
B. Fallout to soil from air pollution	x	x	x	x	x	x	x	x	x	x	x	x		x
C. Sewage sludge soil amendments		x			x	x		x	x	x	x	x		
D. Biocides applied to soil and/or seed		x		x	x			x	x	x			x	
E. Surface water contamination		x				x			x					x
F. Fertilizers		x			x	x		x		x	x		x	
G. Industrial pollution		x			x	x		x		x	x		x	
<u>Uptake by leaves and stems</u>														
A. Pollutant fallout from industrial sources	x	x	x		x	x	x	x	x	x	x	x		
B. Pollutant fallout from auto emissions									x					
C. Biocide applications to plants		x		x	x			x	x	x			x	
D. Pollution fallout from incineration of fossil fuels and refuse	x	x	x	x	x	x	x	x	x	x	x	x	x	x





(Lee et al., 1991)

Figure 2.7 Plant Bioassay Procedure

harvested from the test buckets. The level of chemicals present in the plants can be compared to allowable threshold levels such as FDA crop limits. When limits are exceeded, the sediment management strategy would invoke control measures such as restricted placement of polluted dredge materials in the CDF to minimize exposure, such as placement of clean surface layers, limiting plant growth to desirable plant species, etc. Dredged materials producing excessive plant uptake will require designed control measures (e.g. an engineered final cover).

#### 2.2.4 Animal Uptake

Both upland and inlake CDFs are invaded and colonized by many animal species after each phase of dredge material placement. The type of wildlife depends to some degree on the nature of the setting; particularly whether the CDF filling stage exhibits dry pastoral or marshlike environment. Given the long life of many CDFs, significant animal colonies may be established during various interim phases of dredged material placement. Surface ponds may exist during the operational life of a CDF. Such ponds can support the presence of fish and benthic organisms. Bioavailable metals and organic compounds can then be transferred from the dredged material to fish or benthic organisms. The contaminants then can move quickly up the food chain. Such interim uptake problems can be reduced by the application of clean dredged material to the surface of problematic dredged material. Such "clean" interim covers are discussed in greater detail in Section 7.

Hierarchical food chain development is dependent on the lowest form of plant and animal species. Contaminants that are bioavailable at small concentrations to the lowest species may be magnified during migration up the food chain. A summary of the sources and pathways of toxic trace elements to animals is presented on Table 2-4. The test protocol used by the USACE to evaluate animal

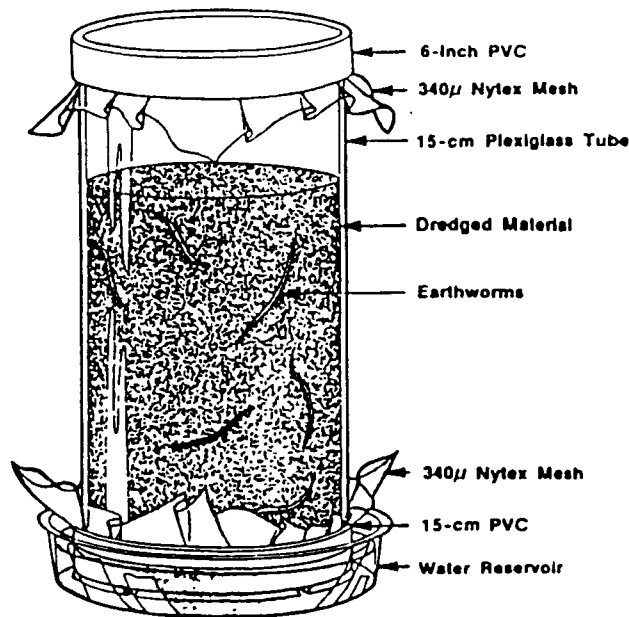
**Table 2.4 Sources and Pathways of Toxic Trace Elements to Animals**

	Sb*	As	Be	B	Cd	Cr	Co	Cu	Pb	Hg	Ni	Se	Sn	V
<u>Terrestrial</u>														
A. Breathing Contaminated air	x	x	x	x	x	x	x	x	x	x	x	x	x	x
B. Eating contaminated plant or animal tissue	x	x	x	x	x	x	x	x	x	x	x	x	x	x
C. Drinking contaminated water	x	x	x	x	x	x	x	x	x	x	x	x	x	x
D. Licking or preening fur or leathers									x					
E. Receiving therapeutic drugs (domestic animals)		x												
F. Eating biocides or poison baits		x											x	
<u>Aquatic</u>														
A. Metal in water	x	x	x	x		x	x	x	x	x	x	x	x	x
B. Runoff and fallout		x			x	x		x	x	x	x	x	x	x
C. Sewage and industrial waste outfalls	x	x		x	x	x	x	x	x	x	x		x	
D. Mine tailings or smelter waste leachate		x			x	x		x	x	x			x	
E. Contaminated plants, animals, or sediment		x	x	x	x	x	x	x	x	x	x	x	x	x
F. Biocides or runoff		x		x				x					x	
G. Lead shot									x					

\*Key: Sb = Antimony; As = Arsenic; Be = Beryllium; B = Boron; Cd = Cadmium; Cr = Chromium; Co = Cobalt; Cu = Copper; Pb = Lead; Hg = Mercury; Ni = Nickel; Se = Selenium; Sn = Tin; V = Vanadium

(Ref Jenkins, 1981)

uptake of contaminants from dredged sediments was borrowed from the European Economic Commission (EEC). This test was used by the EEC to determine the hazardous nature of manufactured chemicals prior to sale in Europe.



(Lee et al., 1991)

Figure 2.8 Earthworm Bioassay Procedure

As adapted by the USACE, the EEC test involves placement of ordinary earthworms in a container filled with polluted dredge materials as shown of Figure 2.8. The material is kept in moist, semi-moist, and air-dried conditions to simulate the expected range of CDF environments. For a period of 28 days, the earthworms are monitored for toxicity and bioaccumulation of contaminants. Lee et al (1991) noted that this test protocol can indicate potential environmental effects for dredged material placed in upland environments. It has also been shown useful for identifying bioavailable metals and organic contaminants. Contaminant problems are identified by comparing body burdens with allowable FDA limits. Contaminated sediments producing excessive uptake in the earthworms will require CDF control measures for the dredge materials (e.g. an engineered final cover).

### 2.2.5 Groundwater Leachate Quality

When a dredged material is placed in an upland CDF or above the water elevation in an in-lake CDF, a downward hydraulic gradient develops as the slurry consolidates. This gradient forces leachate into the underlying strata. The degree of leachate penetration into the underlying strata is influenced by the site hydraulics. For instance, CDFs located at near-shore settings may be within a zone of groundwater discharge that would limit or prevent leachate penetrations. Following consolidation, water seepage through the sediment may continue to generate leachate due to surface infiltration of rainwater. Movement of contaminants due to a hydraulic gradient is termed advective transport. Simultaneously with the advective transport, the contaminants undergo molecular diffusion. This process is more significant through fine grained sediments due to their low

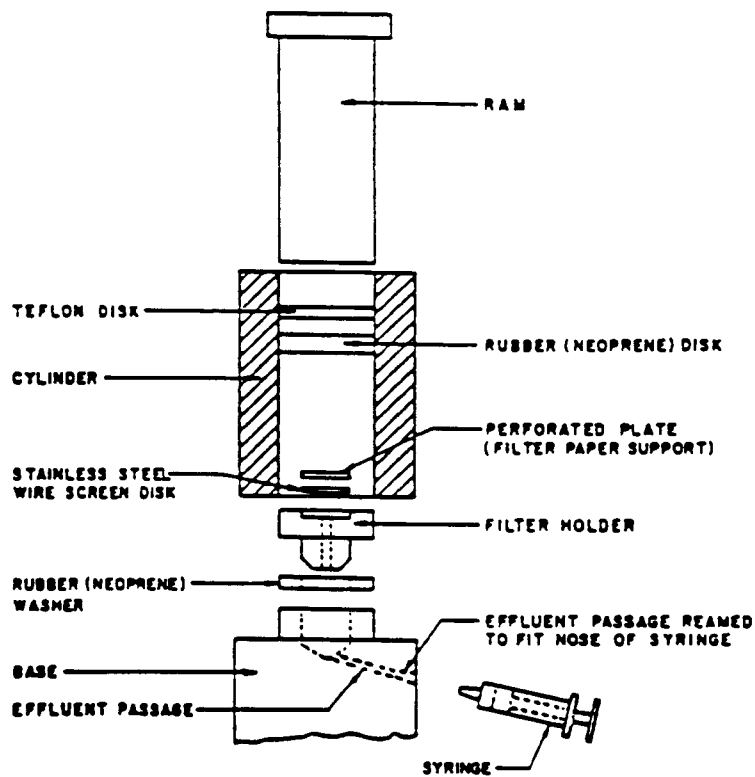
hydraulic conductivity. Diffusion of contaminants occurs due to contaminant concentration gradients and typically at rates so slow that it can be neglected. The quantity of leachate can be accurately predicted from advective flow theory if the site and CDF hydrogeological parameters are known. However the quality of leachate is affected by the type and quantities of pollutants, sediment mineralogy and organic content, equilibrium concentration of contaminants and pH of the pore fluid, and dissolution kinetics to name a few. Many of these parameters that influence leachate quality are influenced by the geochemical factors that change as the CDF is being filled.

There is presently no routinely used leachate testing protocol to define the type and quantity of contaminants carried by leachate from dredged material. There are a number of standardized test methods which could simulate leachate generation from both consolidation and percolation. For example, a soil/sediment press as shown in Figure 2.9 (ASTM,1992) is commonly used to extract pore fluids from marine sediment samples. Contaminant concentrations in such pore waters will generally be at equilibrium. This test could be used to simulate leachate generation from soluble contaminants during consolidation. Additionally, the soil press sample can be extracted from the press for use in a flexible wall permeameter cell to simulate leachate generation due to percolation. The fluids removed from the dredged material by either a soil press or permeameter could be subjected to analysis for typical water quality parameters. Field samples of pore water fluids can also be obtained using cone penetrometers equipped with porous stone sampling ports. An example of such field equipment is shown on Figure 2.10. The cone is pushed into the sediments hydraulically. Once at the depth a sample is required, the cone shaft is withdrawn slightly to expose the porous stone sampling part. At this time, an inner shaft is pushed downward to break a rubber septum that separates the porous stone and a glass vacuum sample tube. A sample of the pore water is then drawn by the vacuum into the glass tube. The pore water sample is then recovered by withdrawal of the cone penetrometer. Pore water samples obtained in this fashion are filtered and represent the actual soluble contaminant present in the subgrade.

The USACE has applied a sequential batch leaching procedure and a column leaching test to evaluate confined disposal of dredged material from Indiana Harbor; Everett Harbor, Washington; and New Bedford Harbor, Massachusetts ( USACE, 1987; Palermo et al, 1989; Myers and Brannon, 1988). The USACE has not yet endorsed a leachate test for routine testing and continues to perform research and evaluation testing on leachate generation.

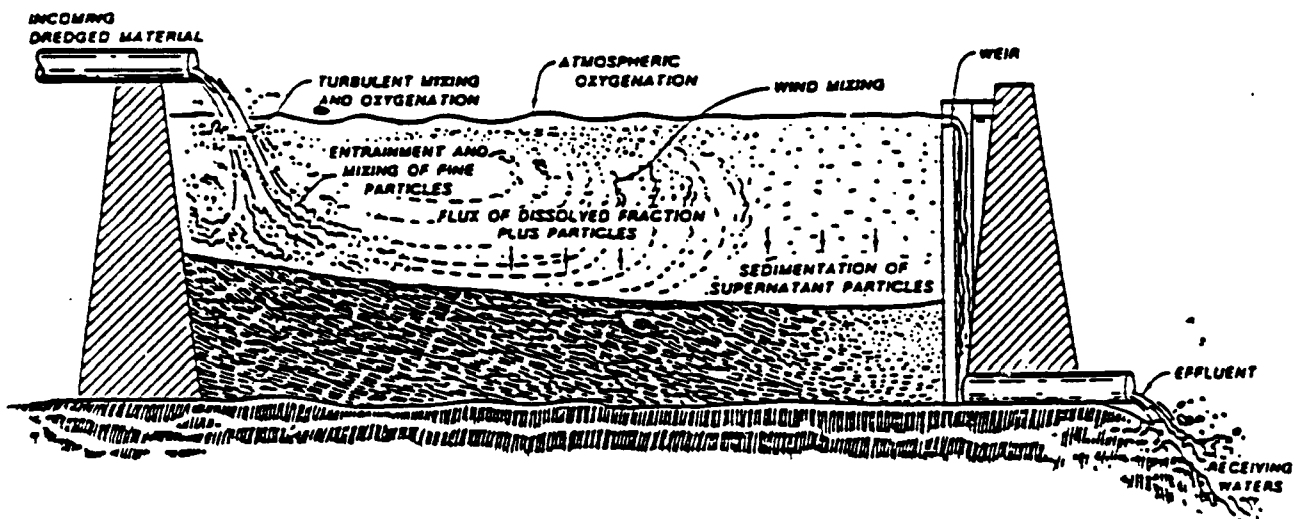
### **2.2.6 Water Column Discharge Quality**

During much of the operational life of an in-water CDF, the surface of the dredged material is below the water level within the CDF. The surface water can act as a host to aquatic animals and provides a contaminant uptake pathway. An interim cover of clean dredged material may be required to limit this short-term contaminant pathway. If required, an interim cover placed over the contaminated sediments must be able to limit the advective movement of contaminants vertically through the interim cover and biological uptake of the contaminants. It is assumed that the sediments and cover are saturated and in direct communication with the water column. The impact of contaminants



(ASTM Method D4542)

Figure 2.9 Soil Press for Sediment Leachate Sampling



(Draft Inland Test Manual)

Figure 2.10 Factors Influencing CDF Effluents

moving through the interim cover have been assessed using small and large scale laboratory water column discharge reactor units (Brannon et al, 1986, and O'Connor and O'Connor, 1983). These units were designed to assess the effectiveness of subaqueous capping at open water sites, but the same principles apply for overlying soil covers for CDFs. The effectiveness of the cover is assessed by following the movements of chemical contaminants and microbial spores found in the contaminated sediments into the overlying water column and by monitoring the biological uptake of chemical contaminants by clams and polychaetes. Such tests on Dutch Kills sediments from New Jersey indicated that as little as 10 cm of sand cover was effective in isolating the water column but 50 cm was required to eliminate biological uptake. No test standards currently exist for the water column uptake reactor test.

### **2.2.7 Airborne Loss of Contaminants**

Contaminants can migrate from the surface of dredged materials that are above the waterline due to direct volatilization of contaminants from the surface of the dredged materials or attached to wind blown soil particles. Both airborne pathways show increase contaminant loss with increasing wind duration and velocity.

The volatilization of contaminants from the dredged materials is governed by Henry's Law; the weight of any gas that will dissolve in a given volume of a liquid, at constant temperature, is directly proportional to the pressure that the gas exerts above the liquid. Henry's Law is expressed as follows:

$$C_{\text{equil}} = \alpha \, p_{\text{gas}}$$

Where  $C_{\text{equil}}$  is the concentration of gas dissolved in the liquid at equilibrium,  $p_{\text{gas}}$  is the partial pressure of the gas above the liquid, and  $\alpha$  is the Henry's Law constant for the gas. The partial pressure of the gas above the dredged materials is influenced by air temperature, wind, and atmospheric pressure.

Wind erosion is a mechanism by which fine particulate matter and soil at the surface become airborne. Soil grain size and shape influence a particle's ability to become airborne. Additionally, particulate matter having an effective aerodynamic diameter less than 10 microns (PM-10) is regarded as the largest particle size that can directly penetrate the human respiratory system (Perera and Ahmed). PM-10 also applies to standards established by EPA for acceptable levels of fine particulate matter in air (40 CFR 50).

### **2.3 AEPP Evaluation Criteria For CDFs**

Prior to reviewing AEPP criteria for potential contaminant pathways from a CDF, it is important to understand the difficulties associated with even the identification of problematic dredged materials.

The current confusion regarding sediment testing guidelines and criteria were expressed by the U.S. General Accounting Office as follows (GAO, 1992):

*According to EPA, some scientists believe that the 1975 testing guidelines EPA developed in conjunction with the Corps under section 404(b)(1) of the Clean Water Act - guidelines the Corps is currently using for disposal decisions on dredged material - are technically inadequate. However, Corps headquarters officials maintain that the guidelines have evolved substantially, have been tested thoroughly, and are adequate. Both the Corps and EPA have conducted detailed research on contaminated sediment, but the agencies have not always agreed on how the research should be used to determine which sediment needs confinement. The lack of agreement occurs generally because of the difficulty in establishing clear cause-and-effect relationships between the contaminant concentration in sediment and a biological impact on humans and wildlife.*

In 1991, EPA and USACE jointly published testing guidance for the discharge of dredged material into ocean waters (EPA/USACE, 1991). Currently EPA and USACE are developing a similar testing guidance for evaluation of material proposed for discharge to inland and near coastal waters (referred to as Inland Testing Manual).

The environmental performance of a CDF should be verified by a monitoring program that assesses the success of control measures for each of the contaminant pathways that are identified during the testing protocol, see Section 8. Evaluation criteria are required to serve as the standard by which the test results from laboratory simulations and field monitoring are evaluated. While finalized evaluation criteria are not currently available for all contaminant pathways, there are sufficient data in the literature from EPA, FDA, the European Economic Community, and research data to help with the decision making process. Table 2.5 summarizes the type of existing information that might be useful for evaluating each contaminant pathway. Specific evaluation criteria are discussed in this section and presented in greater detail in Appendix B. The contaminants or nutrients of concern must be selected on a case-by-case basis. Contaminants of interest are those that have FDA limits, are the subject of state fisheries advisories, or have EPA water quality criteria.

### **2.3.1 Effluent AEPP Criteria**

The factors influencing effluents from CDFs are shown on Figure 2.11. An unacceptable effluent discharge is one in which the concentration of any dredged material constituent, after allowance for mixing, exceeds applicable State water quality standards (WQS). Effluents from a CDF may be discharged as a point source through a weir system or filter cells, or as a non-point sourceflow through the dikes. Assuming that the sediments have been established as potentially contaminated, the modified elutriate and column settling tests are used to predict effluent quality as shown on Figure 2.5. The standards used for final comparison include State WQS as required under Section 401 of the CWA.

**Table 2.5 Evaluation Criteria for Contaminant Pathways**

<u>Pathway</u>	<u>Criteria</u>
Effluent	<ul style="list-style-type: none"><li>• EPA Water Quality Criteria (Table B1)<ul style="list-style-type: none"><li>• State Water Quality Standards</li><li>• CWA Mixing Zone Criteria</li><li>• State Mixing Zone Criteria</li></ul></li></ul>
Run-Off	<ul style="list-style-type: none"><li>• EPA Water Quality Criteria (Table B1)</li></ul>
Plant Uptake	<ul style="list-style-type: none"><li>• Research Results (Table B2)</li></ul>
Animal Uptake	<ul style="list-style-type: none"><li>• FDA and European Action Levels for Foodstuffs (Table B3)</li></ul>
Leachate	<ul style="list-style-type: none"><li>• EPA Drinking Water Standards (Table B4)</li></ul>
Air Emissions	<ul style="list-style-type: none"><li>• Pending EPA Air Quality Standards</li></ul>

### **2.3.2 Surface Water Run-Off AEPP Criteria**

The final closure of the CDF must ensure that water run-off from the facility meets the same criteria discussed above for effluent discharge. Additionally, many states will require a sediment control plan and potential discharge control structures, e.g. sedimentation ponds, to limit erosion and siltation of adjoining bodies of water. As discussed in Sections 3 and 4, current CDFs do not have a standard approach to closure but are consistently very flat in profile. Such minimal grades provide for control of water run-off related erosion at the expense of increased infiltration potential. Site specific testing can be performed using the test device shown on Figure 2.6 and described by Lee and Skogerboe (1983).

### **2.3.3 Plant Uptake AEPP Criteria**

The potential for movement of unacceptable levels of contaminants from the dredged material into the environment through plants and eventually into the food chain must be restricted. Appropriate



management strategies therefore are formulated to place problematic dredged material to minimize plant uptake. The management strategies control and manage plant species on the site so that desirable plant species that do not uptake and accumulate contaminants are allowed to colonize the site, while undesirable plant species are removed or eliminated. Plant uptake can be limited during interim periods of the CDF life when a significant surface area of problematic dredged material may be exposed for years. Therefore control of plant uptake will be considered throughout the life of the CDF and not just after final closure. Limits on plant uptake can be established using criteria presented on Tables B-4 and B-5 using control mechanisms discussed in Section 5.2.1.

#### **2.3.4 Animal Uptake AEPP Criteria**

A potential for animal uptake of unacceptable levels of contaminants from dredged material may exist. Appropriate management strategies therefore need to be formulated that consider the ultimate environment in which the dredged material is placed, the anticipated ecosystem developed, and the physico-chemical processes governing the biological availability of contaminants for animal uptake. Interim periods during the operational life of the CDF may be more critical than after the final closure. Surface ponds created during the filling of a CDF may support aquatic life that will provide the basis for contaminant uptake through the food chain via visiting avian and terrestrial species. Limits on animal uptake can be established using criteria presented on Table B6 and control mechanisms discussed in Section 5.2.2.

#### **2.3.5 Groundwater Leachate AEPP Criteria**

Pollutants that are dissolved in the excess water of the dredged sediments can contaminate the underlying groundwater. Such migration of contaminants may be caused by pressure gradients that develop in the pore water during consolidation of the dredged sediments or at sites that are natural ground water recharge zones and result in advective transport of the contaminant to the groundwater or by diffusion of the contaminant caused by concentration gradients.

Contamination of underlying groundwaters is also a design consideration in common landfills. For instance, the recent promulgation of RCRA part 257.3-4 provides groundwater contamination criteria for solid waste landfills. These revised regulations state that the solid waste facility shall not contaminate underground drinking water sources beyond its boundary or point of compliance. For purposes of this requirement, contamination is defined as concentrations of substances exceeding maximum contaminant levels (MCLs) developed by EPA under Section 1412 of the Safe Drinking Water Act (SDWA) or existing ambient groundwater quality. The list of current MCLs is given on Table 2.6. EPA is in the process of amending this list so adjustments to the MCLs can be anticipated. The point of compliance is usually taken as the water table at the nearest monitoring

**Table 2.6 Maximum Contaminant Levels (MCLs) - SDWA**

Chemical	CAS No.	MCL (mg/l)
Chromium (hexavalent) .....	7440-47-3	0.05
2,4-Dichlorophenoxy acetic acid .....	94-75-7	0.1
1,4-Dichlorobenzene .....	106-46-7	0.075
1,2-Dichloroethene .....	107-06-2	0.005
1,1-Dichloroethylene .....	75-35-4	0.007
Endrin .....	75-20-8	0.0002
Fluoride .....	7	4.0
Lindane .....	58-89-8	0.004
Lead .....	7438-82-1	0.05
Mercury .....	7438-87-6	0.002
Methoxychlor .....	72-43-5	0.1
Nitrate .....		10.0
Selenium .....	7782-49-2	0.01
Silver .....	7440-22-4	0.05
Toxaphene .....	8001-35-2	0.005
1,1,1-Trichloroethene .....	71-55-6	0.2
Trichloroethylene .....	79-01-6	0.005
2,4,5-Trichlorophenoxy acetic acid ...	93-76-5	0.01
Vinyl chloride .....	75-01-4	0.002

well. In addition, many states have non-degradation and cleanup criteria that may be orders of magnitude more stringent than MCL levels. Such small levels of acceptable contaminant presence are commonly due to biologically concentrating contaminants (or bio-magnification) that result in toxicity concerns.

### **2.3.6 Airborne Loss AEPP Criteria**

Past research has examined odor control problems at CDFs but has not developed models for evaluating the nature and quantity of volatile emission of contaminants from dredged materials. New Source Performance Standards (NSPS) are now being promulgated under the Clean Air Act (CAA). While NSPS for CDFs are not currently available, they have been promulgated (May 30,

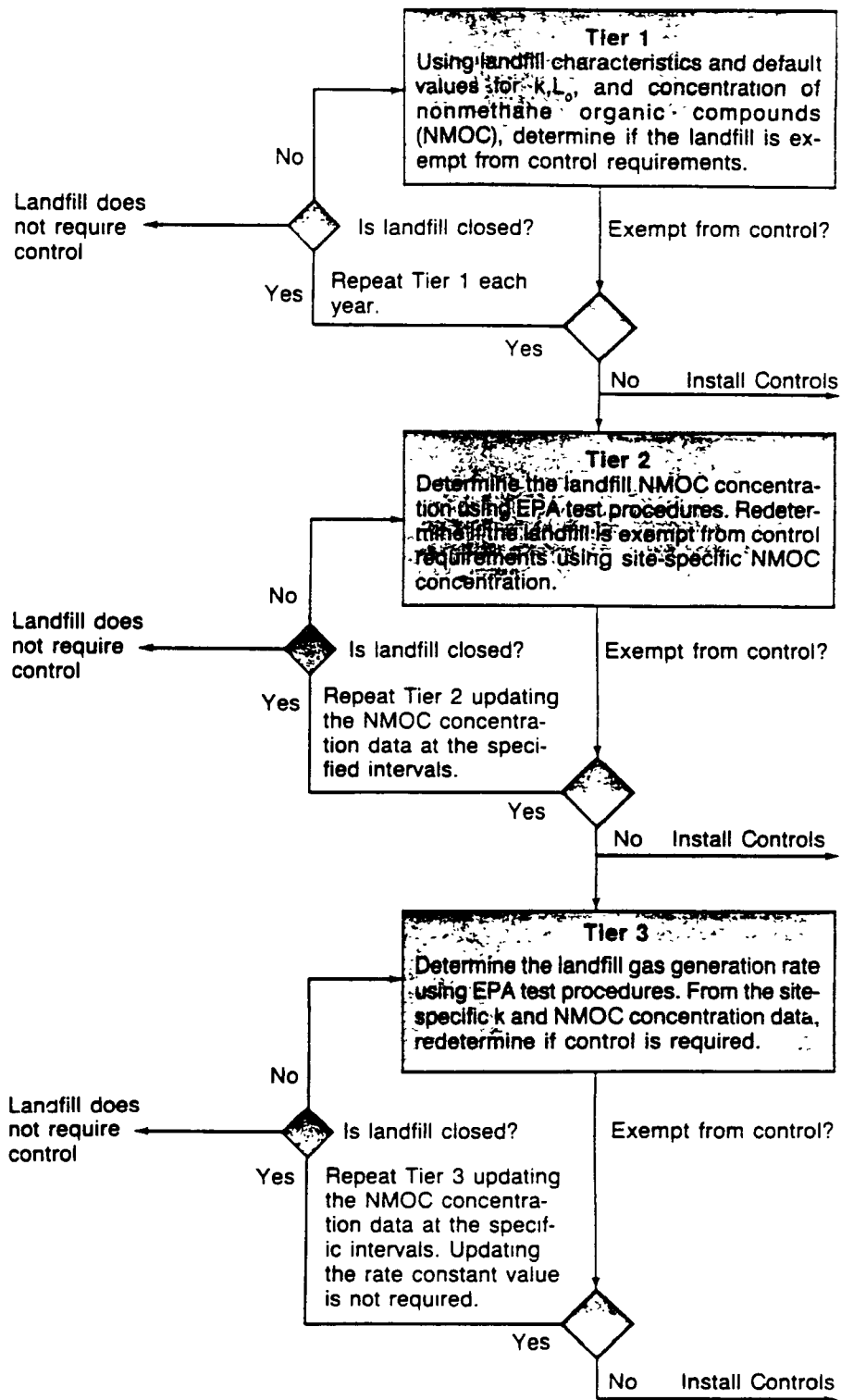
1991 Federal Register) for Municipal Solid Waste (MSW) landfills. The proposed MSW performance standards focus on the quantity of non-methane organic compounds (NMOC) released by the landfill annually. The proposed NSPS establishes a maximum annual emission of 150 metric tons per year for a landfill. A tiered evaluation system, see Figure 2.11, is proposed to evaluate the actual NMOC discharge for a given MSW landfill. Tier 1 evaluation uses an EPA computer model that over estimates NMOC release. Tier 2 and 3 evaluations require varying degrees of field measurements to develop more accurate site specific volatilization quantities.

The 1990 amendments to the Clean Air Act (CAA) established three broad categories of airborne pollutants:

- Releases of volatile organic compounds (VOCs) are controlled because they react to form smog,
- Routine releases of 189 hazardous air pollutants (HAPs) are limited to protect both human health and the environment; and
- Accidental releases of extremely hazardous substances (EHS).

The first two categories of airborne pollutants are directly applicable to potential releases from a CDF. The CAA requires every major source (e.g. producing more than 10 tons of emission) in the United States that omits a regulated pollutant to obtain an operating permit and pay an annual emissions fee for each regulated pollutant. Additionally, the CAA requires that new sources must not lead to a significant deterioration of the one existing air quality. The prevention of significant deterioration (PSD) is particularly applicable to sites having air quality cleaner than national standards.

$Q_T$  Total NMOC emission rate from the landfill (Mg/yr)  
 $k$  Landfill gas generation constant (1/yr)  
 $L_o$  Methane generation potential (m<sup>3</sup>/Mg)  
 $M_i$  Mass of refuse in the  $i^{th}$  section (Mg)  
 $t$  Age of the  $i^{th}$  section (yrs)  
 $C_{NMOC}$  Concentration of NMOC (ppmv)



(Federal Register, Jan, 1993)

Figure 2.11 Tiered Gas Emission Model (RCRA-D)

## SECTION 3

### DREDGED MATERIAL IN THE GREAT LAKES

#### 3.1 Navigation Dredging by the USACE

Prior to the 1960s, economic considerations typically dominated the selection of dredged material disposal alternatives, with little regard for environmental impact. This generally meant open water disposal of harbor and channel sediments, and land (or wetland) impoundment of river sediments. In the mid-1960s, questions were raised about the effects of dredging on water quality in the Great Lakes. Open water disposal of contaminated dredged material was openly criticized and USACE, in cooperation with the Federal Water Pollution Control Administration (the predecessor of EPA), studied and evaluated the alternative approaches to the disposal of contaminated dredged materials. The primary concern at first was to control nutrient loadings such as nitrogen and phosphorous and to limit sediment transport.

The studies included a two-year, 12-volume report by the Corps entitled "Dredging and Water Quality Problems in the Great Lakes" (USACE, 1969). This report reviewed dredging and disposal practices, examined the impact on water quality and recommended some modifications and control measures. This study and many subsequent studies found that the effects of dredging and disposal activities were localized, short-lived and difficult to measure in terms of impact on water quality and biological communities. However, the nature of dredging and disposal operations is such that very high levels of dilution occur which complicate the problems of measurement. USACE report concluded that open water disposal of contaminated material is "presumptively" undesirable.

The first CDF in the Great Lakes was constructed at Grassy Island along the Detroit River in 1960, before the environmental impact of contaminated sediments was appreciated. In 1970 Congress passed Public Law 91-611, called the Diked Disposal Program, which provided the Corps with funds to construct CDFs for storage of polluted dredged materials in the Great Lakes. The same law provided funds to the Corps' Waterways Experiment Station (WES) to manage a research program on the environmental effects of dredging and disposal. Today, a total of about 40 CDFs exist around the perimeter of the Great Lakes on the American side (EPA, 1990), as shown on Figure 3.1. Fourteen are constructed upland using diked or depressed areas and 26 are built in-lake, either adjacent to the shore or as an island adjacent to a navigable channel, or harbor, as shown schematically in Figure 1.1. A summary of the contaminant types, size, age, and location for these facilities is presented in Table 3.1. Several small and filled CDFs from the Detroit District are not included in this table. Many of the CDF sediments are categorized as moderately to heavily polluted according to the 1977 EPA guidelines presented in Table 2.1. Many of the CDFs are currently being enlarged by raising the perimeter dikes as the direct result of an inability to site new CDFs.

**Table 3.1 Summary Data for Confined Disposal Facilities, U.S. Great Lakes (EPA, 1990)**

-----CONTAMINANTS-----										
	Year Constructed	Fill Date	% Filled	Capacity (CU YD)	Approximate Remaining Capacity (CU YD)	Metals	TKN, AMM, N, COD, P <sup>(1)</sup>	PCBs	Volatile Organics	Oil & Grease
<b><u>BUFFALO DISTRICT</u></b>										
1 Cleveland # 12	1974	1979	100	2,760,000	0	x				x
2 Cleveland # 14	1979	1991	40	6,130,000	3,678,000	x				x
3 Dike #4 (Buffalo)	1974	1995	40	6,900,000	4,140,000	x(Hg)			x	x
4 Erie	1979	1993	40	1,600,000	960,000	x	x		x	
5 Huron	1975	1990	70	2,150,000	645,000	x	x			x
6 Lorain	1977	1990	70	1,850,000	555,000	x	x		x	x
7 Small Boat Harbor (Buffalo)	1968	1972	100	1,500,000	0	x				
8 Times Beach (Buffalo)	1972	----	45	1,500,000	Inactive	x			x	x
9 Toledo (Facility 4)	1976	1992	65	10,000,000	3,500,000	x	x	x	x	
10 Toledo (grassy Is )	1967	1978	100	5,000,000	0	x	x	x	x	
<b><u>CHICAGO DISTRICT</u></b>										
1 Chicago	1984	1995	10	1,300,000	1,170,000	x(Hg)				x
2 Michigan City	1978	1989	80	50,000	10,000	x	x	x		x
<b><u>DETROIT DISTRICT</u></b>										
1 Bayport (Green Bay)	1965	1979	100	650,000	0	x(Hg)	x			x
2 Bolles	1977	1990	25	335,000	251,000	x	x			x
3 Clinton River	1989	----	98	370,000	0					
4 Crooked River	1982	1992	20	19,500	15,000	x	x			
5 Dickinson Is (Lake St Clair)	1976	1990	48	2,031,000	1,015,000	x(Hg)	x			
6 Erie Pier (Duluth)	1979	1993	50	1,100,000	550,000	x	x	x		x
7 Frankfort	1982	1990	100	30,000	0		x			x
8 Grassy Is (Detroit R )	1960	1984	100	4,320,000	0	x(Hg)	x			x
9 Harbor Is (Grand Haven)	1974	1985	97	310,000	0	x	x			
10 Harsen's Is (Lake St Clair)	----	----	--	30,000	Inactive					
11 Kawkawlin River	----	----	--	-----	Inactive	x	x			
12 Kenosha	1975	1990	66	750,000	225,000	x	x	x		x
13 Kewaunee	1982	1992	57	500,000	200,000		x	x		
14 Kidney Is (Green Bay)	1979	1986	97	1,200,000	0	x(Hg)	x	x	x	x
15 Manitowoc	1975	1992	61	800,000	280,000		x			
16 Milwaukee	1975	1990	44	1,600,000	800,000	x	x		x	x
17 Monroe (Sterling)	1984	1995	--	4,200,000	-----	x	x	x		

						-----CONTAMINANTS-----				
						Approximate Remaining Capacity				
						Capacity (CU YD)				
						Year Constructed				
						Fill Date				
						% Filled				
						Capacity (CU YD)				
						Metals				
						TKN, AMM, N, COD, P <sup>(1)</sup>				
						PCBs				
						Volatile Organics				
						Oil & Grease				
18	Monroe (Edison)	----	1984	--	-----	0	x	x		x
19	Pionte Mouvile	1979	2009	38	18,460,000	11,184,000	x(Hg)		x	x
20	Port Sanilac	1979	1983	100	143,300	0		x	x	
21	Riverview (Holland)	1978	1993	--	120,000	-----	x	x		
22	Saginaw	1978	1990	48	10,000,000	5,000,000	x	x	x	
23	Sebewaing	1979	1989	65	84,000	29,000		x		
24	Verplank (Grand Haven)	1974	1977	--	134,000	Inactive		x		x
25	Whirlpool (St Joseph)	1978	1987	100	25,000	0	x			x
26	Windmill Is (Holland)	1977	1988	75	370,000	92,000	x	x		

(1) TKN = Total Kjeldahl Nitrogen

AMM = Ammonia

N = Nitrogen

COD = Chemical Oxygen Demand

P = Phosphate



(EPA, 1990)

Figure 3.1 Locations of Confined Disposal Facilities, U.S. Great Lakes



### **3.1.1 In-Lake CDFs**

A summary of the technical specifications and design trends for the 25 in-lake CDFs built by the USACE is presented in Table D-1 in Appendix D. Most of the facilities built prior to 1975 consist of rubble mound dikes with limestone, sand and gravel fill. Such dikes promote free drainage of effluent during filling, while retaining most solid particles by natural settling and filtration. In some instances, overflow weirs were installed in the dikes. However, the weirs were not needed or were ineffective until the sediments clogged the pervious dikes to cut off drainage. The water level is essentially the same on the lake and fill sides of such pervious dikes: never differing by more than a few inches. Most of the engineering analyses of such CDFs were concerned with the long-term stability of the dike during storm wave attack or subsoil settlement.

Since the mid-1970s, there has been increased design emphasis on the use of natural settling and dike filtration to retain fine particles. As discussed in Section 5, such designs attempt to provide sufficient effluent retention time to allow for natural gravity settling and/or incorporate natural aggregate or geotextile filters in the dikes. On some projects, geomembranes and clay/silt layers were used to line the bottom or sidewalls of a CDF to control flow of effluent through the permeable filter dike. Many projects have incorporated special filter cells into the dike walls which were specially designed to remove suspended particles from effluent before being discharged back to the lake. At the Calumet Harbor facility in Chicago, special sand/carbon filter cells were built on land so that effluent from the CDF during placement of dredged material could be pumped through the cells to remove suspended particles and soluble contaminants before discharge into the Calumet River. The filters were designed to receive influent having suspended solids of 100 ppm and produced effluent having suspended solids less than 15 ppm.

The capacity and useful life of most in-lake CDFs tend to be large. The capacity varies from the small 0.12 million cubic yards (MCY) Riverview facility to 18.6 MCY facility at Pointe Mouillee with an average capacity of about 3.5 MCY. The surface area of these facilities varies from 11 to 700 acres with an average of 112 acres. Several of these facilities are filled to capacity and over half are more than two-thirds filled which suggests that many new facilities will soon be needed. Fortunately, most of these in-lake facilities have a useful life of more than 15 years except at the major ports of Buffalo, Cleveland and Green Bay, which were completely filled after several years because of the frequency and volume of dredging.

### **3.1.2 Upland CDFs**

Technical specifications for 13 of the upland CDFs on the Great Lakes are summarized in Table D-2 in Appendix D. Upland sites are generally selected adjacent to the contaminated area to be dredged and not far inland because transportation costs are a major factor. Typical sites are either natural land depressions as at Frankfort Harbor or flat flood plains adjacent to the polluted waterway. Substrate soils are highly variable and include sand, silt, clay and glacial till. Most sites need earthen dikes around the perimeter to form the containment area.

While most upland CDF dikes were constructed of impermeable clays, several of the diked facilities were constructed of local soils including silts and sands. Most of these facilities used an impermeable clay liner on the bottom and sides to inhibit leachate migration. A few, such as the Whirlpool (St. Joseph) disposal area, used a PVC geomembrane as the liner. Design components such as clay and geomembrane liners are discussed in greater detail in Section 4.

The polluted dredged materials are placed into the facility by either mechanical (clamshell) or hydraulic dredging. During hydraulic dredging, the influent pipe is placed at a location remote from the weir within the CDF to insure that the dredge slurry has sufficient retention time for natural settling of solids before the effluent passes through the outflow weir. Thus, coarse particles such as sand, gravel and clay balls are rapidly deposited near the pipe while fine-grained silts and clays migrate toward the weir and settle. Some fine-grained particles and water-soluble contaminants are discharged from the CDF. Such point source CDF discharges are frequently monitored to insure that water quality standards are not exceeded. Oil skimmers can be used to improve effluent water quality from the CDF when oil and grease are present in the polluted dredged material.

At Michigan City, a sand filter and drain pipes were incorporated into the dike to dewater the hydraulic dredge material. The filter became clogged during the first dredging operation, rendering the CDF incompatible with hydraulic dredging. The facility was subsequently filled by mechanical dredging and trucking since mechanical dredging minimizes the addition of water to dredged sediment and, thus, the need for a dewatering system. Filter systems are discussed in greater detail in Section 4.

By comparison, most upland CDFs are very small and have a short useful life, compared to in-lake facilities. As summarized in Table D-2 in Appendix D, the capacities of the existing upland facilities vary from 0.020 MCY at Crooked River to 2.0 MCY at Dickinson Island. The average capacity is only 0.28 MCY for 13 of the upland CDFs around the Great Lakes compared to an average of 3.5 MCY for in-lake facilities. The average surface area is only 36 acres for upland sites compared to 112 acres for in-lake CDFs. Upland sites are politically difficult to locate in populated industrial areas. At this time 10 of the 14 upland facilities are filled to capacity.

### **3.2 Sediment Remedial Actions by EPA and States**

Since the mid-1970s there has been a concerted effort in Region 5 by EPA and Region 5 states to remediate contaminated sediments at high priority sites (Elster, 1992) to hasten the goal of improving water quality in the region. At 20 sites, as summarized in Appendix D on Table D.3, involving both navigable and non-navigable water bodies, clean-up actions were directed by EPA and/or the State, using a variety of enforcement authorities and employing a number of remedial technologies. The EPA has exercised authority under CERCLA, CWA and, to a lesser extent, through RCRA/TSCA. The states have used the authority provided under the CWA, state environmental regulations, voluntary agreements with Potentially Responsible Parties (PRPs), and through Federal grant programs.

As noted in Table D.3, there have been nine CERCLA and two CWA actions by EPA and nine State actions dating back to 1977. The effected sediments tend to be heavily contaminated with metals and organic compounds. The volume of polluted material ranges from a few hundred cubic yards to tens of thousands of cubic yards. Such volumes are small in comparison to USACE dredging projects. The remedial actions usually include:

- 1) excavation and dewatering of contaminated sediment
- 2) incineration of heavily contaminated sediments to destroy organic compounds such as PCBs;
- 3) placement of contaminated sediments or treated residue in a RCRA type landfill with appropriate bottom liner and low-permeability caps; or
- 4) in-situ hydraulic isolation (or containment) of polluted material.

In general, some of the earlier remedial efforts (e.g. Cast Forge Steel in Howell, Michigan) were ineffective because of poor containment design and were often left incomplete because of cost overruns (Elster, 1992). Recent remediations tend to be more successful because they emphasize in-situ containment with dredging and treatment of contaminant hot spots. For instance, sediments from the contaminant hot spot at the Outboard Marine Corp. site in Waukegan, IL were dredged and thermally treated to remove the PCBs. Peripheral contaminated sediments (<500 ppm) were dredged, dewatered, and placed in a hydraulically isolated waste disposal cell on site. The treated hot spot sediments were placed over the isolated peripheral sediments and were in turn covered with a low permeability cap.

## **SECTION 4**

### **DESIGN AND PERFORMANCE OF EXISTING CDFs**

This section compares recent in-lake and upland CDF projects by the USACE to EPA/State sediment remediation projects. All projects referenced are within EPA Region 5. As discussed in Section 2, the CDFs are designed to handle dredged materials that can contain a high volume of free water. The CDFs are designed to ensure that effluent coming from within the CDF will not cause levels of contamination in adjacent surface waters that exceed the CWA established MCLs and State water quality standards (WQS). The effluent can be treated, filtered, or allowed to dilute within a defined mixing zone. TSCA and RCRA disposal facilities are, however, primarily designed for waste streams that have no free water. These disposal facilities must provide maximum possible isolation of the waste from proximal ground and surface waters.

The significant quantity of free water associated with dredged material disposal provides for design complexities not common to PCB or hazardous waste landfill designs. Such considerations include evaluating the potential for contaminant solubility in the effluent waters, the level of contamination bound to dredged material solids, the impact of sediment dredging, handling, and disposal operations on contaminant migration potentials at the CDF, and sediment or effluent treatment alternatives if the effluent within the mixing zone does not satisfy CWA or State WQS.

#### **4.1 USACE Projects**

The design and construction of in-lake and upland CDFs has evolved during the past 25 years to include new technologies and updated environmental criteria. Many of the CDF design details are site- and facility-specific, and require a detailed evaluation of prospective site conditions. The Corps has frequently published guidance documents during this period as part of the Dredged Material Research Program DMRP (1973-1978) and several other programs to deal with specific problems such as dewatering/densifying (USACE, 1978), disposal area reuse (USACE, 1978a) and estimating the quality of effluent from a CDF (Palermo, 1986). These and other documents have evolved into a manual entitled "Confined Disposal of Dredged Material" (USACE, 1987a) which conveys the state of the art in design, operation and management of CDFs.

##### **4.1.1 CDF Design Criteria/Objectives**

At the present time the USACE CDF Manual (USACE, 1987a) emphasizes two primary objectives associated with the design of in-lake and upland CDFs to store contaminated sediments:

- 1) **Maximize Retention of Fine Particles.** The Dredged Material Research Program has shown that most contaminants are adsorbed to the surface of the finer soil particles such as silts and clays. The sediment pore fluid is significantly less contaminated and is diluted during dredging and upon release from the CDFs as an effluent.

- 2) Maximize Storage Capacity/Useful Life. The economics of dredged material disposal includes the administrative process by which most CDFs on the Great Lakes were planned and constructed. This process presently takes about 10 or more years, which dictates the minimum capacity/useful life of a CDF be at least 15 to 20 years.

From an engineering perspective, existing CDFs are designed as wastewater treatment facilities where the objective is to capture particles with adsorbed contaminants. These CDFs assume the partitioning potential of the contaminants is minor or moderate as previously detailed on Table 1.2. Effluents and other discharges are regulated by the CWA, as noted in Section 1, and must satisfy State WQS. Therefore, the sediment basin and weir are designed and operated to promote gravity settling of solids. According to the USACE CDF Manual, the settling process will normally remove suspended particles down to a level 1 to 2 g/l in the effluent for freshwater conditions. This is about 99% efficient when considering a typical CDF influent of 100 g/l. If water quality standards are not met by gravity settling, the designer must provide for additional treatment of the effluent by flocculation or filtration or use a mixing zone or zone of dilution in the receiving waters. Filters have been included into the design of several CDFs as noted in Tables D-1 and D-2. However, the effective operation of a filter is often short-lived because fine particles quickly plug the pores of a filter and cut off flow unless the filter face is cleaned periodically. The size of a potential mixing-zone depends upon a number of factors including the effluent contaminant concentration, concentrations in the receiving water, the applicable water quality standards, effluent density and flow rate, receiving water flow rate and turbulence, and the geometry of the discharge structure and receiving water boundaries. The evaluation of mixing-zone geometry is based on calculation of near-field dilution and dispersion processes which can be performed using the available computer models that yield order-of-magnitude estimates (see Inland Testing Manuals 1993). While computational methods provide an excellent estimate of dispersion, a dye plume study at the proposed discharge site is considered to be the best method of evaluating mixing zone dimensions although it is costly and time consuming. Also, many state regulatory agencies specify limits on the dimensions of the mixing zone that can be incorporated into a CDF design, thus limiting the mixing zone as a design element.

From a structural perspective, CDFs are generally created by constructing dikes around the perimeter of the site with the goal of creating stable, long-term containment of dredged material. Upland facilities typically have compacted low-permeability earth dikes, whereas most inlake CDFs have permeable stone dikes that are constructed with layers of stone of increasing size over a core of sand and gravel. In-lake CDFs with stone dikes are generally permeable when first constructed but become progressively less permeable due to clogging during filling operations. Variations to these basic dike structural designs have included the use of sheetpiles and liners, such as clay layers and plastic membranes, for improved structural or hydraulic performance.

Several examples of in-lake and upland CDFs are presented in the following sections to illustrate the design features used to contain polluted dredged materials compared to RCRA/TSCA approved

hazardous/toxic and solid waste disposal facilities. For contaminants having a high partitioning potential (reference Table 1.2), the trend in CDF design has been away from the solids retention approach and towards the hydraulic isolation of "dewatered" sediments through the use of natural and synthetic impermeable liners and caps to control the release of pollutants through the base and dikes of the CDF. Such hydraulic contaminant CDFs force the effluent to exit the CDF through a point source. This allows the potential for better control, treatment, and monitoring of effluents.

Because of the limited availability of land for siting CDFs in populated areas and public concern for the environment, the last in-lake CDF was built at Monroe Harbor, Michigan in 1983 and the last upland CDF at Clinton River in 1989.

#### **4.1.2 Example of In-Lake CDFs**

**Buffalo/Lackawanna - Dike #4** ---- An early example of a rubble mound in-lake CDF is the Buffalo/Lackawanna Dike #4 which was constructed in 1974 at the south end of Buffalo Harbor (Figure 4-1). This facility was used to contain dredged materials from Buffalo and Dunkirk Harbors which were heavily contaminated with several metals including mercury, plus oil, grease and PAH's. The outer walls of the CDF are in 30 feet deep water depths, and exposed to large wind induced currents and wave forces. Rubble mound construction is an economical solution for this harsh environment and costs were reduced by incorporating the adjacent coast line and an existing sheetpile breakwater into the containment structure.

A typical design section of the rubble mound structure is shown in Figure 4-2 which reveals the various zones of granular fill, armor stone and 5-foot thick filter blanket that abuts the dredged material. Because the subsoil is a soft lake clay to sandy silt, 50-foot wide berms were added to each side of the main dike to improve the support capacity of the soft subsoil and prevent instability of the dike.

Contaminated sediments are dredged using both hydraulic and mechanical methods. When placed in the CDF, the dredged material is dewatered by natural settling. Solids in the effluent are minimized given an adequate residence time before the effluent is discharged through a single weir located along the existing sheetpile breakwater. Placement of dredged materials within the CDF has not yet risen to a level where the weir is used. In addition, dredging fluids are filtered at the inside face of the dike by the natural aggregate filter. However, there is considerable uncertainty about the efficiency of this filter because of the hydraulic construction techniques.

There are no monitoring wells in the dike to evaluate effluent quality and water quality is not monitored at the weir since no effluent has yet risen to the level of the weir. Monitoring outside of the CDF has shown no degradation of background water quality. This CDF should be filled to capacity by 2015. While there are currently no plans to cap the facility, the ultimate intended use is as a wildlife area.

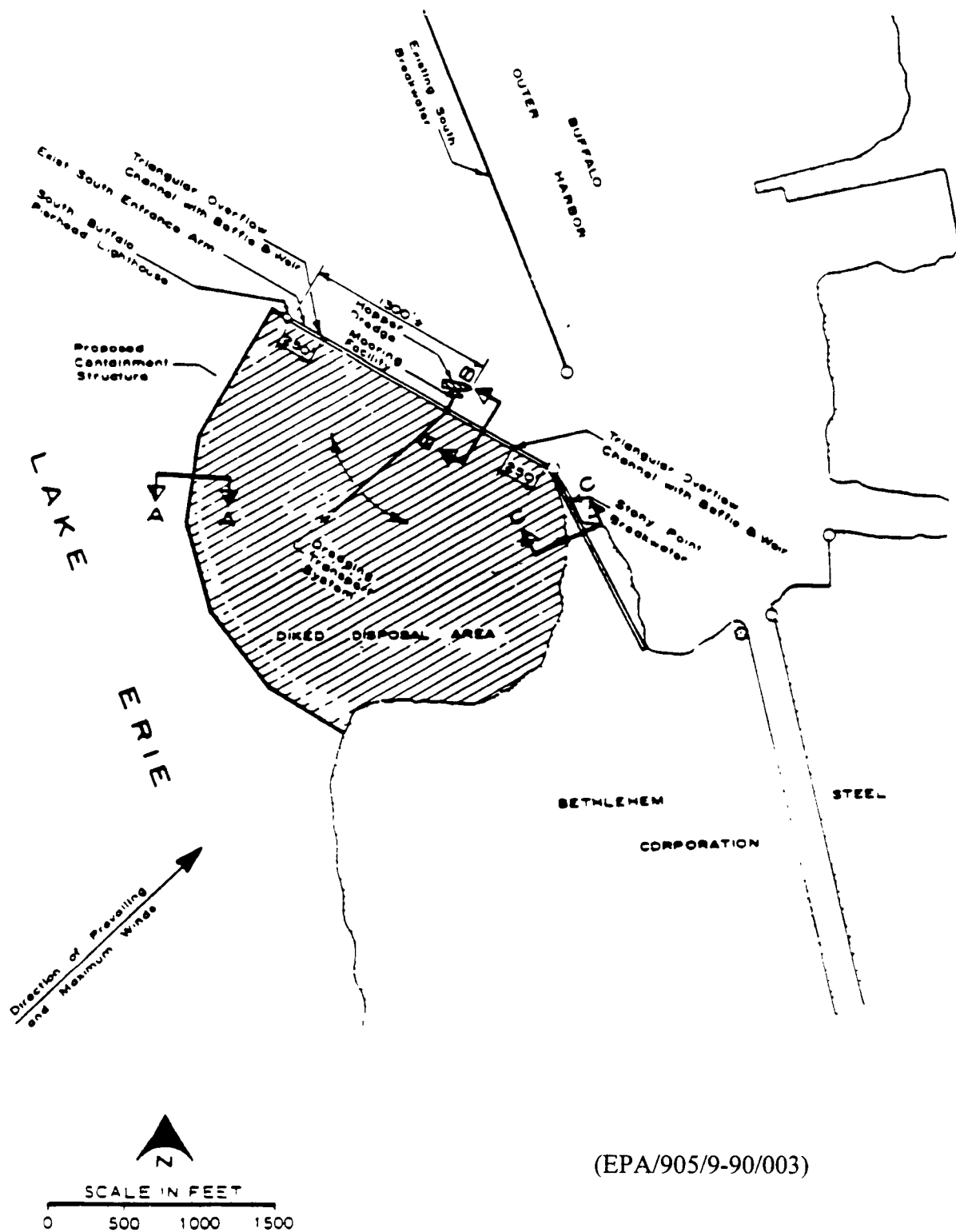


Figure 4.1 Dike Disposal Area for Harbor Dredging - Buffalo, New York

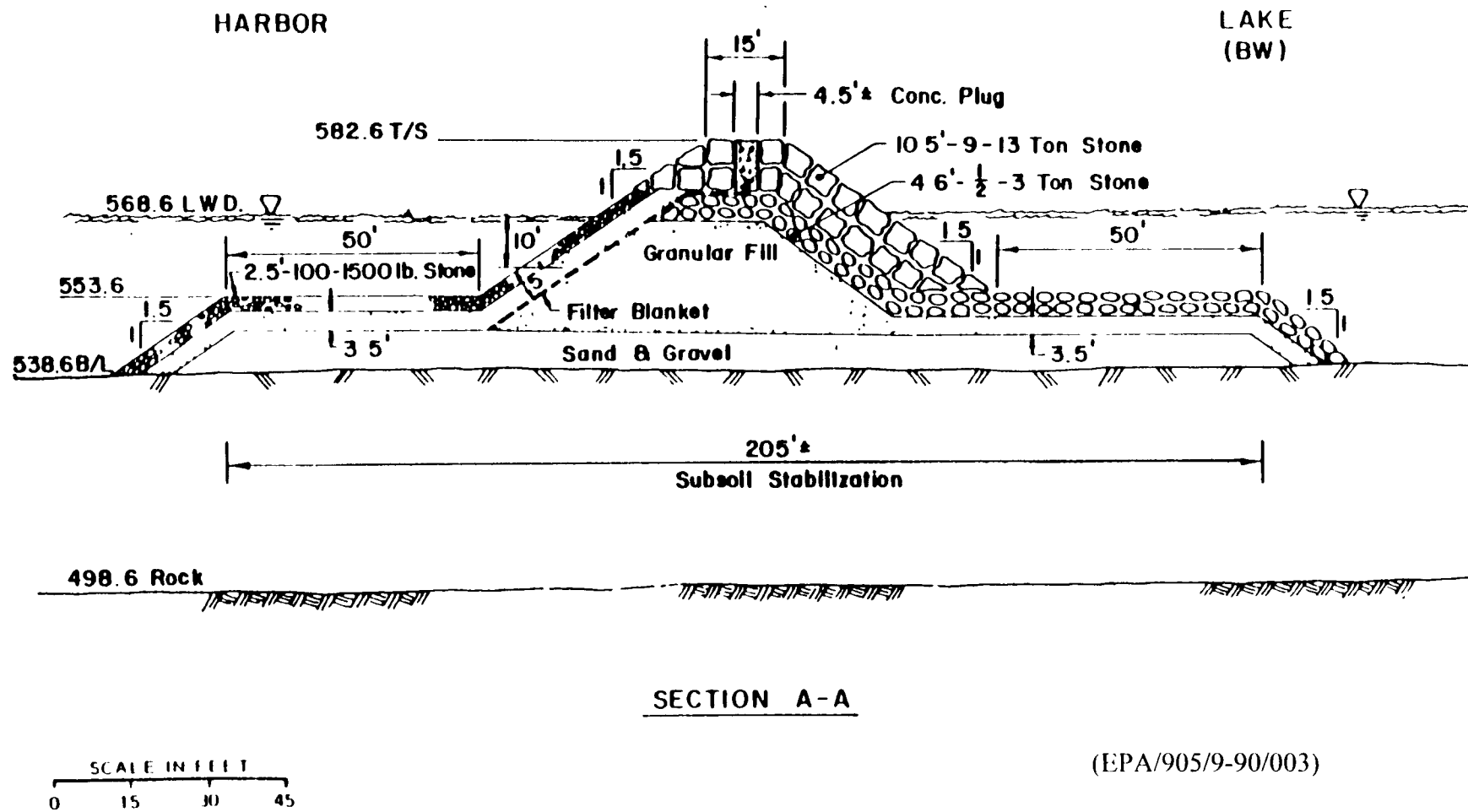


Figure 4.2 Typical Dike Section - Buffalo, New York



**Kidney Island CDF, Green Bay Harbor, WI ----** The Kidney Island CDF is a 60 acre facility built during 1979 about 800 feet offshore in about 10± feet of water (Figure 4-3). It was designed to accept dredged materials from the Fox River and Green Bay Channels which are excavated using either hydraulic or mechanical methods. The dredged materials are polluted with metals such as mercury, arsenic and chromium, in addition to PCBs and volatile organic compounds.

The dike design consisted of a core of limestone rubble as shown in Figure 4-4. A 72 mil plastic liner was originally planned to contain the fine grained dredged materials but was apparently abandoned during construction. Ideally, the plastic liner would force effluents through a filter cell which was constructed of sheet piles driven within the dike wall (Figure 4-5). However, without the membrane, flow through the permeable dike walls would eliminate discharge through the weir/filter cell until the dike walls become plugged with dredged materials. The CDF as constructed did not incorporate the plastic liner but did use sheet piles with asphalt interlocks as a cutoff wall to limit effluent discharge through the dikes. The limestone core was also felt to be significant in limiting the movement of metals through the dikes.

There has been some monitoring of water quality during and after dredging operations. This was achieved by sampling fluids at the dredge pipe influent discharge, inside of the filter cell, within the mixing zone outside of the weir, at an open water site, and at three monitoring wells – two in-dike and one in-filter. This CDF is about filled to capacity and is intended to remain a wildlife habitat. Some special biological studies have been performed at this site including bird nesting activities and a plant survey.

**Chicago Area CDF, Calumet Harbor, IL ----** The Chicago Area CDF was constructed in 1982 to contain heavily polluted dredged materials from the Calumet River and Harbor and the Chicago River and Harbor. This 40 acre facility is located within Calumet Harbor adjacent to the Illinois International Port Authority's Iroquois Landing development (Figure 4-6). The Chicago CDF represents the first of the "hydraulic barrier" CDFs designed for problematic dredged materials under the regulatory scenario shown on Table 1.2.

As with other in-lake facilities, this CDF is comprised of a prepared limestone core and is covered by a protective armor stone as shown in Figure 4-7. The particle size distribution of the prepared limestone has 100% of the particles smaller than 6½ inches and virtually no fines passing the 200 sieve. This gradation creates a highly permeable core through which water and fine particles could migrate freely. To minimize migration of contaminated fines and effluent through the limestone core, the original design included an impervious membrane placed on the inside surface of dike and a filter cloth on the lake side surface of the dikes core as part of the dike's aggregate filter. The filter cloth was omitted during the final design, although its inclusion was suggested in the EIS. Armour stone was to be placed over the membrane and filter cloth. Consequently, there was damage to the membrane during installation and a dye study was performed to evaluate the extent of damage. The dye study showed that discharge from the CDF was occurring so a layer of fine sand was placed along the inside face of the dike to restrict the movement of fines through the dike.

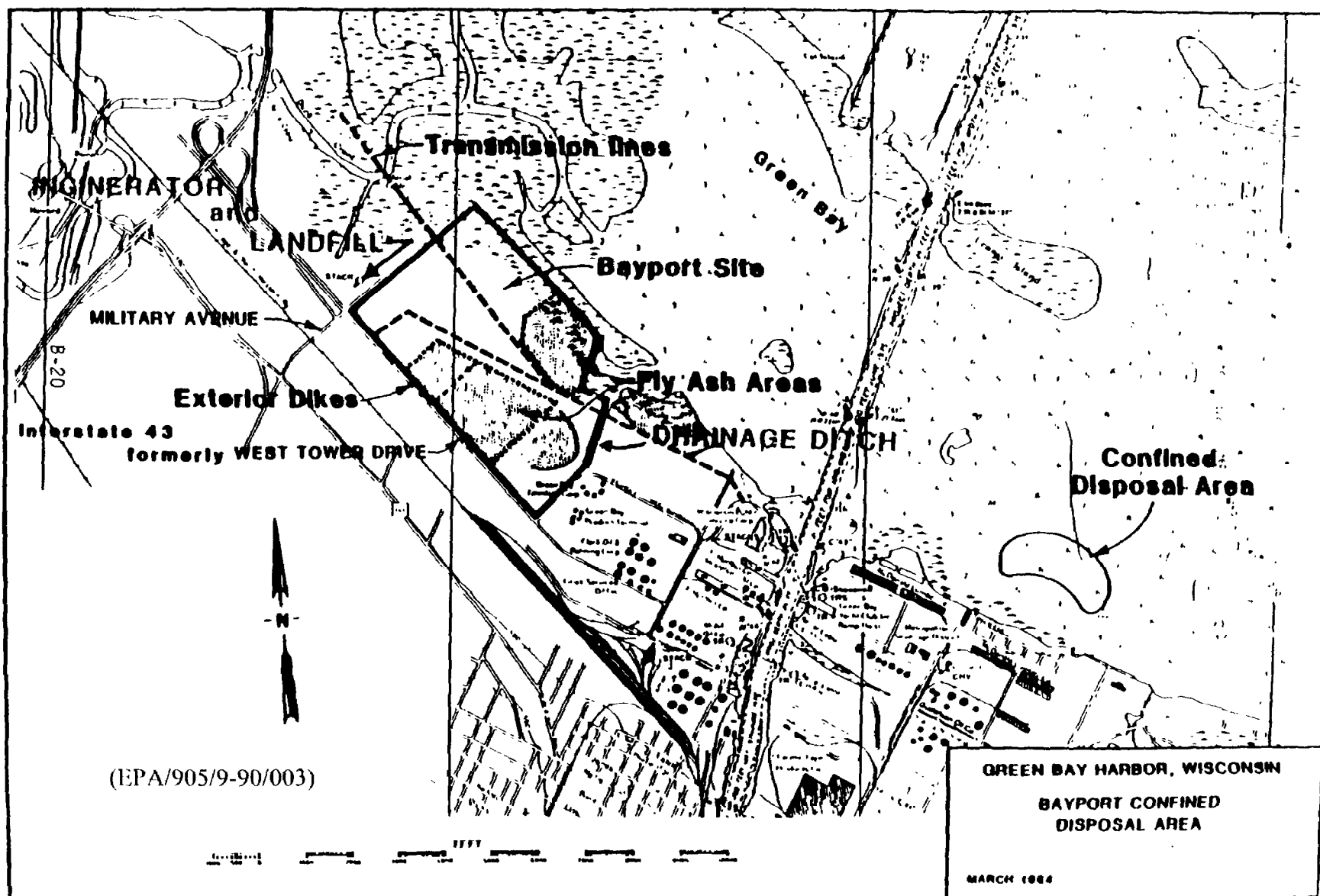


Figure 4.3 Bayport Confined Disposal Area - Green Bay Harbor, Wisconsin

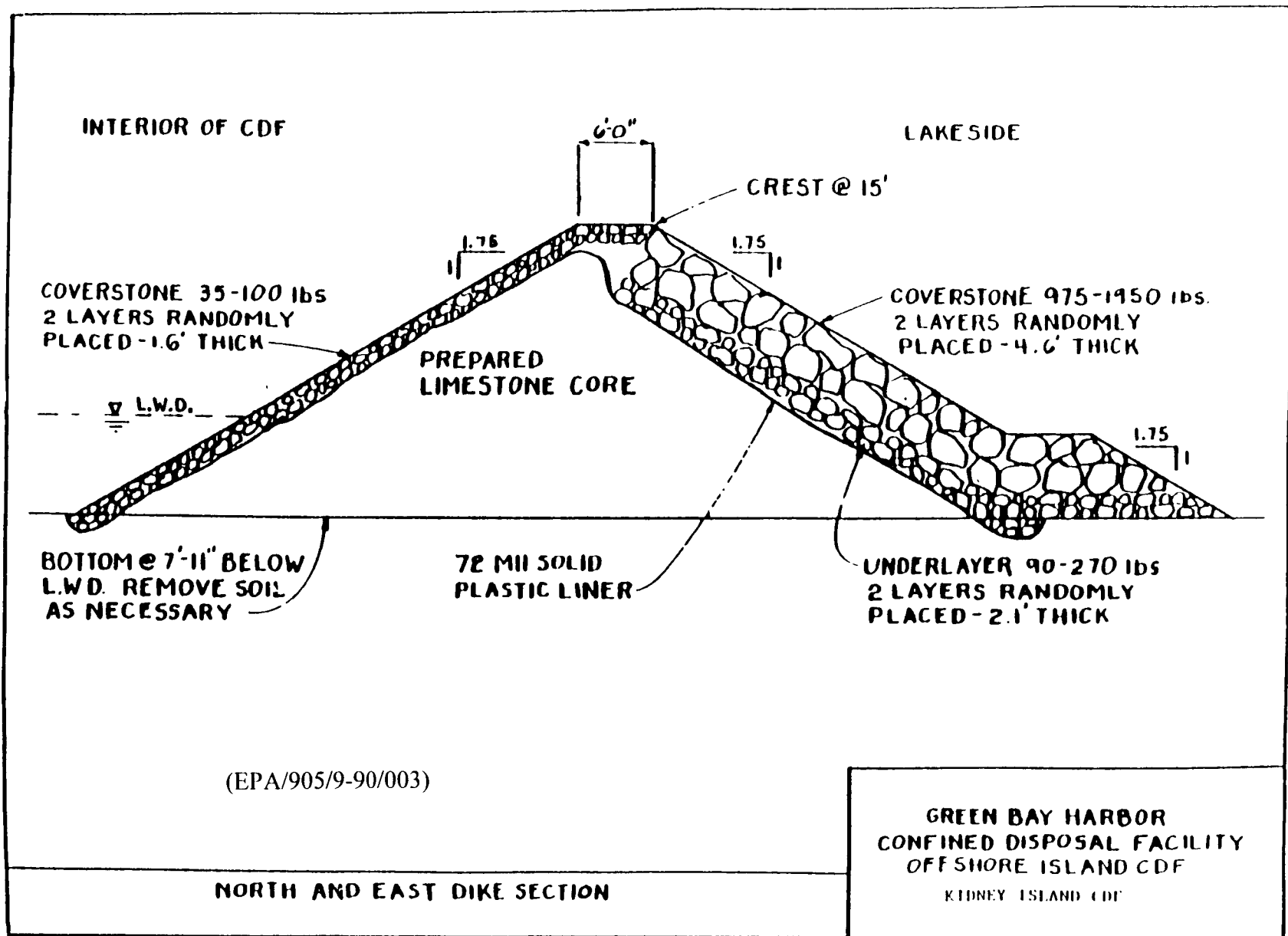
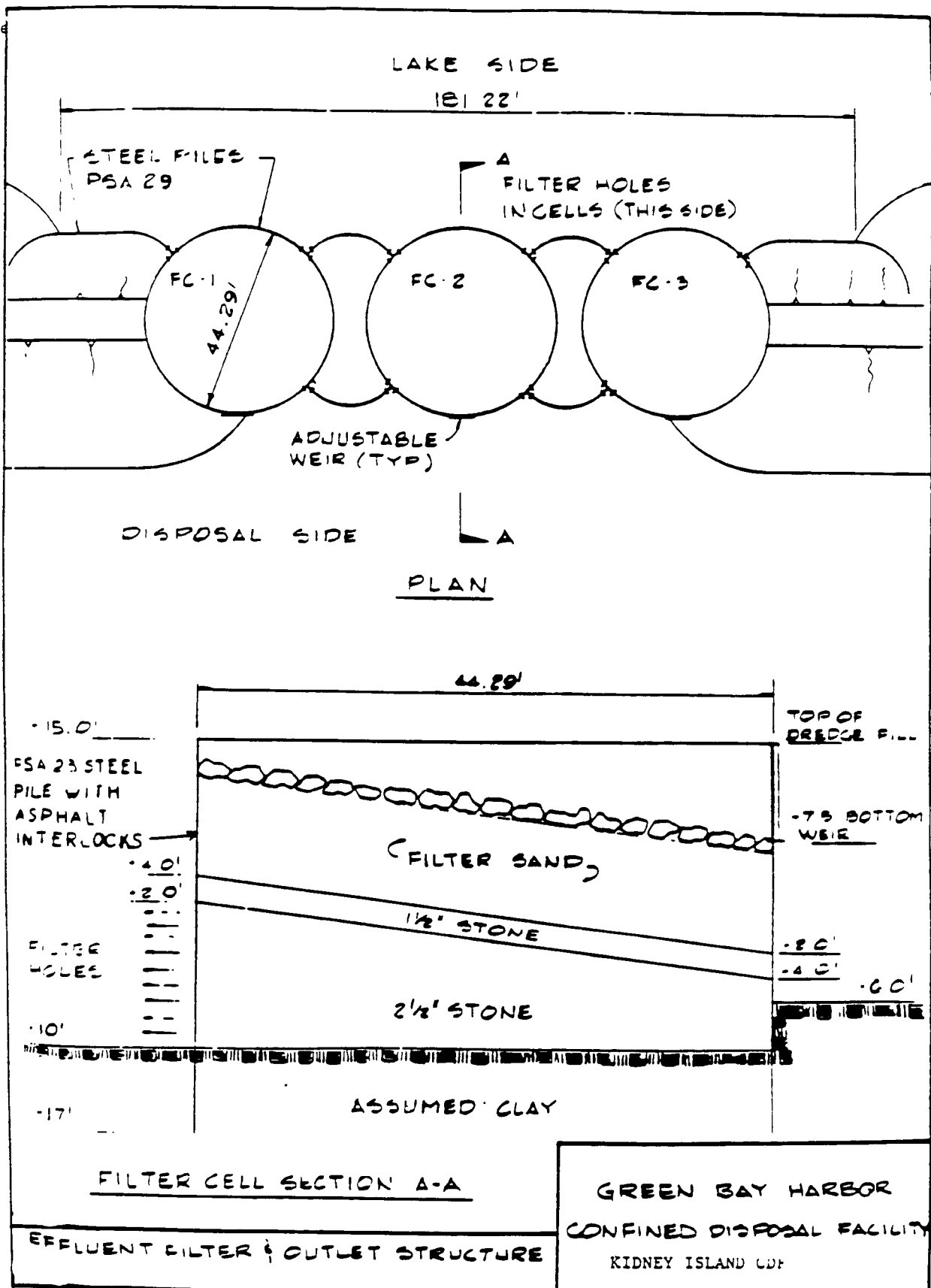
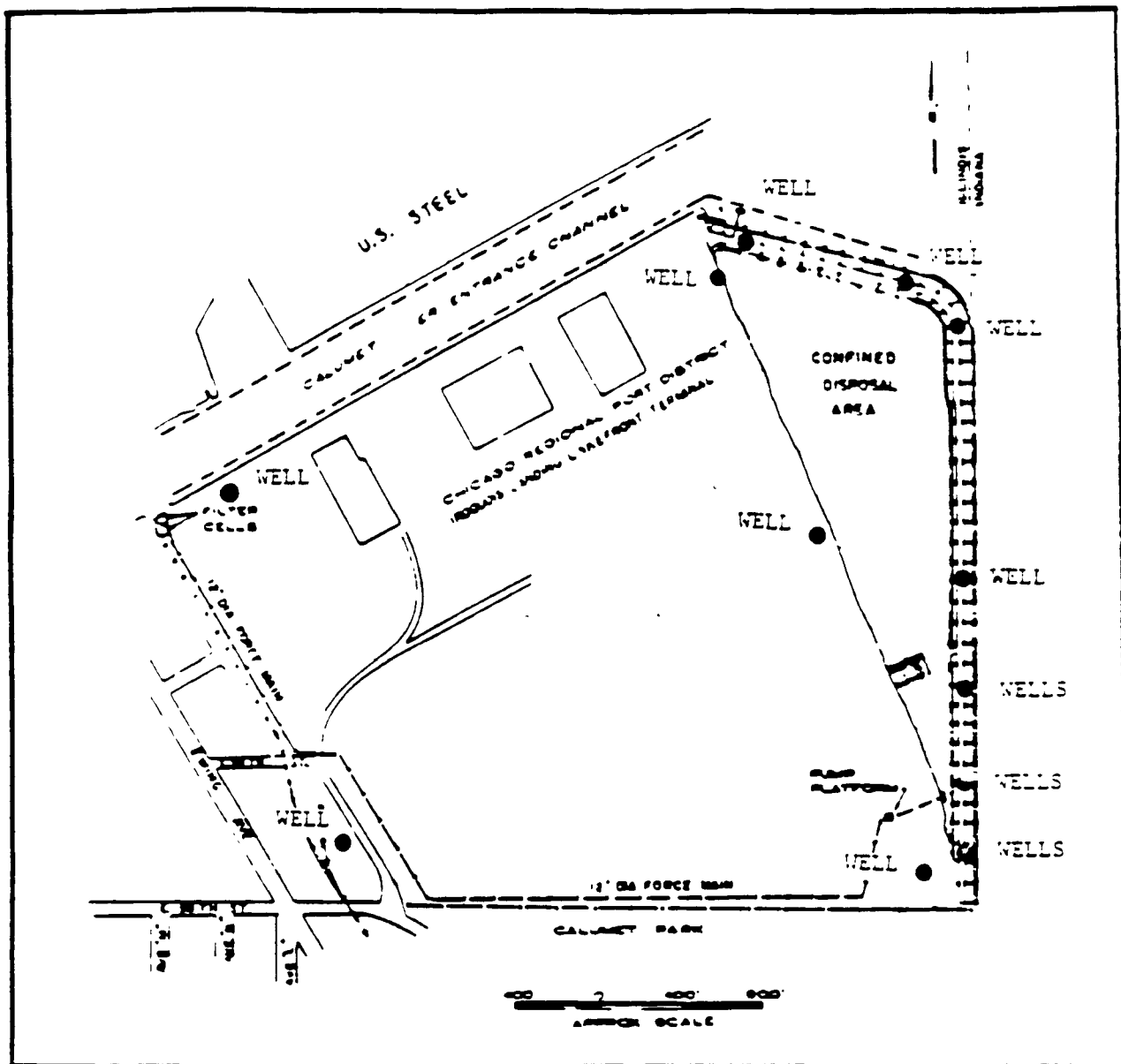


Figure 4.4 Typical Dike Section - Green Bay Harbor, Wisconsin



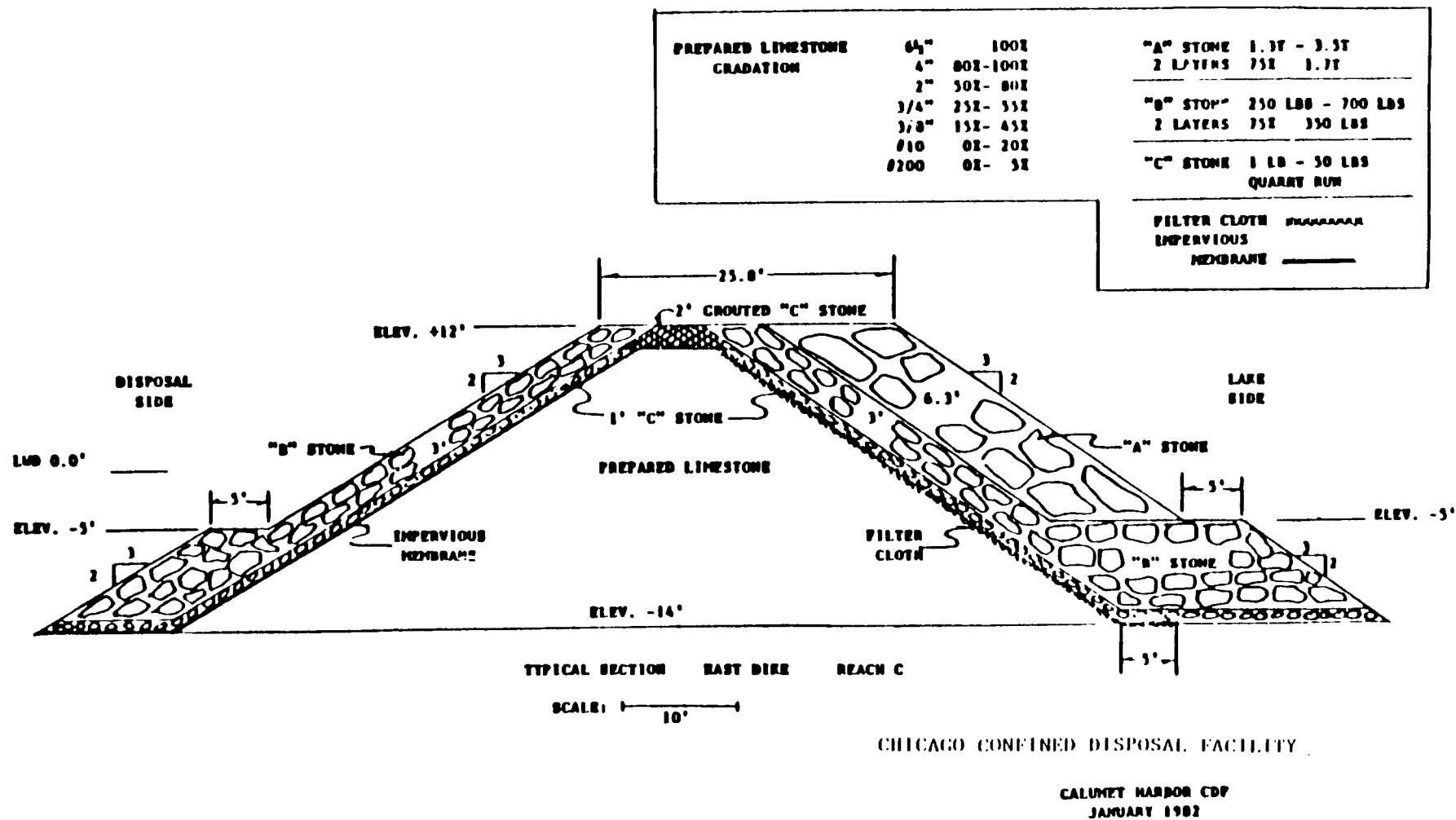
(EPA/905/9-90/003)

Figure 4.5 Effluent Filter and Outlet Structure - Green Bay Harbor



(EPA/905/9-90/003)

Figure 4.6 Siteplan of Chicago Confined Disposal Facility



(EPA/905/9-90/003)

Figure 4.7 Typical Dike Section - Chicago CDF

During the filling operation and following primary settling, all effluent flowed to a secondary settlement basin from which it was pumped to two large sand/charcoal filters for additional filtration before release to the Calumet River. Pumping from the CDF creates a negative hydraulic gradient in the dike and limits flow out of the CDF during dredging operations. The pumping is stopped following placement of dredged material.

There has been an extensive water quality monitoring program at the CDF and a number of special studies. During disposal operations, water quality samples are obtained from 5 stations in the Calumet River and Harbor and filter cell influent and effluent. In addition, monthly samples are taken from the 9 monitoring wells around the CDF as shown in Figure 4-6. Special studies have included dye tests during construction to determine liner integrity, field observation of wildlife and PCB body burdens of CDF fish and benthos.

This CDF will be filled after the year 2000 and will be capped by a 2-foot layer of clay plus one foot of topsoil and cover.

#### **4.1.3 Examples of Upland CDFs**

**Dickenson Island CDF, Clay Township, MI ----** The largest upland CDF in the Great Lakes is the Dickenson Island facility with an area of 174 acres and a capacity of 2 million cubic yards. It was built in 1976 on two sites at the north end of the island to accommodate dredged material from the channels in the St. Clair River delta at Lake St. Clair (Figure 4.8). The sediments are heavily polluted with the metals, mercury, lead and arsenic, plus nutrients and were placed in the CDF using hydraulic and mechanical dredging methods.

This CDF was created by building an earthen clay dike around the perimeter of each site as shown schematically in Figure 4-9. A weir structure was built into the dike to return clarified effluents back to the North Channel after natural settling was used to separate the sediment fraction from the water fraction. The site is underlain by a substrate of permeable silty sand. When this CDF is filled to capacity in the late 1990s, the site will be acquired by the State of Michigan for incorporation into the St. Clair Flats Wildlife Area. There are currently no plans to construct a final protective cover (clay cap) over the facility.

There has been some monitoring of water quality by the USACE during and after dredging using samples acquired at the dredge pipe influent discharge, weir overflow and within the mixing zone upstream and downstream of the weir discharge, and from monitoring wells in the dike. The USACE (1982) study concludes that "there is no significant alteration of ambient stream water detected ---- during the two sampling events." and "No leaching through the dike wall was observed or detected from the well samples." Yet "the well samples had consistently higher lead concentrations as compared with dredge discharge water, weir, plume and stream samples." No special studies, such as biological testing, were performed at the site.

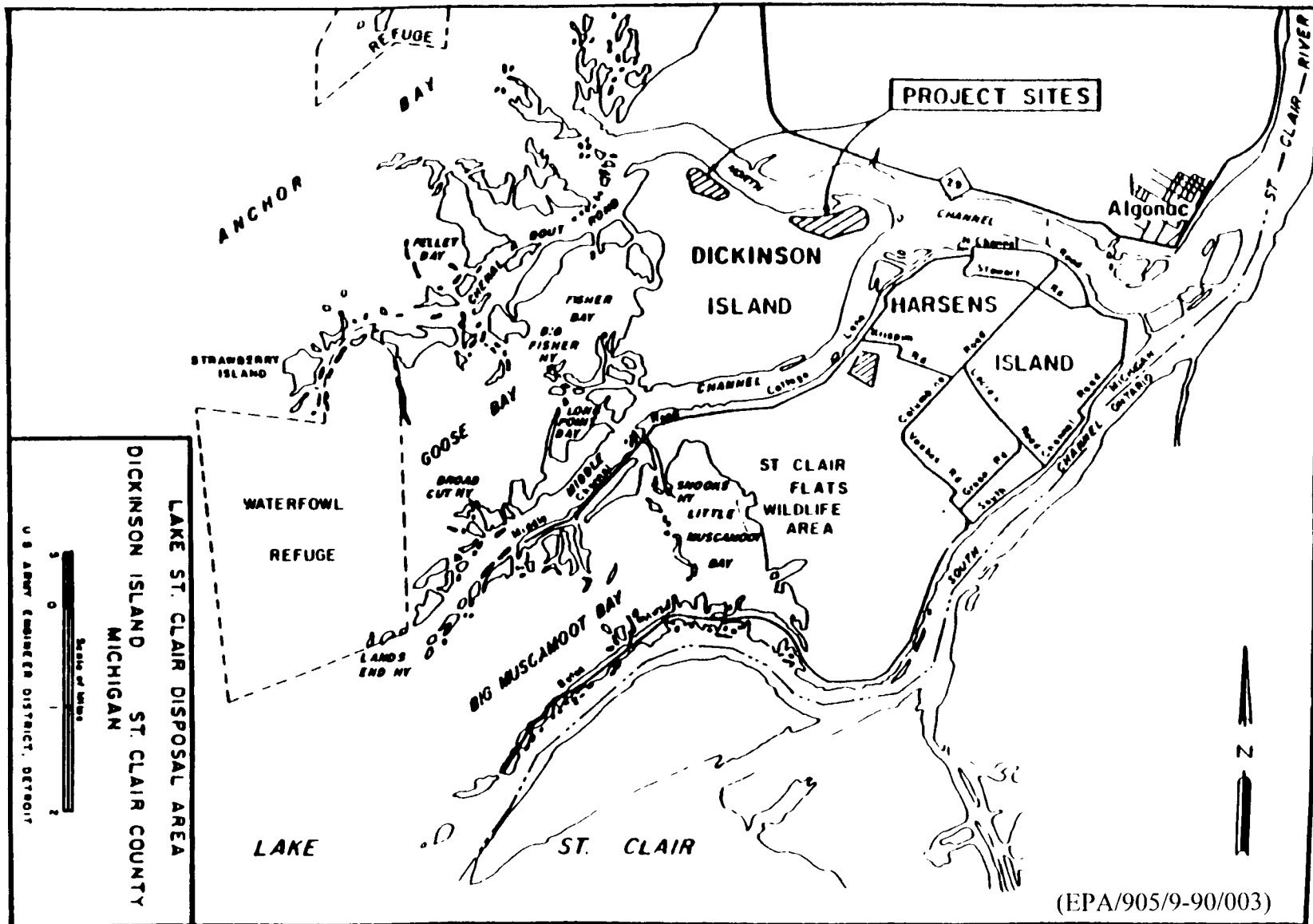


Figure 4.8 Site Plan of St. Clair Disposal Area - Dickenson Island, MI



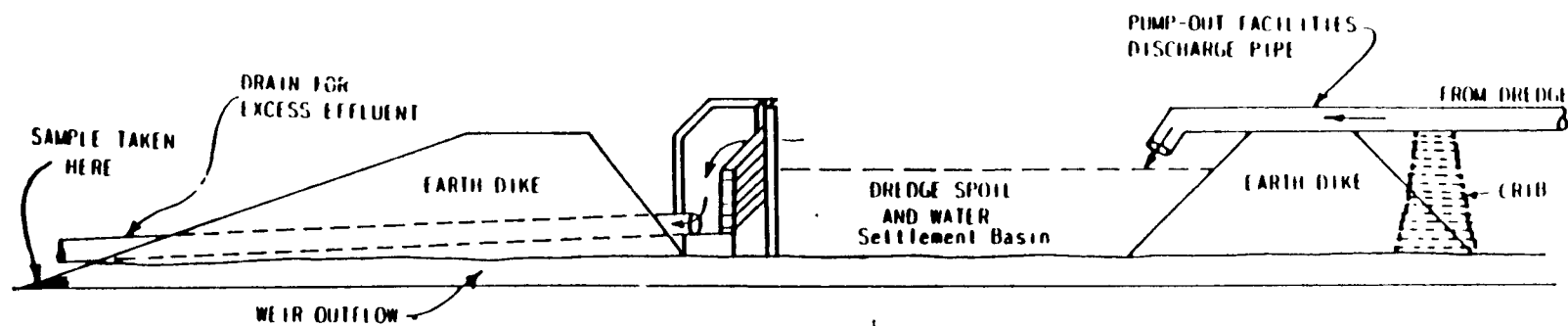


Figure 7: WEIR STRUCTURE

DICKENSON ISLAND CDF

(EPA/905/9-90/003)

Figure 4.9 Wier Structure - Dickenson Island, MI

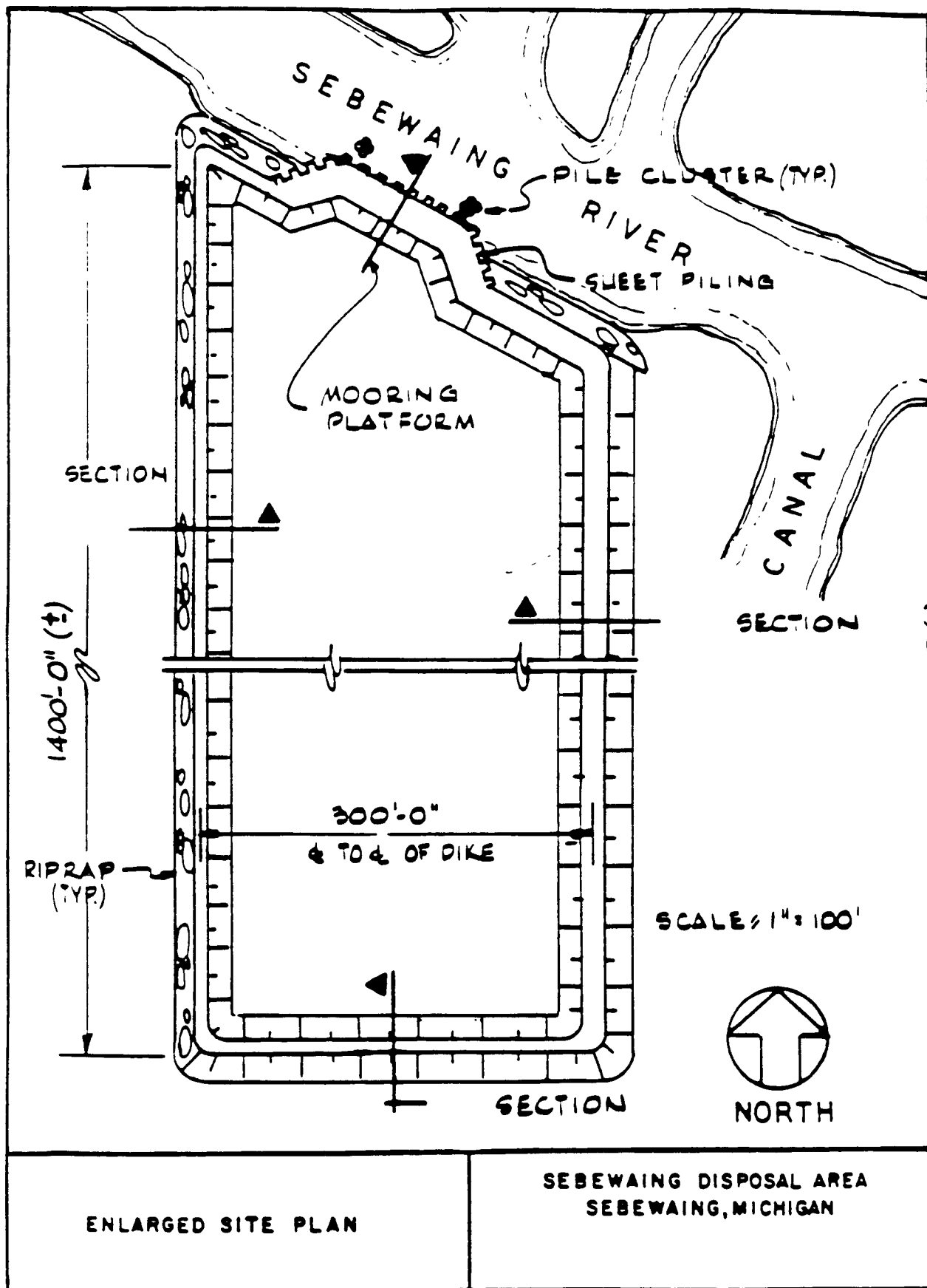
**Sebewaing Disposal Area, MI ----** The Sebewaing, Michigan disposal area was constructed in 1979 adjacent to the Sebewaing River (Figure 4.10) just upstream from Lake Huron. This is a small facility with an area of 9 acres, capacity of 84,000 cubic yards, and a rectangular shape. It was designed to contain slightly contaminated dredged materials from the Sebewaing River and Harbor where the primary pollutants are nutrients derived from agricultural runoff.

This facility was constructed by placing a 7-foot high clay dike around the perimeter of the site. Typical dike sections are presented in Figure 4-11 which show the low dike geometry and a surface armoring of rip rap and filter cloth on the outside of the west dike to prevent storm flood damage from Lake Huron. In 1987 repairs were needed to the west and north dike walls. The dikes were built on a substrate consisting of a thin layer of organic wetland soils on top of glacial till. The combination of impermeable substrate and clay dike create a very effective containment structure for polluted sediments since little or no leachate would be released. Dredging effluents were subjected to natural settling to remove solids before discharge over a weir to the Sebewaing River.

Water quality data were obtained at the weir and in the mixing zone during placement of dredged sediments from maintenance dredging operations at the navigational channel at Sebewaing Harbor (USACE, 1988). The water in the mixing zone was light brown and could be easily delineated from normal background. Suspended solids in the overflow were as high as 94 mg/l (94 ppm) and 38 mg/l in the mixing zone. Water quality data indicated elevated total Kjeldahl nitrogen (TKN) concentrations at the weir (28 mg/l) and within the mixing zone (17 mg/l) compared to upstream river concentrations (0.87 mg/l). Similarly, chemical oxygen demand (COD) concentrations at the weir and within the mixing zone were elevated compared to upstream concentrations. The CDF discharge caused slight increases in TKN, COD, and ammonia nitrogen levels in the mixing zone but had little impact on downstream river concentrations. The report concludes that "There was minimal impact on water quality in the Sebewaing River." When filled, this facility will be acquired by the State of Michigan to extend the Sebewaing County Airport with portions used as a wildlife habitat.

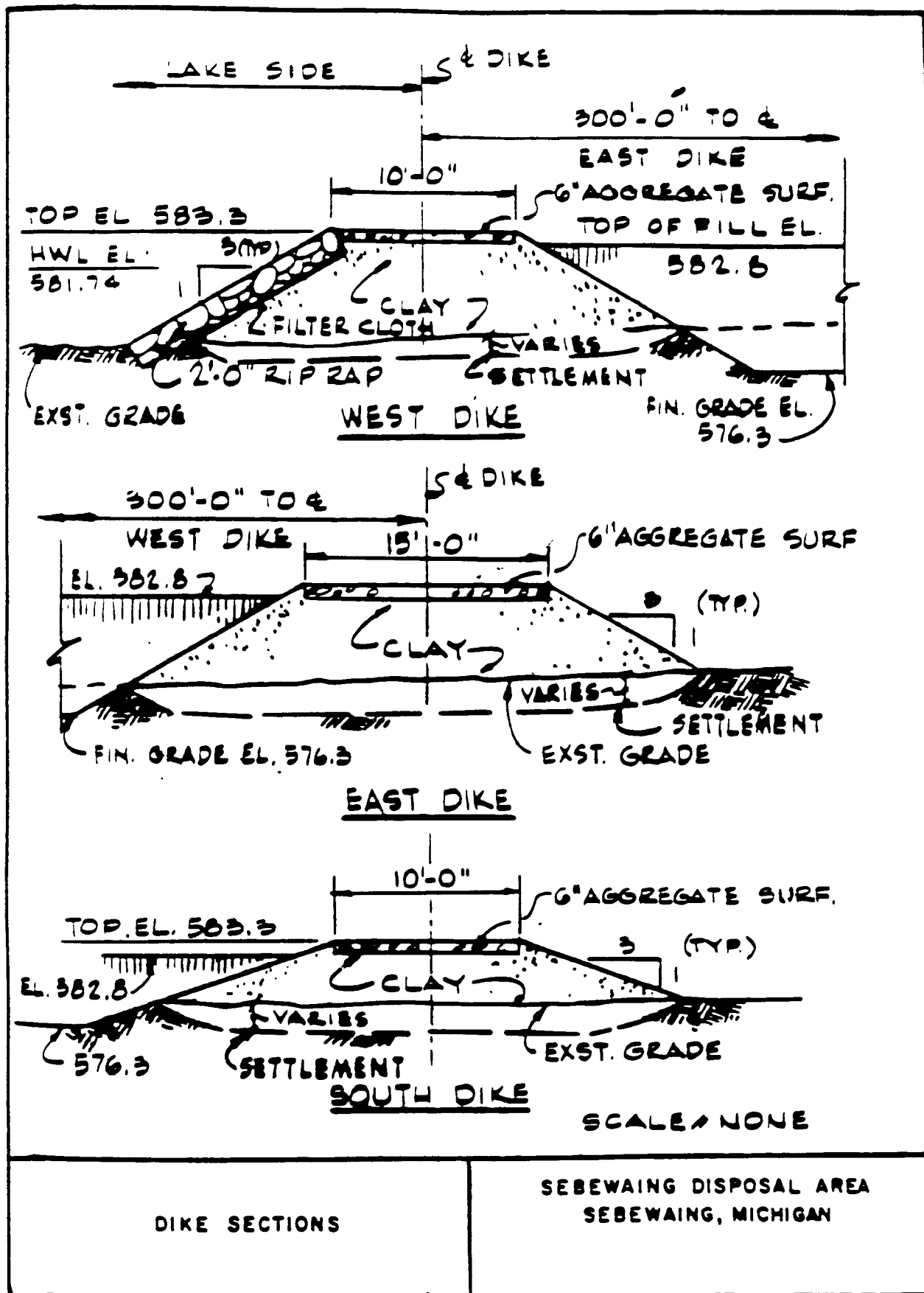
**Michigan City CDF, IN ----** The Michigan City CDF is the smallest CDF constructed to date at only 3.3 acres. It was constructed in 1978 on the edge of the Trail Creek about 1.5 miles upstream from Lake Michigan. The facility contains 50,000 cubic yards of sediments that are contaminated with metals such as arsenic, cadmium and chromium, in addition to PCBs and oil and grease that were discharged by a nearby wastewater treatment plant and local industry into Trail Creek.

The dike was constructed of compacted earth with the substrate consisting of a silty sand over clay which acts as a lower impervious liner. The outside of the dike along the creek has a stone rip-rap surface for erosion protection. The facility includes a sand filter in the dike to supplement the primary settling of effluent. Hydraulic dredging was first used to fill the facility but the filters became clogged. This necessitated a change to mechanical dredging and trucking to complete the filling. This site has been filled to capacity and capped with 2 feet of clay and 2 feet of top soil.



(EPA/905/9-90/003)

Figure 4.10 Site Plan of Sebewaing Disposal Area



(EPA/905/9-90/003)

Figure 4.11 Typical Dike Section - Sebewaing Disposal Area

There has been a considerable monitoring effort at this site. This has included sediment grab samples and surface water samples during dredging and disposal. Borings were also made in the dike after clogging to evaluate contaminant migration. Groundwater was monitored before the last disposal operation and for one year following on a quarterly basis from three wells, 1 upgradient and 2 downgradient of the CDF. These results showed that the groundwater between the CDF and Trail Creek had higher levels of ammonia-nitrogen and metals iron, manganese, and barium than the upgradient well.

## **4.2 EPA/State Remediation Projects**

### **4.2.1 Sediment Remediation Criteria/Objectives**

The remediation of contaminated sediment sites by the EPA and regional States is primarily concerned with the improvement of water quality (both groundwater and overlying surface water) and a reduction in contaminant loads to the lakes and the potential long-term impacts on aquatic biota and human beings. Since most in-situ sediment pollutants are adsorbed to the surface of sediment particles, contaminated sediments can continue to act as a pollutant source and degrade water quality long after point and non-point sources are eliminated. Contaminant release continues to occur as a result of polluted sediment erosion during storms, sediment stir-up by vessels and biota, groundwater flow through the polluted sediment and, to a lesser degree, from diffusion of pollutants off sediment to the overlying water. As discussed in Section 1, the EPA and States have been given the authority to implement contaminated sediment remedial activities from a number of legislative acts.

Superfund (CERCLA/SARA) provides funding and the authority to remediate inactive or abandoned hazardous waste sites that pose a hazard to human health and the environment. The major objective of Superfund is to recover, treat or destroy pollutants to the degree dictated by economics and to hydraulically isolate wastes and contaminated environmental media. Hydraulic isolation can be achieved by either constructing barriers in-situ or by excavation and placement of polluted sediments in approved disposal facilities.

Sediment remediation authorities are also provided under RCRA-C. These authorities apply to sediments that were contaminated as the result of the release of hazardous waste or hazardous constituents from a solid waste management unit (SWMU) located at a RCRA-C facility. A RCRA-C facility is defined as a facility authorized to treat, store, or dispose of hazardous waste as defined under 40 CFR 261.

An important factor in the Agency's decision to remediate a fresh-water site is the environmental impact of the dredging excavation process with its resuspension of particles and potential further spread of pollutants. Where an unacceptable adverse dredging impact is anticipated, a decision of "no removal action" usually termed the "no action alternative" may be considered as the solution. At low energy sites where resuspension of contaminated sediments is not a problem, a decision of "no

removal action" may also be chosen to allow natural sedimentation or the placement of an artificially cover consisting of clean sediment upon the polluted materials. Because of the potential for risks associated with a remedial action to excavate and treat a polluted sediment, the "no removal action" decision is currently preferred over the other alternatives when site conditions mitigate against removal. Table 1-2 indicates that on-site disposal has been the preferred remediation alternative in Region 5. This was in part due to the high liquids content of the sediments and the difficulties associated with the transport of such large volumes. The decision to remediate a fresh-water site by dredge excavation and placement of the sediments in a CDF facility or through treatment requires special planning and precautions to minimize the resuspension and spreading of pollutants.

#### **4.2.2 Example Remediation Projects**

**OMC/Waukegan Harbor Superfund Site**---The Outboard Marine Corporation (OMC)/Waukegan Harbor, Illinois Superfund site provides an example of a PCB contaminated sediment remediation involving the recovery and incineration of PCBs and hydraulic isolation of additional polluted sediments.

From about 1960 to 1975, the OMC purchased hydraulic fluids containing PCBs for use in die-casting operations. During plant operation and maintenance, large quantities of PCBs escaped into adjacent Waukegan Harbor and onto OMC property (Figure 4.12A). The EPA estimates that over one million pounds of PCBs were left at the site including about 700,000 pounds remaining on the north side of OMC property and about 300,000 pounds to slip 3 and Waukegan Harbor. Some of the PCBs are known to have affected water quality in Lake Michigan.

Following a long study of the site and protracted litigation between EPA and OMC, the remediation design and construction was started in the late 1980's. The remediation included the construction of three slurry wall containment cells around the PCB hotspots: one in Slip 3, and two in the north portion of the site. Each slurry wall penetrates into the underlying clay till and is three feet thick. At the mouth of Slip 3 (Figure 4.12B) a double sheetpile cut-off wall with clay slurry fill is used to isolate Slip 3 from the Upper Harbor. Hotspot sediments from Slip 3 (>500 ppm) and the other two sites (>10,000 ppm) were excavated and treated on site by a low temperature extraction procedure to remove at least 97% of the PCBs by mass. The recovered PCBs were removed to a TSCA approved facility for destruction. Residual treated sediments and soils were returned to the respective containment cells. In the Upper Harbor, sediments with PCB concentrations between 50 and 500 ppm were hydraulically dredged and placed in the Slip 3 containment cell. Each of the containment cells is to be capped with a clay layer and have extraction wells installed to prevent PCB migration from the cells. All water generated at the site is treated by filtration to further remove PCBs before discharge.

**Deer Lake, Michigan**---The Deer Lake remedial effort is interesting from the perspective of a "low-action" alternative. The 906 acre impoundment is located in Michigan's Upper Peninsula and is connected to Lake Superior by the Carp River. Iron mining is the major industry in the area but

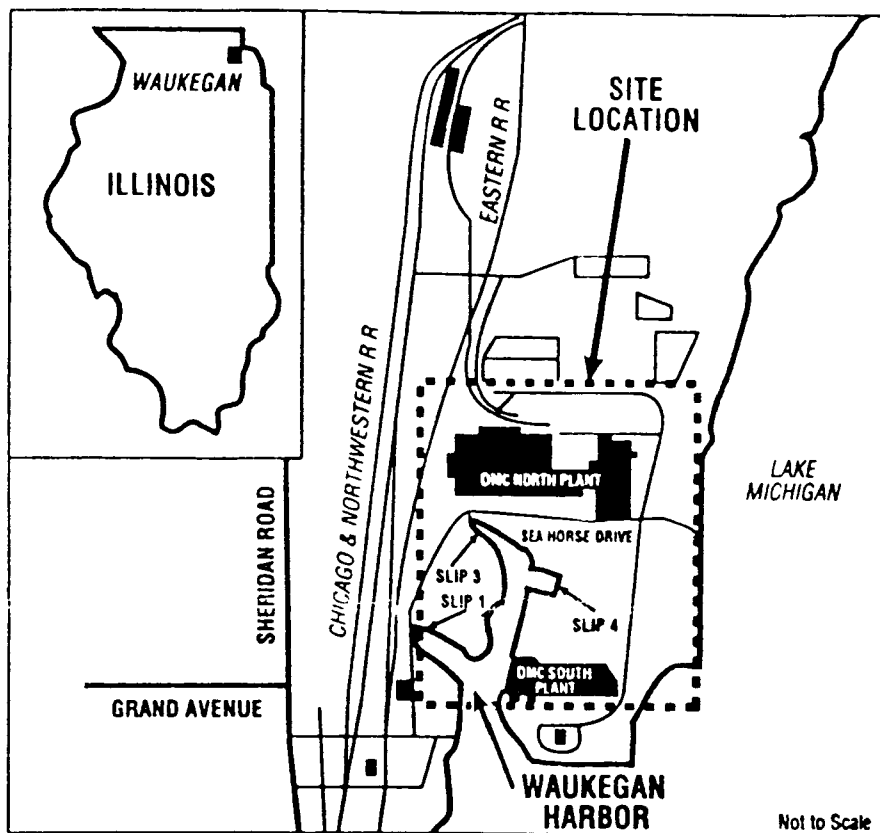


Figure 12A Site Location of OMC/Waukegan Harbor Superfund Site

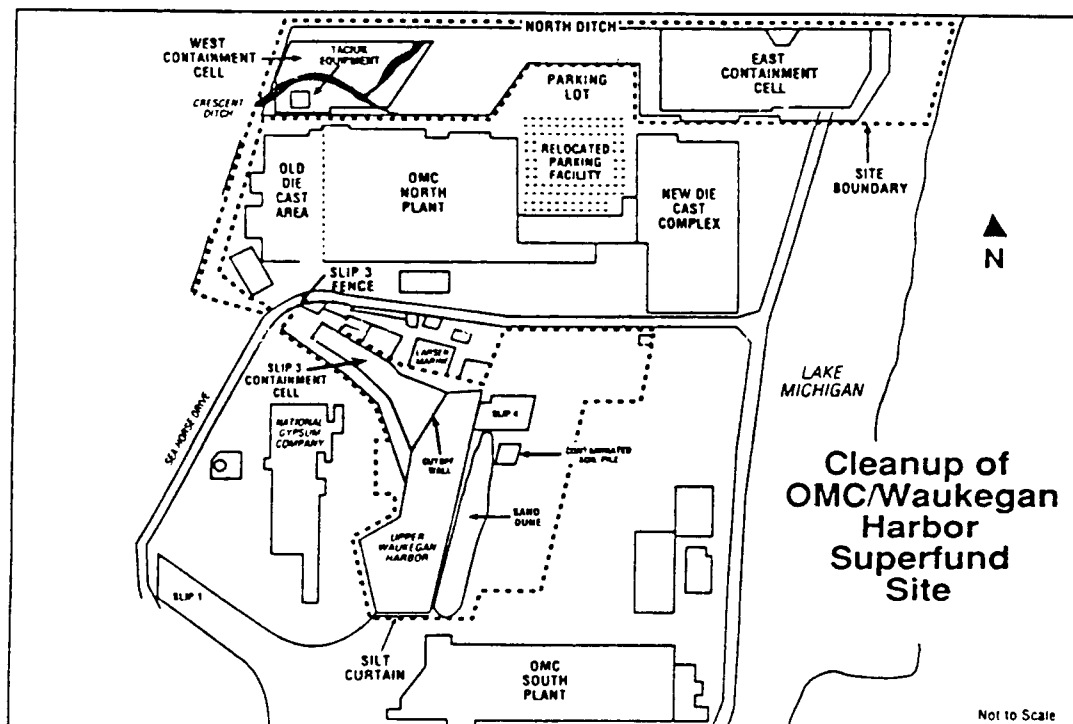


Figure 4.12B Site Plan of OMC/Waukegan Harbor Superfund Site

the lake's drainage basin. Mercury was detected in fish at levels exceeding the FDA action level of 1.0 ppm wet weight and the state of Michigan consumption advisory level of 0.5 ppm. This led to fish consumption and health advisories in 1981 which are still in effect. Lake sediment hot spots contain mercury in concentrations up to 10-15 ppm. The major source of pollution was the Cleveland Cliffs Iron Company (CCI) laboratories which used mercuric chloride for its ore assays and research. Mercury discharges were passed to Deer Lake by CCI via the Ishpeming, Michigan Wastewater Treatment Plant and Carp Creek. Disposal of mercury was curtailed in 1981 when the source was identified.

In the fall 1984, the Michigan Department of Natural Resources (MDNR) and CCI signed a consent decree which outlined a restoration and monitoring plan for Deer Lake with financial responsibility assigned to CCI. The primary goal of the plan was to create an uncontaminated fishery over a 10 year period. This was to be achieved by allowing natural sedimentation to bury the contaminated sediment to eliminate their mobility. The plan initially required lowering the lake to eradicate the contaminated fish. The fish were first netted and the remainder subsequently treated with rotenone to kill about 90% of the population. To prevent downstream transport of rotenone, a diversion trench for Carp Creek was excavated around the lake. In the spring 1987, the lake level was restored to the top of the dam where it will remain until 1997. Fish were stocked in the lake. A 10-year monitoring program requires periodic sampling and testing of fish, sediment, water and ice that formed over impacted tailing piles. While mercury levels in the fish only allow for catch-and-release fishing, the mercury levels in surficial sediments has dropped from a high of 15 ppm to about 8.3 ppm in 1991 (Elster, 1992) which appears to be a small improvement. Yet, at the end of the 10 year monitoring period, the mercury levels in the fish are expected to be comparable to other lakes in the area. There are no price data on this restoration project but it is undoubtedly a "low-cost" effort compared to the alternative of excavation followed by treatment and landfilling.

**PR Mallory - Crawfordsville, Indiana**----The EPA remediation (CERCLA/SARA) of the PR Mallory site in Crawfordsville, Indiana represents a "classic" example of the EPA approach to hydraulic isolation of contaminated waste and environmental media, in this case, sediments. The PR Mallory facility manufactured capacitors from 1957 to 1969 but the facility was abandoned in 1970 after total destruction by fire. The company was later acquired by Duracell International, Inc. In 1985 the Indiana Department of Environmental Management investigated the site and found capacitors in a ravine that leads to a creek. The capacitors contained oil with PCB concentrations up to 100%. A subsequent EPA site investigation found PCB concentrations up to 165,402 ppm in the soil and up to 9,695 ppm in the ravine sediments. EPA issued a CERCLA Administrative Order to Duracell and the current owners and Duracell agreed to perform the specified remediation.

The Order specified removing all the contaminated soil and ravine sediments above 25 ppm PCBs and placement in a hazardous waste landfill. An extensive sampling and testing program was initiated to determine the areas requiring excavation. During excavation, contaminant migration through the ravine was controlled by a series of sediment traps and oil-absorbent booms across the stream. The ravine sediments were dewatered and stabilized in place prior to excavation and



placed in an interim storage facility. Upon completion of the excavation, the sediment traps and oil booms were removed and added to the interim storage facility. The ravine was regraded with clean fill to promote drainage and revegetated.

The final phases of the remediation included excavation of contaminated soil beneath the manufacturing building and placement of all contaminated soils and sediments in the TSCA landfill in Emelle, Alabama. As of June 1990, 60,000 c.y. of contaminated material had been processed (Elster, 1992) at a cost of \$28 million or \$460/c.y. More excavation is needed beneath the facility. Monitoring of the ravine and downstream creeks will continue for several years.

## SECTION 5

### CONTAMINANT PATHWAY CONTROL

Contaminants from sediments contained within a CDF can be discharged to the environment via the six potential pathways discussed in this document. These pathways are shown on Figures 1.3 and 5.1 and include three water borne pathways (1,2,3) the direct uptake of the contaminant by plants or animals (4,5) and air borne emission of contaminants (6). With the addition of the air borne emission pathway, these pathways are consistent with the five potential contaminant pathways identified in the USACE technical framework (EPA/USACE, 1992) discussed in Section 2.1 and shown on Figure 2.2.

#### 5.1 Water Borne Contaminants

The control of water borne contaminants must consider both the contaminants dissolved in the effluent and the solid contaminant fraction associated by adsorption or ion exchange with the total suspended solids (TSS) within the effluent (Thackston and Palermo, 1990). Given sufficient retention time in a containment area, non-colloidal suspended solids will settle out of the effluent and be retained. This designed practice of "solids retention" is the basis for the USACE design process but may be limited by either high contaminant concentrations or partitioning, see Table 1.2. A "hydraulic isolation" design criteria for the CDF is assumed when high contaminant concentrations or partitioning threaten release of excessive contaminants to the environment. It is also anticipated that effluent treatment would be required under these circumstances.

The suspended solids concentration in effluent water is influenced by the pond surface area and residence time for the effluent within the CDF. The conventional USACE design procedure determines the design surface area or the residence time required for sedimentation to meet effluent suspended solids requirements. Both design calculations assume that the CDF dikes are impermeable to the effluent and that the dredged material was hydraulically dredged or disposed.

The procedure for calculating the minimum required surface area, shown on Figure 5.2, recognizes that sediments fall out of suspension quicker in ponds having larger surface areas and shallow depths. The reason for this is that, in deep ponds, the falling sediment particles begin to collide and creates what is termed compression settling. Compression settling is very slow compared to normal settling rates of soil particles and therefore results in an increase in the required retention time. The minimum required surface area for the pond is calculated in two ways: (1) based on the storage volume required for the dredged material once it settles out of suspension, and (2) based on the settling time required for the sediments to fall out of suspension. The larger of the two areas is then assumed to be the minimum required surface area for the pond within the CDF.

Having solved for the minimum pond area in the previous paragraph, the USACE procedure then calculates the minimum residence time for the supernatant within the pond as shown on Figure 5.3. A percent solids removal verses time relationship is first established based on the pond depth and a

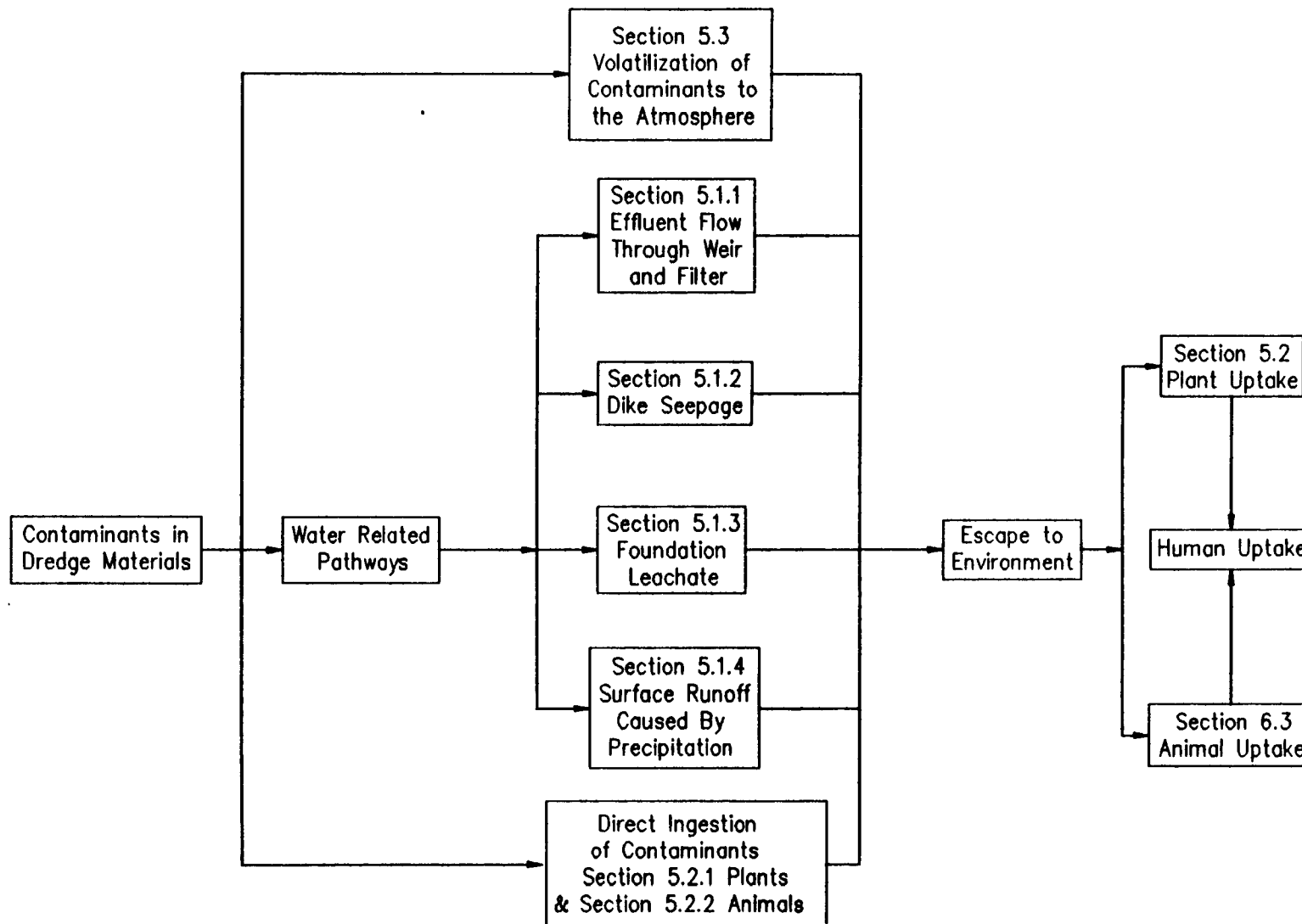


Figure 5.1 Transport Mechanisms of Contaminants to Environment

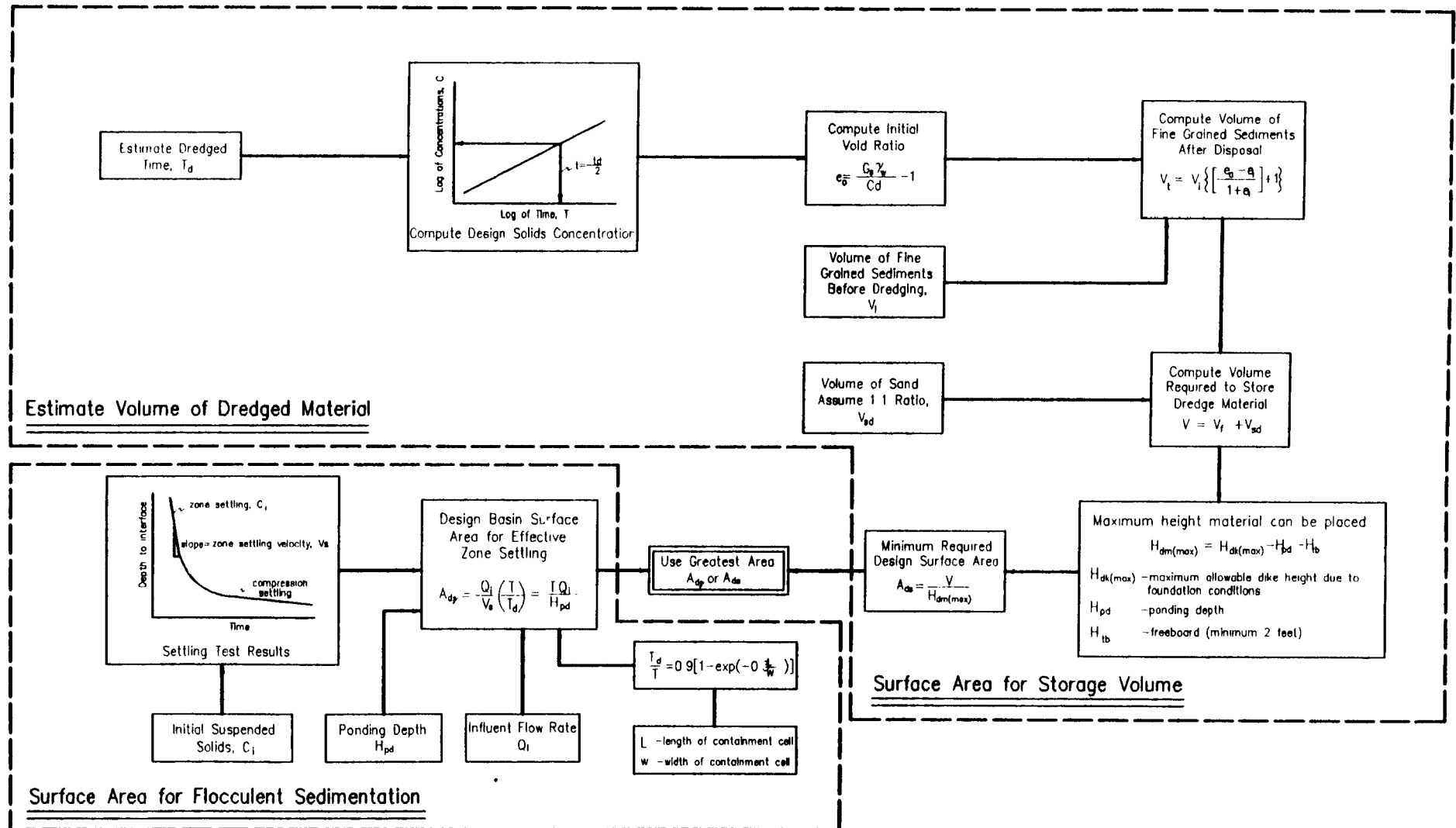


Figure 5.2 COE Design Procedure for Determining the Design Surface Area Required for Sedimentation to Meet Effluent Suspended Solids Requirement

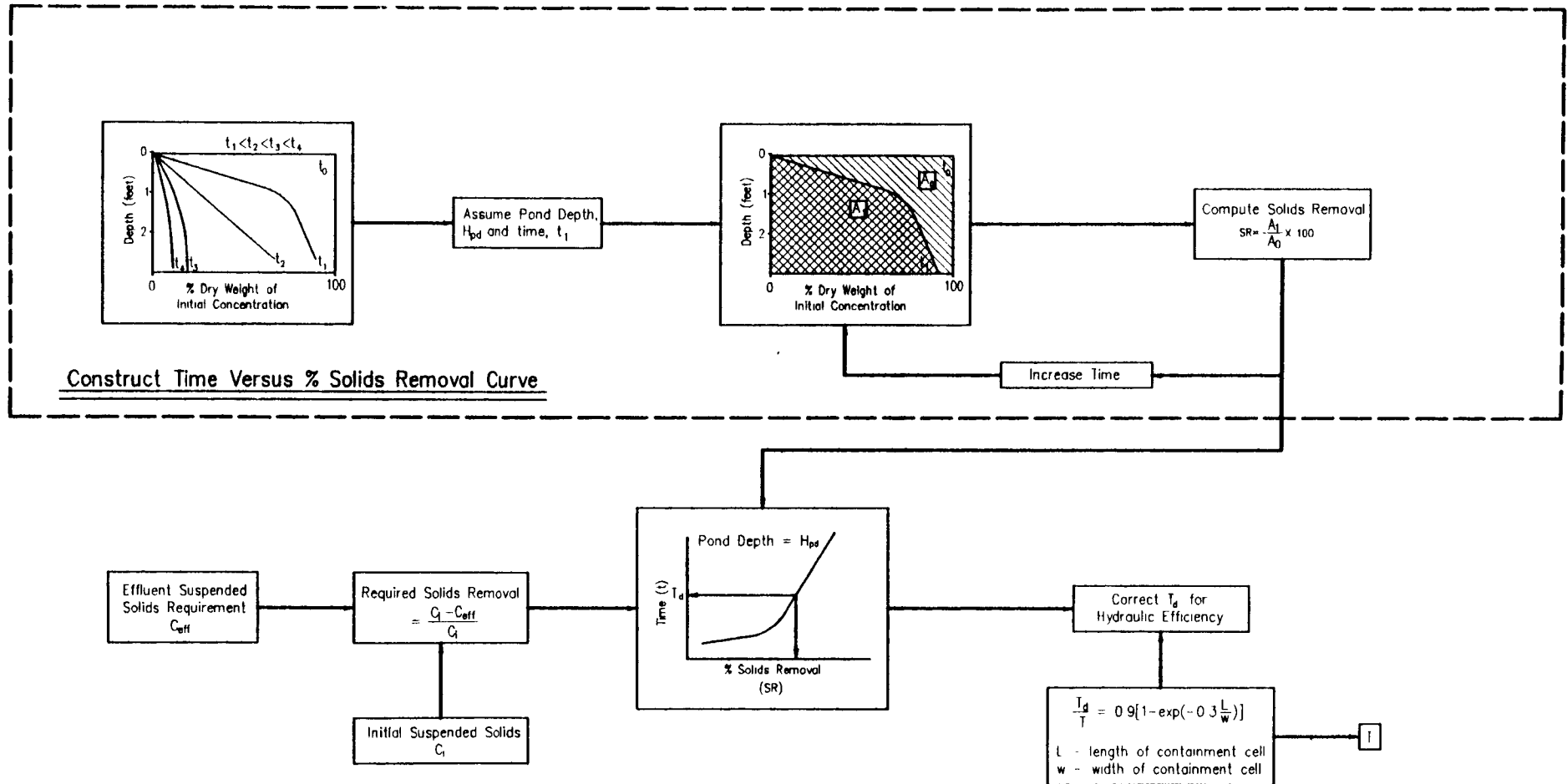


Figure 5.3 COE Design Procedure for Determining Residence Time (T) Required for Sedimentation to Meet Effluent Suspended Solids Requirement

range of assumed times. Knowing the suspended solids requirement for the effluent, the residence time ( $T_d$ ) based on pond depth is established. The actual design residence time ( $T$ ) is obtained by modifying  $T_d$  based on the actual length and width of the pond.

Within this section, the water borne contaminant pathways are discussed independently. This discussion reflects the differences in release mechanisms and associated design of pathway control devices.

### **5.1.1 Effluent Flow Through Weirs and Filters**

Pathway controls for contamination related to TSS in effluent leaving the CDF through a weir are charted on Figure 5.4. Current USACE weir design procedures focus on the removal of suspended solids from the effluent. This assumes that significant partitioning of the contaminants to the water will not occur, see Table 1.2. Four design alternative courses of action for the control of suspended solids in the effluent are charted on Figures 5.5 (Krizek, et al, 1976). Pervious dikes are recommended by the USACE to filter effluents with concentrations of suspended solids up to 0.5 gm/l (Case 1). Such dike filters constitute a low maintenance filter that is characterized by very large filter depths and long effective lifetimes. For cases where the influents are expected to have suspended solids concentrations up to 1 to 2 gm/l, the sandfill weir offers an attractive alternative (Case 2 and 3). Sandfill weirs designed without backwash capabilities require maintenance to replace clogged filter media at periods significantly shorter than pervious dike lifetimes. Although the type of influent to be treated with the sandfill weir is similar to that for pervious dikes, its mode of operation is much more flexible.

Granular media cartridges can be used with waters having loads of suspended solids loads up to 10 gm/l (Case 3); however, maintenance requirements are expected to be excessive at loads higher than a few grams per liter. Typical filter systems include pervious dikes (Figure 5.6), and downflow/upflow weirs or cartridges (Figure 5.7). The pervious dikes are designed to filter out the suspended solids by selecting the filter media particle size distribution using conventional geotechnical filter criteria. Clogging of the pervious dike is minimized by using stratified or baffled dike sections that provide a control over the maximum flow gradients that develop within the dike section. The larger the potential flow gradient; the smaller the potential for clogging of the filter. The filter weirs and cartridges shown on Figure 5.7 function similar to the filter dikes. Such systems allow the designer to maximize the removal of suspended solids and minimize the potential for system clogging.

The suspended solids concentration in effluent can be significantly influenced by the length of the weir (sharp crested, rectangular or shaft type) and the depth of the pond as shown on Figure 5.8. Water borne suspended solids and the associated contaminants that cannot be removed by basin or weir design, may render the effluents from disposal areas unacceptable for discharge to open waters and it may be necessary to employ a filter system or chemical methods (Schroeder, 1983) to clarify disposal area supernatants.

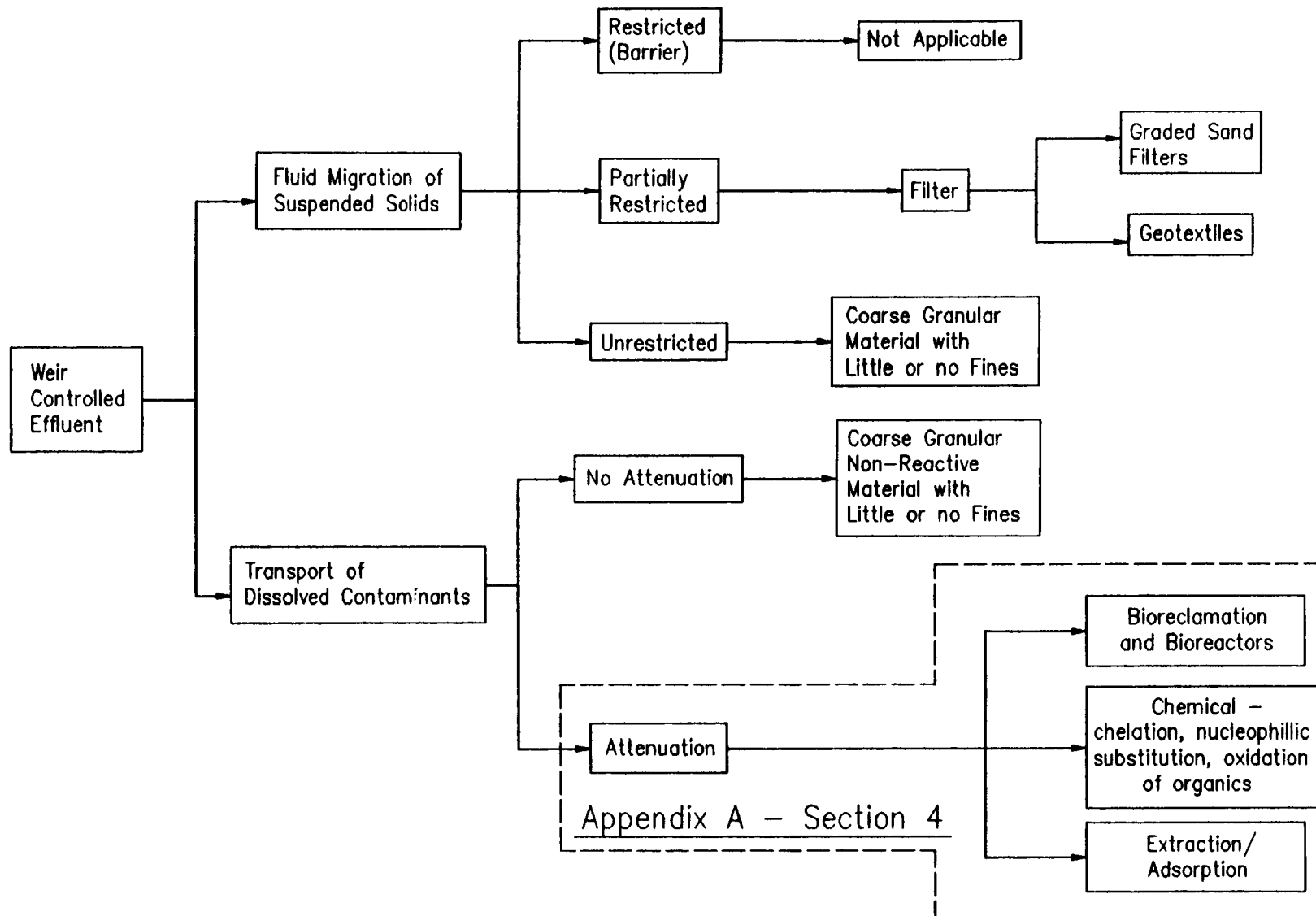
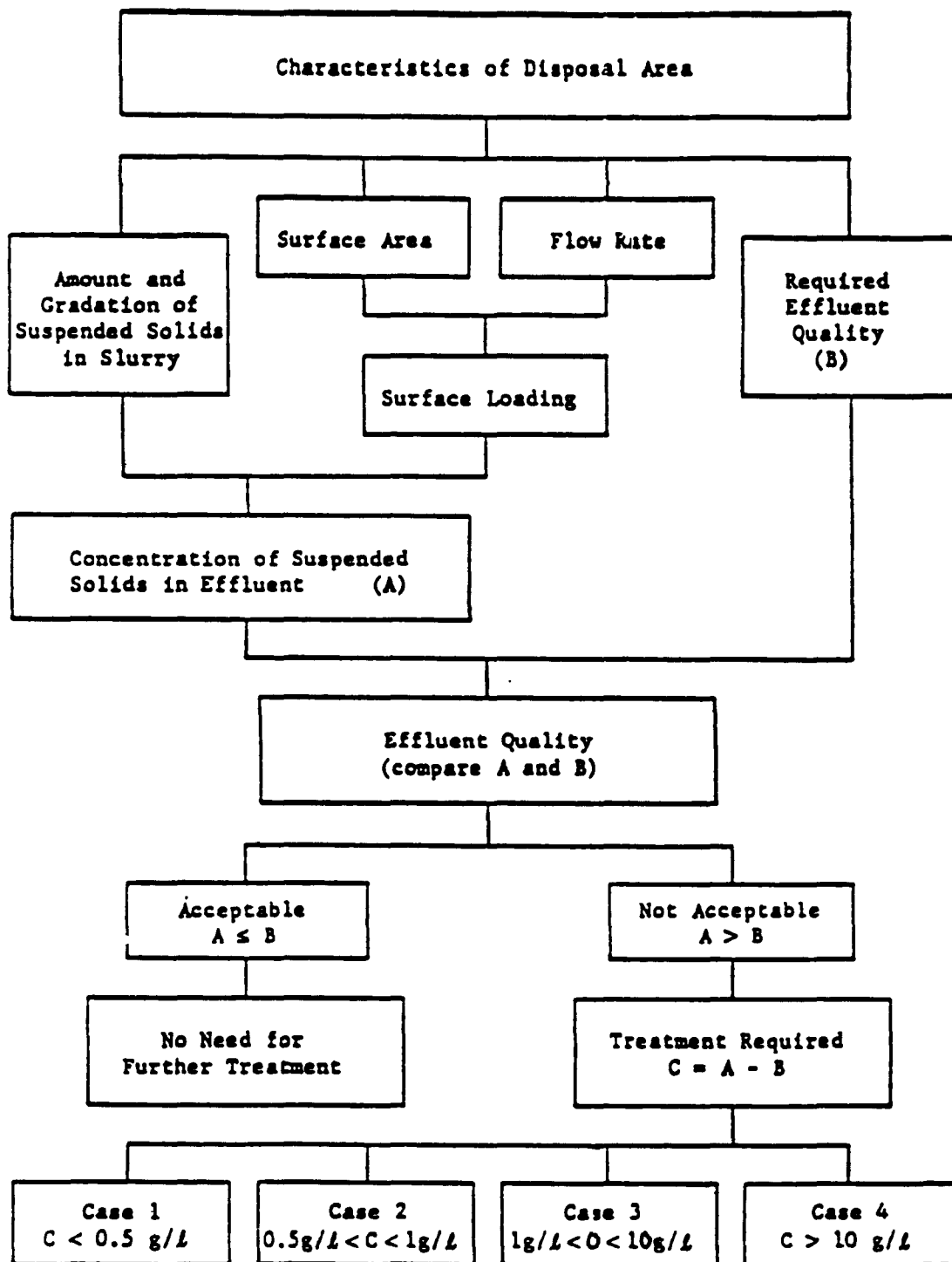


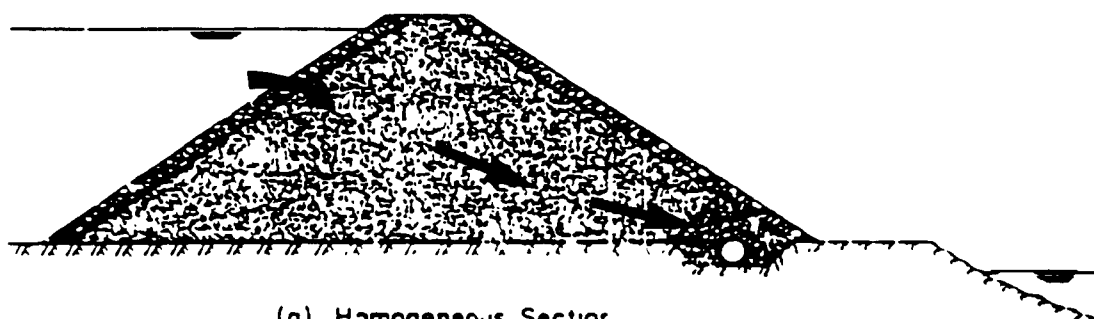
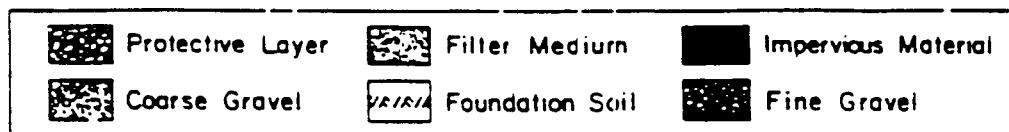
Figure 5.4 Control of Contaminant Pathway Through Weir



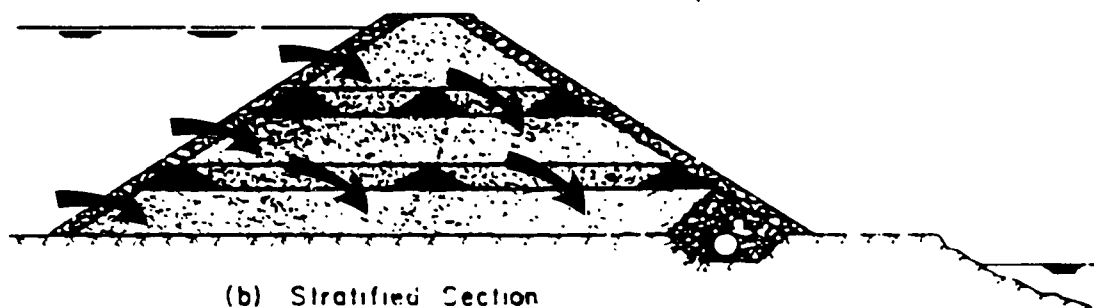
(Ref. Krizek et al, 1976)

Figure 5.5 Flow Diagram of Alternative Courses of Action to Evaluate Effect of Sedimentation of Disposal Area Effluents

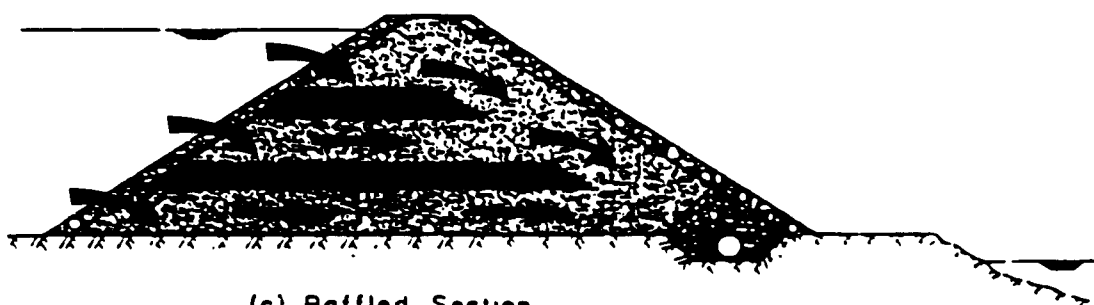




(a) Homogeneous Section



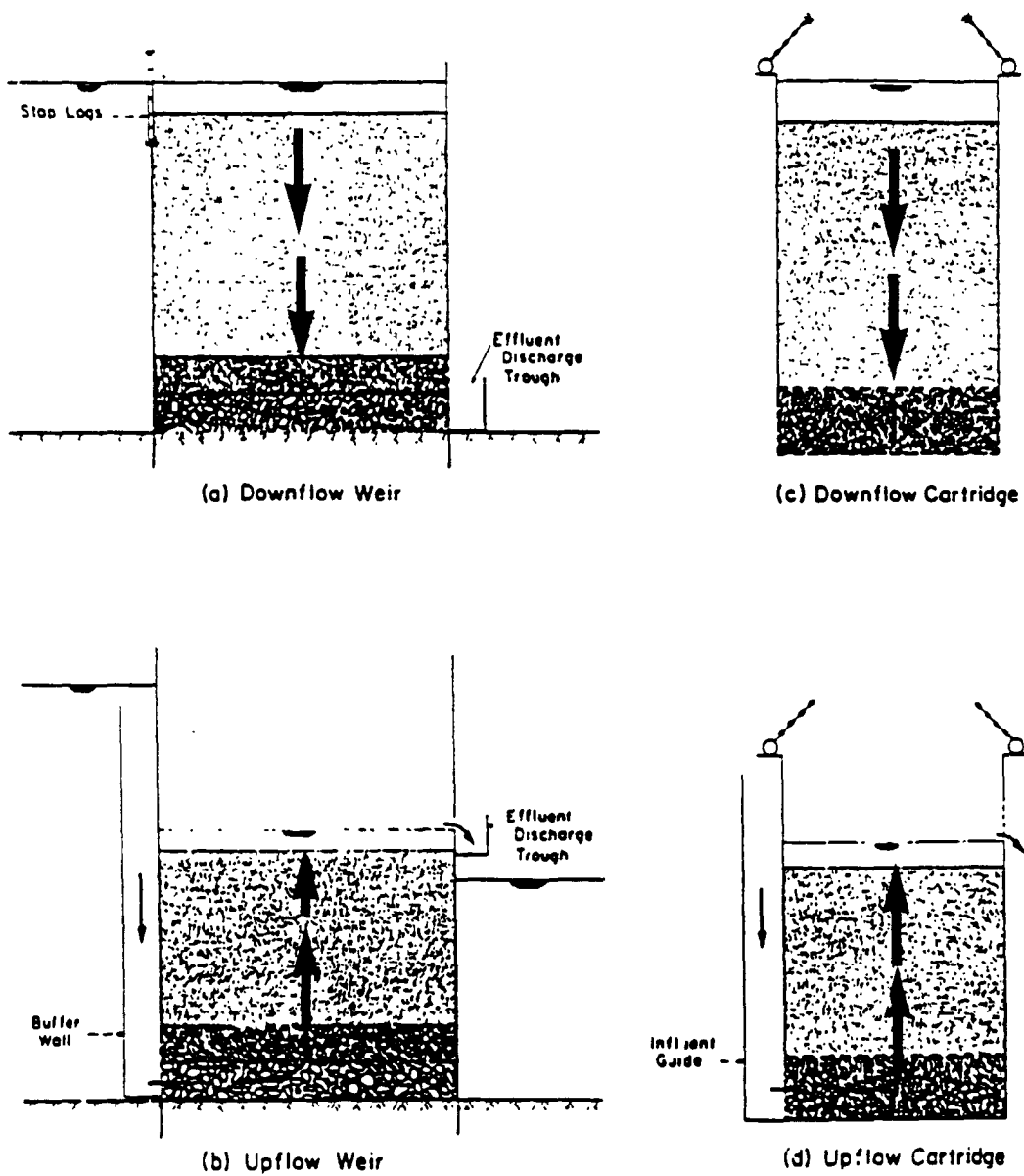
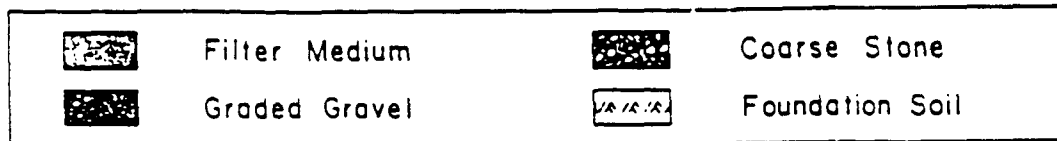
(b) Stratified Section



(c) Baffled Section

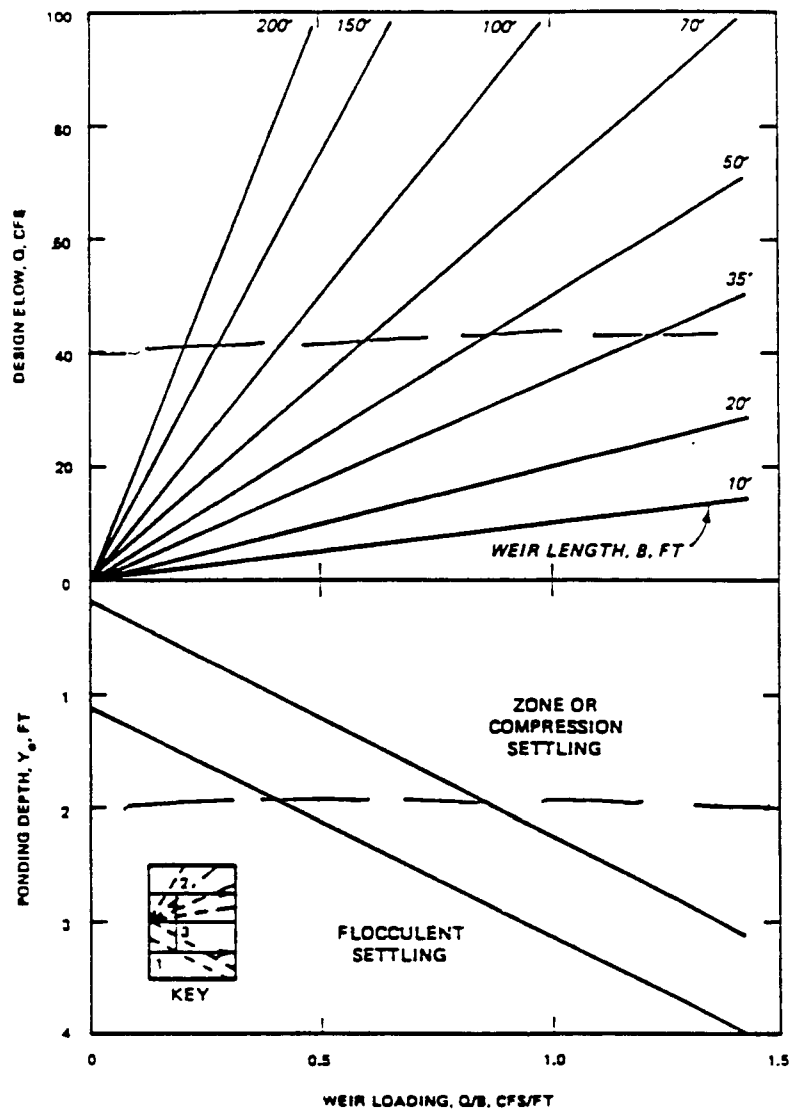
(after Krizek, et al. ,1976)

Figure 5.6 Pervious Dike Filter Systems



(after Krizek et al., 1976)

Figure 5.7 Filter Weirs and Cartridges



(Ref. EM 1110-2-5027)

Figure 5.8 Weir Design Nomograph

The removal of dissolved contaminants from effluent leaving the weir is performed using treatment technologies that are very contaminant specific. A general discussion of these technologies is presented in Appendix A.4.

### 5.1.2 Dike Seepage

Movement of contaminated pond water through the dike structure will occur unless a mechanism is provided to either restrict the actual water migration or attenuate the water borne contaminants. The flow through a dike can be restricted either by controlling the hydraulic gradient that exists across the dike (e.g., keep the water elevation equal on both sides), or by reducing the permeability of the dike. Dye tracer studies performed in Great Lakes CDFs (Pranger, 1986) showed that discrete points of significantly higher dike seepage were measured at several CDFs including Kenosha and Manitowoc. At these facilities, the dikes were made of sheet pile cutoff walls within a rip-rap dike. The discrete points of high discharge were thought to be due to localized failures of the cutoff wall. At Milwaukee and Kewaunee facilities, zones of higher outflow were observed, but no discrete points of high discharge were found. These latter dikes had cores of crushed limestone gravels and sands. During this study it was also observed that significant decreases in outflow occurred in areas where deltas of previously dredged material were placed against the dike within the CDF.

Design considerations to limit the release of contaminants through dike seepage are shown on Figure 5.9. The design of dike seepage control systems must reflect the nature of the subgrade upon which the dike is built. Vertical barrier systems must intercept and key into an underlying low permeability soil layer (e.g. aquitard) that prevents contaminated ground water from flowing beneath the barrier. Obviously the economy of a vertical barrier system is significantly influenced by the depth of penetration required to intercept such a confining layer. Lacking a natural aquitard, a low-permeability liner may need to be incorporated in the basin design.

Mechanisms to totally restrict water migration through the dike involve constructing either an impermeable barrier in or on the dike consisting of either a low permeability soil, a geomembrane, or a geosynthetic clay liner (see Appendix C for a discussion on geosynthetic barriers). Such "hydraulic isolation", see Table 1.2, are used when either the concentrations of the contaminants are high or when the potential of the contaminants partitioning to the water is high. The low permeability soil barrier can be constructed using either a compacted clay liner (CCL) or geosynthetic clay liner (GCL) designed into the CDF dikes or by an intentional operations placement of clean, fine grained sediments against the surface of the dikes. While geomembrane and clay barriers will be highly restrictive, the operationally placed barrier may be only partially restrictive depending upon the sediment particle size and placement method.

Attenuation of water borne contaminants in the seepage may require both the removal of suspended solids and dissolved contaminants from the effluent. The suspended solids can be allowed to settle out of the effluent or can be physically filtered as described above. Removal of soluble contaminants from the effluent may require changing the effluent water chemistry or filtering the

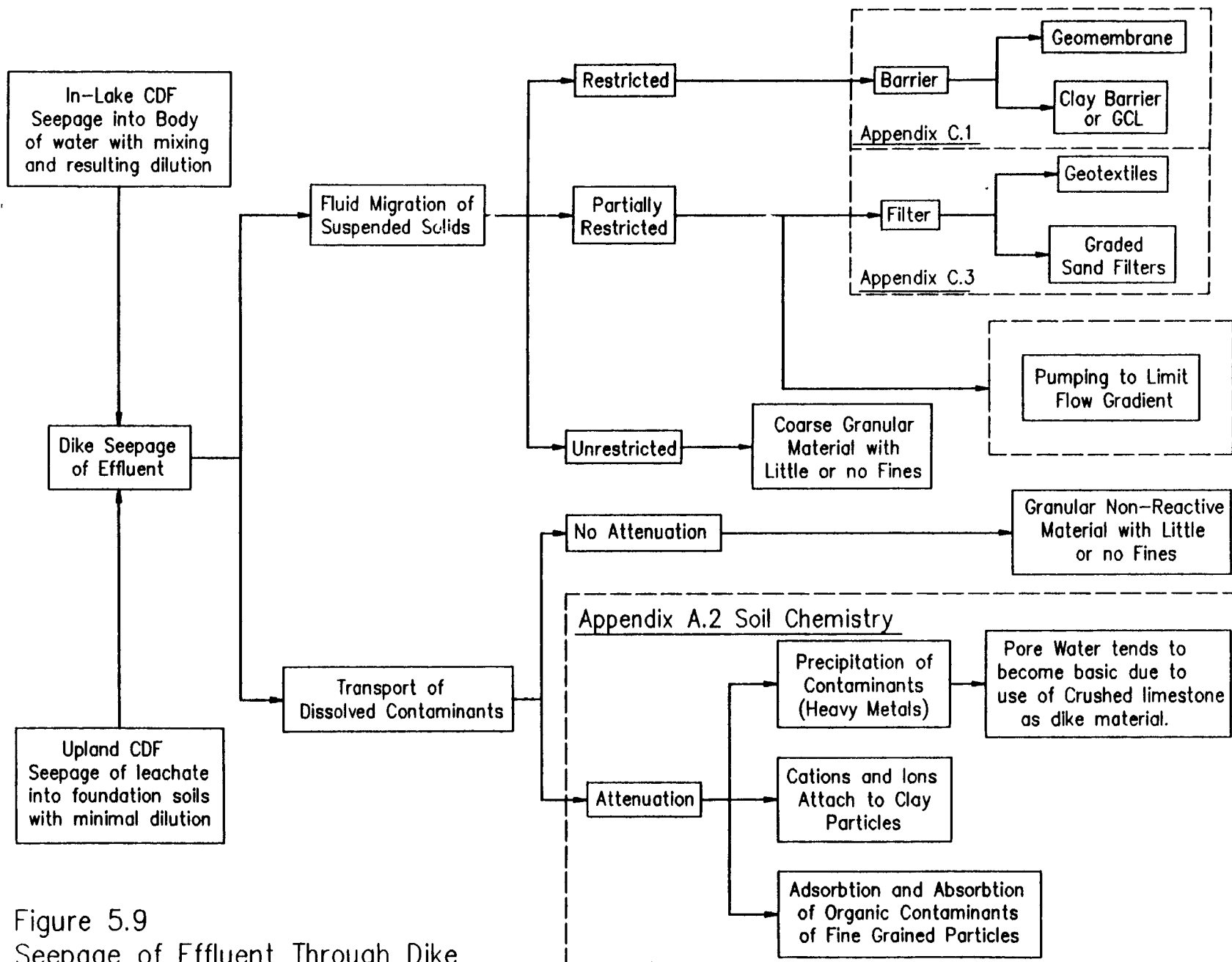


Figure 5.9  
Seepage of Effluent Through Dike

water through a treatment system..

### 5.1.3 Foundation Seepage of Leachates

The migration of partitioned contaminants into the foundation soils involves two different mechanisms as shown in Fig. 5-10. These two mechanisms are: (1) advective transport of suspended particles or dissolved contaminants, and (2) diffusion. Laboratory and field investigations sponsored by the USACE (Chen et al, 1978) clearly showed that leachate problems can exist even when effluent quality is acceptable. For the particular CDFs monitored, the leachate showed high levels of ammonia, nitrogen, iron, and manganese in facilities where the supernatant and effluent had very low concentrations. This work concluded that the physical and chemical properties of soil underlying the CDF should be considered. Leachate entering the foundation soils will undergo less dilution than seepage passing through the dike structure for in-lake or shoreline CDFs. Such potentials for contaminant migration may require use of the "hydraulic isolation" option previously discussed on Table 1.2.

Advective transport of contaminants into the foundation soils is caused by the flow of leachate under Darcy's Law. The rate of flow is controlled by hydraulic gradient (change in hydraulic head divided by flow length), and the permeability of the soils. Shoreline sites are commonly associated with groundwater discharge zones (e.g. wetlands) that have natural upward flow gradients. Such natural upward flow gradients minimize leachate migration into foundation soils beneath a CDF located at such sites. Leachate migration into foundation soils is driven by these natural hydraulic gradients and the heads produced by the varying depth of effluent within the CDF for infiltration and excess pore pressures generated during placement of dredged sediments. The extent or significance of surface infiltration is dependent upon whether a final cover is in place or interim conditions exist. During interim periods where the dredged material is exposed, the advective mobility of contaminants may be greater due to the chemical actions of acid rains or oxidation related breakdown of contaminants.

The actual flow of contaminants into the foundation soils is controlled by the three different types of barrier conditions which can exist at the limit of the dredged material. These are: (1) restricted -- no flow barrier, (2) partially restrictive barrier, and (3) unrestrictive barrier. The fully restricted or no flow barrier is typically the result of a CDF foundation liner of compacted clays or a geomembrane. In contrast, a partially restricted barrier can be a function of site stratigraphy, site hydrogeology, or the presence of a filter media at the bottom of the CDF. The filter media can be constructed of a clean sediment layer on filter fabric (refer to Appendix C for a discussion of design procedure). An unrestrictive barrier is typically comprised of clean granular foundation soils.

The advective transport of soluble contaminants in the leachate can potentially undergo attenuation depending on two different processes. These processes are: (1) attachment of anions/cations to clay minerals, and (2) adsorption/absorption of organic contaminants on humic materials. A detailed discussion of the attenuation of contaminants in soils and soil-like materials is presented in Section

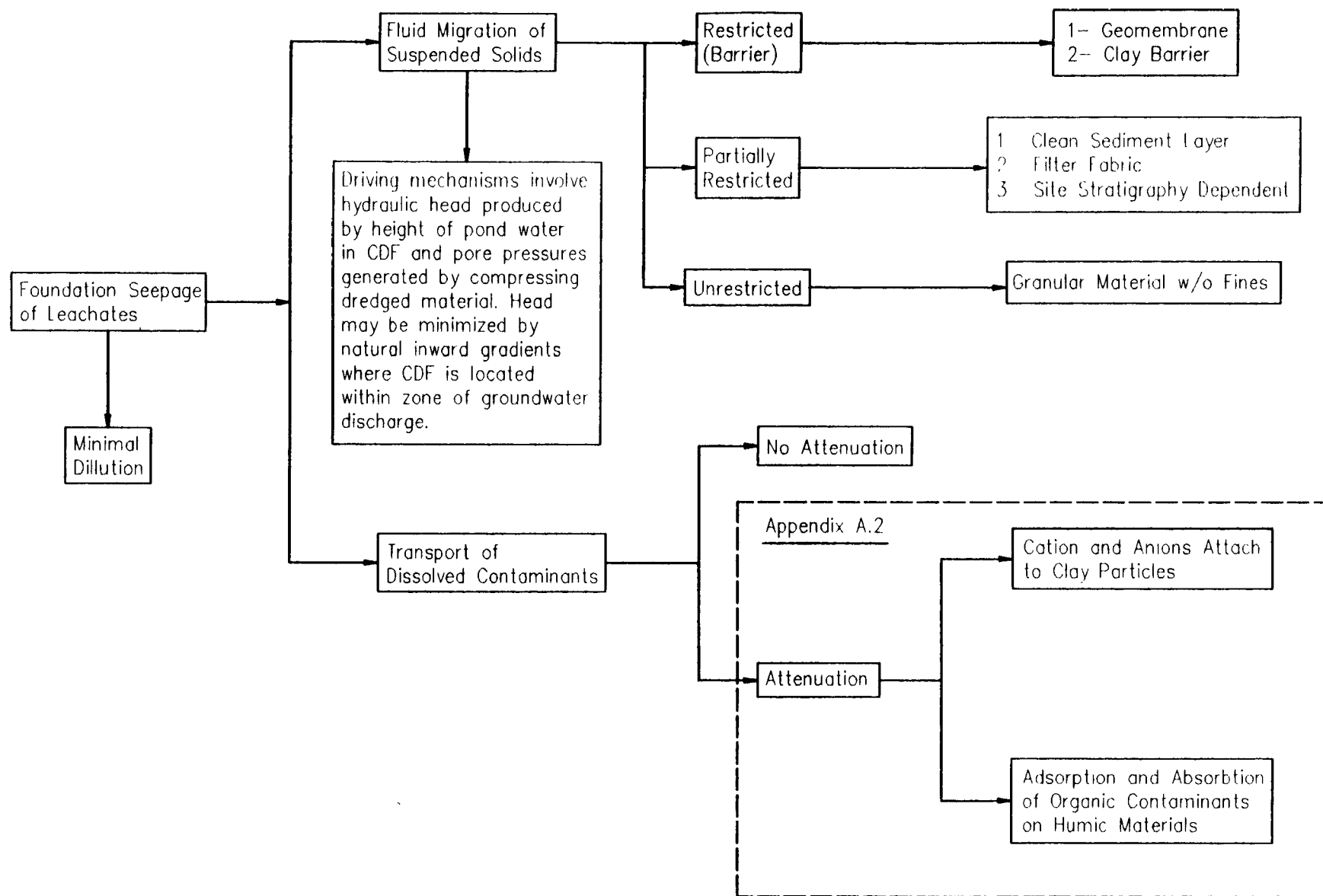


Figure 5.10 Control of Foundation Leachate Generation

## 2 (Soil Chemistry) of Appendix A.

Diffusion transport of dissolved contaminants is driven by concentration gradients and is evaluated using Ficks First Law. This contaminant transport can occur in the absence of water movement. Fortunately, the concentration of contaminants within most leachates is very low and does not lead to significant diffusion rates.

### 5.1.4 Run-Off Contaminant

As shown on Figure 5.11, precipitation falling on a CDF can contribute to contaminant migration by increasing infiltration and surface water run-off. The acidic nature of precipitation in Region 5 may lower the pH of the exposed dredged material and supernatant and place more metal contaminants into solution. The potential for contaminant transport due to run-off is influenced by whether the dredged material remains exposed to air during interim operations such that geochemical changes in the sediments are possible, and whether a final cover has been placed over the dredged material.

During interim operations, the surface water run-off over air exposed dredged materials can cause significant erosion losses if no vegetation or significant slopes exist. Contaminant losses from run-off during the interim operations period can be reduced by providing surface vegetation, limiting slopes to less than 5 percent, and ensuring that run-off does not over top perimeter dikes. It should be noted that interim operations may last several decades so that the vegetation of exposed dredged materials may be very cost effective. During this same period, settlement of the dredged material may result in ponds forming within the CDF. Such ponds provide the potential for plant and animal uptake as discussed in Section 5.2.

Once a clean final cover is placed over the dredged material, the significance of surface water run-off as a contaminant transport mechanism is eliminated. The presence of a thick vegetative layer improves the resistance to soil erosion and the removal of suspended solids and soluble nutrients such as ammonia, nitrogen, and soluble phosphorous (Chef, 1978). Such run-off will have had no contact with contaminants if a barrier layer is incorporated in the final cover and therefore would not be a potential contaminant transport mechanism.

The primary control of the surface water run-off contaminant pathway is conventional erosion control practices such as limiting slopes and surface vegetation. A typical erosion control program will include limiting slopes to <5%, vegetation of cover surfaces with native grasses and temporary containment of all run-off in sedimentation basins.

## 5.2 Contaminant Pathways to Plant and Animal Communities

Contaminant pathway considerations for plant and animal communities are presented in this section using the general food web flow relationships presented on Figure 5.12. Such food web flow diagrams show the general movement of nutrients and contaminants within and between the plant



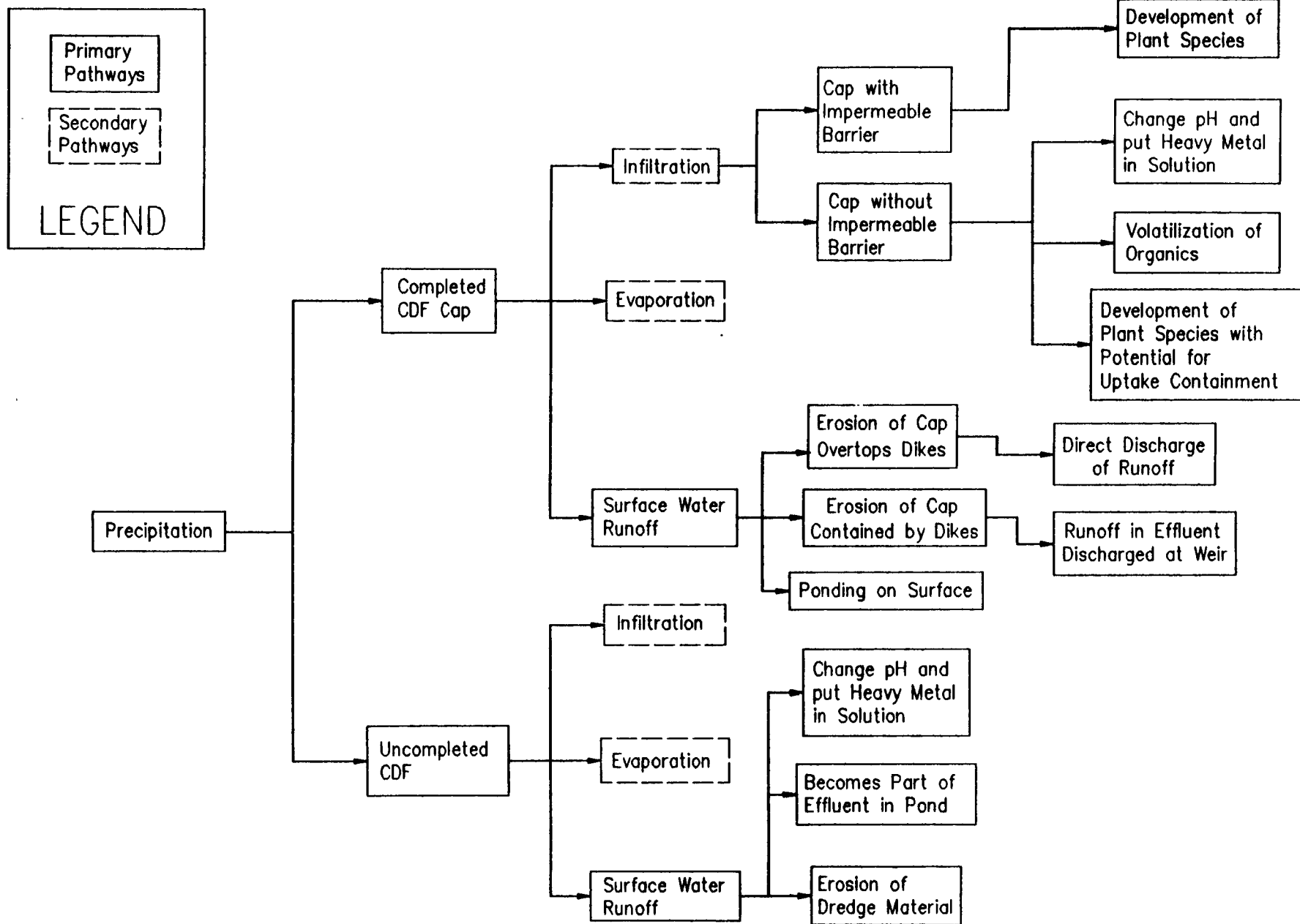
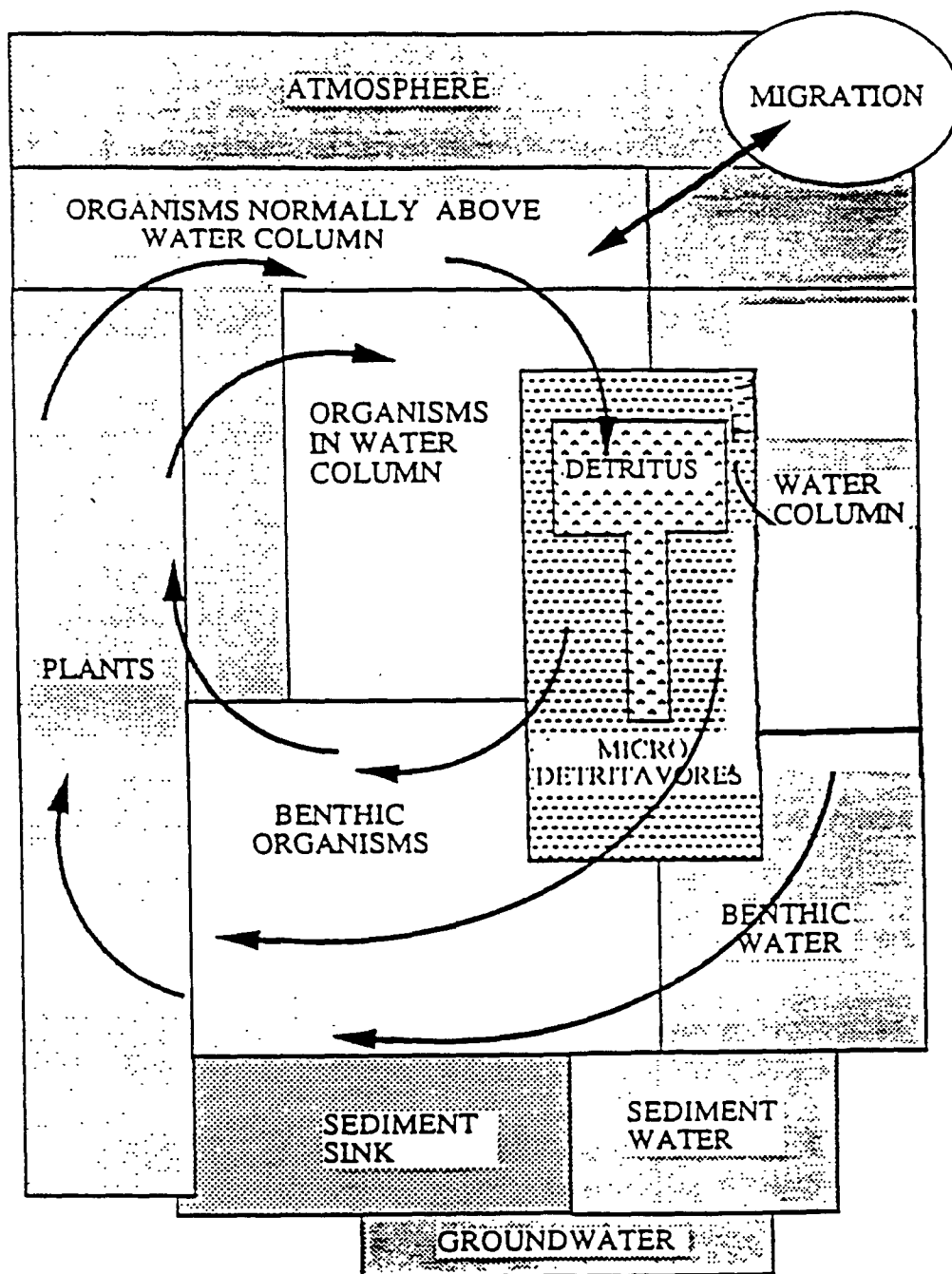


Figure 5.11 Surface Water Mechanisms Related to Precipitation on CDF



(Adapted From Seliskar and Gallagher, 1983)

Figure 5.12 Food Web Drawing Showing General Flow of Nutrients and Metals

and animal community. This movement can be "up" the food chain, e.g. fish in ponds within the CDF, or "down" the food chain, e.g. excretion or death. Such movement of contaminants by biological mechanisms is in addition to the movements caused by the non-biological flow shown on Figure 5.1. These non-biological movements are discussed in Section 5.1.

The uptake of contaminants by plants and animals can be estimated by the use of simple mathematical relationships presented in Table 5.1, (Kelly, 1988). As shown on Table 5.1, the larger the animal bioconcentration factor (BCF) or Plant Uptake Factor, the greater the amount of contaminant absorbed. The various bioconcentration factors (BCF) and Uptake Factors associated with specific chemicals are discussed in sections 5.2.1 and 5.2.2.

Contaminant pathways to plant and animal communities must be considered during both the operational and post-closure time periods. In particular, ponds that form on the dredged materials during the decades long operation of the CDF may offer the most significant opportunities for plant and animal uptake. The ability to limit these contaminant transport mechanisms prior to placement of the final cover should be evaluated.

The control of long-term contaminant uptake by plants requires a final cover over the problematic dredged materials that controls the movement of the plant roots into the dredged material or limits the capillary rise of leachate in the final cover. The movement of roots into the waste can be prevented by the use of a geomembrane barrier or a clean soil cover that has a total thickness greater than the maximum root depth of the target vegetation. The capillary rise of contaminated water from the dredged materials can be limited by the use of a geomembrane or capillary break in the final cover. The capillary break can be formed using a coarse granular sand or gravel layer and could be formed with dredged material. Section 5.2.1 presents a general background on factors influencing plant uptake of contamination.

Limiting the long-term uptake of contamination by animals is accomplished if plant uptake is prevented and burrowing of animals into the cover is discouraged. Burrowing by animals can be prevented by the use of a geomembrane or biotic barrier in the final cover. Typical a biotic barrier consists of a layer of stone, with each stone weighing more that the target animal can lift or move. Section 5.2.2 presents general background of factors that influence animal uptake of contamination.

### **5.2.1 Contaminant Uptake by Plants**

Contaminant pathways for plant uptake are illustrated on Figure 5.13 for terrestrial, submergent, and emergent plants such as eelgrass, duckweed and bulrush. Vegetation production is primarily a function of light, soil moisture, nutrients, and interactions with surface water and soil microbes. There are 16 elements that must be absorbed by all plant life in order to complete a full life cycle (National Nutrients, 1988). These include the major elements oxygen, hydrogen, carbon, nitrogen, phosphorous, and potassium; secondary elements are magnesium, and sulfur; and the micronutrients include iron, boron, copper, manganese, chlorine, zinc, and molybdenum. The

**TABLE 5.1**

**Summary of Contaminant Uptake Relationships For Plants and Animals**

**A. Dredged Material - Plant**

$$CP = \text{Uptake Factor} \times Cs$$

**B. Plant - Animal (grazer)**

$$C_{ag} = C_p \times BCF$$

**C. Dredged Material - Soil Biota (Direct Ingestion)**

$$C_{sb} = C_s \times BCF$$

**D. Animal (grazer or predator) - Animal (Predator)**

$$C_{ap} = C_{ag} \times BCF \text{ or } C_{ap_{after}} = C_{ap_{before}} \times BCF$$

**Nomenclature**

$C_{ag}$  - animal (grazer) tissue concentration (ug/g)

$C_{ap}$  - animal (predator) tissue concentration (ug/g)

$C_s$  - chemical concentration in dredged material (ug/g)

$C_p$  - chemical concentration in plant tissue (ug/g)

$C_{sb}$  - chemical concentration in soil biota (ug/g)

\*BCF - bioconcentration factor (unitless)

\*Uptake Factor - chemical uptake rate by plant (unitless)

Notes: \* - chemical specific value obtained from literature

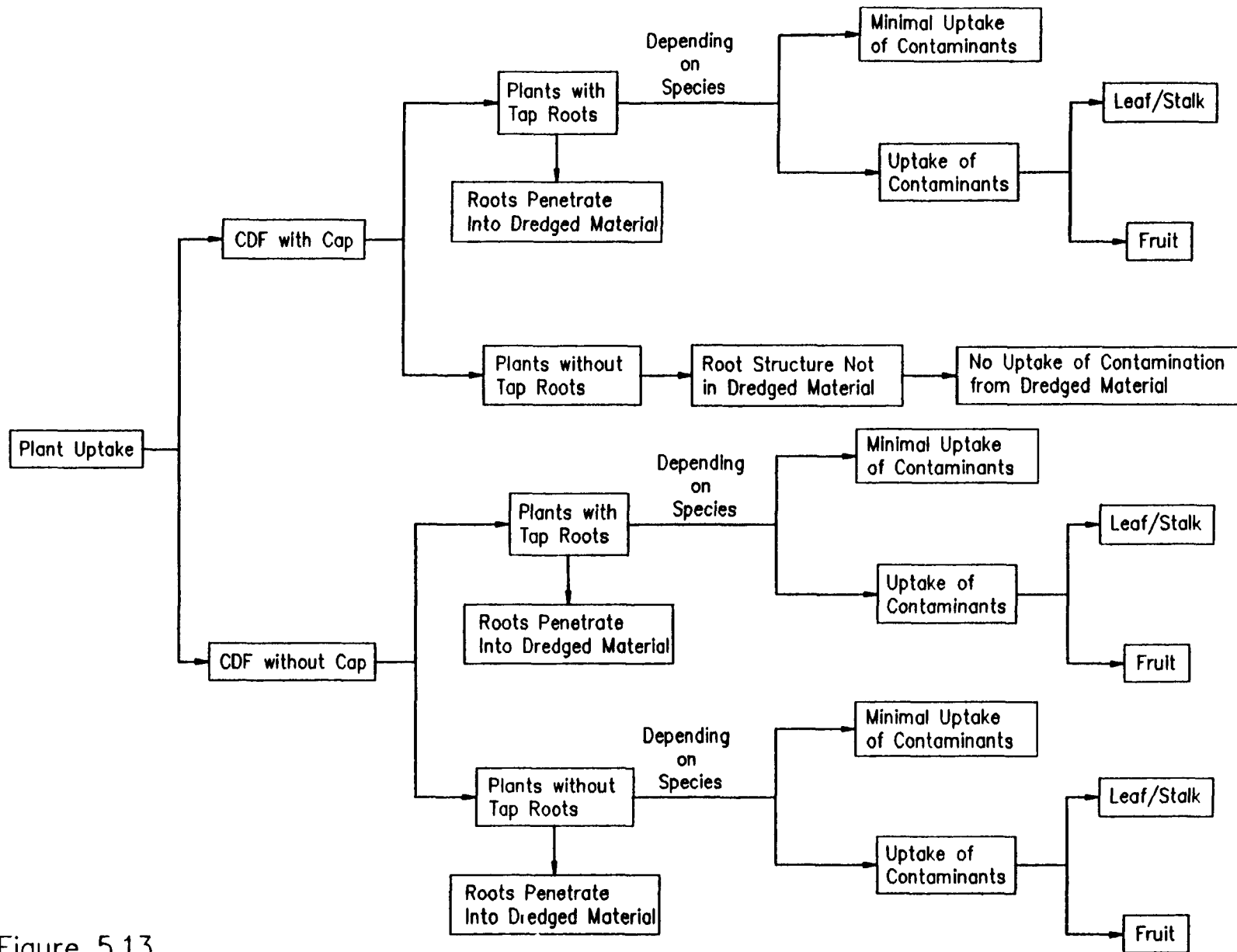


Figure 5.13  
Mechanisms Involved in Plant Uptake of Contaminants in Capped and Un-Capped CDF's

micronutrients are typically required by plants in concentration of less than two parts per million (ppm) (National Nutrients, 1988). The mechanisms involved in the uptake of contaminants by plants are dependent both on whether the plants roots extend into dredged material and on the particular plant species. The bioavailability of an element or contaminant can be increased by the following (Maybeck et. al. (eds.), 1989):

1. Small particle size
2. Aqueous/lipid solubility
3. Complexation
4. Specific active processes for elements or complexes which mimic essential nutrients.

Interactions between various metals and other contaminants can vary for a given plant (or other organisms) and media, and can be controlled by pH and other factors. Organic contaminants typically have large molecules that cannot pass through the cell walls of plants, thus limiting uptake. Bursztynsky (1981) notes 6 primary biochemical pollutant uptake and removal processes in wetland vegetative systems. These are:

1. Uptake through plant - soil interface via roots, rhizomes, holdfasts and buried shoots and leaves.
2. Uptake through plant - water interface via submerged roots, stems, shoots, and leaves.
3. Translocation through plant vascular system, from roots to stems, shoots, leaves, and seeds during the growing season.
4. Differential pollutant uptake, such as preferential storage of trace contaminants in specific plant parts and preferential uptake/accumulation of certain trace elements.
5. Nonspecific pollutant uptake, occurring primarily as plants absorb large quantities of nutrients from water and sediments.

As the main sources of trace elements to plants are their soils or nutrient solutions, Kabata-Pendias and Pendias (1984) conclude that plants readily take up metals dissolved in soil solutions in either ionic or chelated and complexed forms, and binding of metals to soil constituents is one of the most important determinants of availability. For example, these authors note that metals adsorbed onto clay minerals are most readily available to plants, compared to those fixed by oxides or bound onto microorganisms. In general. Plant absorption can be summarized as (Kabata-Pendias and Pendias, 1984):

1. Capable of operating at very low concentrations in solution.

2. Depends largely on the concentration in solution (esp. at low ranges).
3. Depends strongly on the occurrence of hydrogen and other ions.
4. Varies with plant species and stage of development.
5. Selective for a particular ion.
6. Accumulations of some ions take place against a concentration gradient.
7. Micorrhizae play an important role in cycling between external media and roots.

A summary of typical plant uptake factors for chemicals in soils and sludge is presented in Table 5.2. A review of Table 5.2 indicates that the metals that have the greatest potential to be absorbed by plant tissue are: arsenic, cadmium, nickel and zinc.

### **5.2.2 Contaminant Uptake by Animals**

Contaminant animal uptake pathways are flow charted on Figure 5.13. There is an abundance of data on the bio-effects on metals and to a lesser extent for other contaminants. EPA published the Fourth Annotated Bibliography on Biological Effects of Metals in Aquatic Environments (Eisler, 1979) which lists 886 titles and abstracted material from research published in only a two year period (1978 to 1979). Articles were selected for information on growth, bioaccumulation, retention, translocation, histopathology, and interaction effects of metals and their salts in combination with other substances. The first three volumes of this series covered previously published research.

More recently, the U.S. Fish and Wildlife Service has produced a series of Biological Reports on metal and organic compound hazards to fish, wildlife, and invertebrates. These are synoptic reviews of bio-effects and cycling data for specific metals. Of primary interest are Lead Hazards to Fish, Wildlife and Invertebrates (Eisler, 1988), Cadmium Hazards to Fish, Wildlife, and Invertebrates (Eisler, 1985), Chromium Hazards to Fish, Wildlife, and Invertebrates (Eisler, 1986), Mercury Hazards to Fish, Wildlife, and Invertebrates (Eisler, 1987), Arsenic Hazards to Fish, Wildlife, and Invertebrates (Eisler, 1988).

EPA sponsored a literature review titled Metal Bioaccumulation in Fishes and Aquatic Invertebrates (Phillips and Russo, 1978) with separate chapters on 21 metals. This is a valuable collection of bioaccumulation data up to 1978. In the section on conclusions and recommendations, it is noted that some chemical forms of metals, such as methylmercury, are far more toxic and more readily accumulated by aquatic organisms than are others, and that most bioaccumulative and toxic forms of other hazardous metals should also be determined. This stresses the need to understand the

**TABLE 5.2****Typical Plant Uptake Factors for Chemicals in Soils and Sludge**

<b>Chemical</b>	<b>Uptake Factor*</b>	<b>Plant Type</b>	<b>Soil Type</b>	<b>Comments</b>	<b>Reference</b>
<b>Arsenic</b>	0.02	Chard	Sludge		Chisholm, 1972 MacLean, 1978
<b>Cadmium</b>	0.01	Carrot	Compost		Connor, 1984
<b>Chromium III</b>	No significant uptake	—	—		Cary, et al., 1989
<b>Copper</b>	No significant uptake			Based on dry weight of plant and soil	EPA, 1988
<b>Lead</b>	0.006	Lettuce	Sludge		CAST, 1976
<b>Mercury</b>	0.001	Dry Legume		Hg is highly bound by humic substances. Sludges can decrease Hg crop concentration, the exception is mushrooms which bioaccumulate Hg (Domsch et. al., 1976)	EPA, 1988
<b>Nickel</b>	0.09	Lettuce	Sludge		Chaney, et al., 1980
<b>Zinc</b>	0.03	Leafy Vegetable	Sludge		EPA, 1988

\*Reference Equation B, Table 5.1



chemical and physical movement of metals in the ecosystem along with the biological food web movements.

Leland and Kuvabara (1985) state: "The classic idea of food chain enrichment developed from studies of DDT and methylmercury (which have high affinities for lipids) where the highest trophic levels contain the highest toxicant concentrations, does not hold for most heavy metals." More typical distributions show that sediment-feeding organisms contain higher metal concentrations than do other consumers because sediments generally contain higher concentrations of heavy metals than are present in aquatic organisms (Leland and Kuvabara, 1985). This thinking is illustrated with a study by Armstrong and Hamilton (1973) which showed that concentrations of mercury in preferentially occur detritus feeders, omnivores, or taxa that feed primarily on benthic invertebrates (Leland and Kuvabara, 1985). A summary of typical bioconcentration factors for fish and animals is presented in Table 5.3.

### **5.3 Airborne Emissions Control**

The control of airborne contaminant emissions includes limiting the direct volatilization of contaminants into the air and the wind related loss of soil particles that are contaminated. The direct volatilization of contaminants into the air is a potential problem when the dredged materials are exposed to the atmosphere. Thus the volatilization of contaminants during the operation of the CDF can be limited by maintaining the material level within the CDF below the water elevation. For upland CDFs and where hydraulic or evaporation considerations prevent such action, the exposed contaminated dredged material can be covered with clean dredged material to limit volatilization.

In a similar manner, the wind erosion of the dredged material is controlled by limiting the exposure of the contaminated dredged material. If historical surface wind velocities and the grain-size distribution of the dredged materials indicates significant wind erosion (e.g. a large percentage of solid particles having an effective diameter less than 10 microns), then the use of a clean granular soil cover over air exposed dredged materials is recommended. The generation of significant wind erosion (See Section 2.3.6) must be avoided during the operations and post-closure periods.

TABLE 5.3

## Typical Chemical Bioconcentration Factors in Animals

Chemical	Bioconcentration Factor (BCF)*	Comments	Reference
<b>Arsenic</b>	No significant uptake		EPA, 1988
<b>Cadmium</b>	0.00002	Cattle, muscle tissue, sludge study, chicken eggs	EPA, 1988
<b>Chromium III</b>	0.4	Guinea pigs, fed Swiss chard grown on sewage sludge. Tissue: muscle	Furr et al., 1976
<b>Copper</b>	No significant uptake	Vole, Tissue: muscle	Williams et al , 1978
<b>Mercury</b>	0.0001	Cattle, muscle	Johnson et al., 1981
<b>Inorganic</b>	0.85	Mice	Fitzhugh et al., 1980
<b>Organic</b>	5.0	Mink, Tissue: muscle	Auerlich et al., 1974
<b>Nickel</b>	No significant uptake	Mammals have a mechanism to limit intestinal absorption	Gough et al., 1979
<b>Zinc</b>	0.01	Guinea pigs, fed Swiss chard grown on sewage sludge. Tissue: muscle	Furr et al., 1976

\*Reference Table 5.1

## SECTION 6

### CDF BASIN DESIGN RECOMMENDATIONS

Conventional CDF design focuses on retention of sediment solids within the facility. Depending upon the nature of the site, the contaminants of concern, method of dredging, physical properties of the dredged material, operational aspects, and many other factors including socio-political, supplemental environmental design criteria may be required for the CDF. This section presents design alternatives to control contaminant loss from the CDF basin through (1) effluent or leachate discharge through the dikes, and (2) leachate drained from the sediments that discharges into the groundwater. The designs must satisfy the AEPP given in Section 2.2.1 for effluent quality and Section 2.2.5 for groundwater leachate quality. These design alternatives include both the use of additional designed components and the use of operational constraints. These two pathways are the most significantly impacted by partitioning of the contaminants to the supernatant waters. The use of "hydraulic isolation" design criteria in such cases has been previously discussed (see Table 1.2 and related discussion). The remaining pathways are impacted by interim and final closure and are discussed in Section 7.

Additional design considerations may pertain to the CDF basins in new "hybrid" CDFs that have been proposed as a closure system for coastal Superfund sites, e.g., Indiana Harbor. The presence of existing contamination beneath the CDF basin may result in pathway design considerations not fully developed herein.

The containment basin of a CDF is formed by the perimeter dikes and the subgrade of the site. Water can potentially leave the basin as a non-point source by either seepage through the perimeter dikes or by leaching into the underlying subgrade. The control of either pathway is therefore dependent upon limiting hydraulic gradients and/or the design of a barrier to limit advective transport of contaminants, or design of a filter to attenuate the flow of the dredged material itself. Hydraulic gradients may be significantly influenced by the type of CDF, e.g. in-lake CDFs typically have very low gradients as compared to high gradients common to upland CDFs.

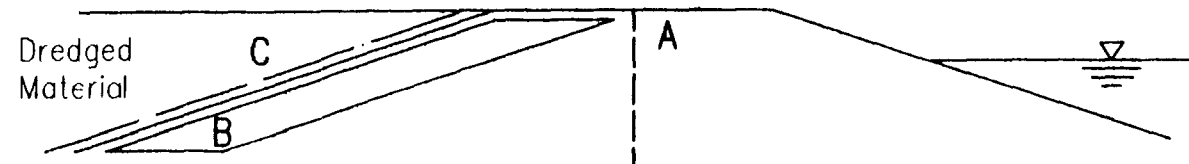
#### 6.1 Effluent Discharge Through the Dikes

Water carried by the dredged sediments must be removed from the CDF to provide space for additional sediments and to develop a stable base for construction of the final cover over the dredged material. Effluent can leave the CDF by seeping through perimeter filter dikes or through a weir point discharge system. The latter is particularly attractive if the effluent must be processed to remove or attenuate contaminants. The design of point-source effluent filter and treatment systems has been discussed in Section 5.1.1 and will not be elaborated on in this section. Monitoring of effluent release through conventional CDF dikes (Schroeder, 1984) indicates that point discharges from porous zones in the dikes occur rather than uniform

TABLE 6.1 DIKE BARRIER SYSTEM APPLICATION IN CDF'S

	Barrier System	Barrier Location*	COE Usage	In-Lake CDF	Shoreline CDF	Upland CDF
"Impermeable" Barriers	Compacted Clay Liner (CCL)	C		N/A	N/A	●
	Geomembrane Liner (GML)	C	X	○	○	●
	Geosynthetic Clay Liner (GCL)	C		N/A	○	●
	Geomembrane Cut-off Wall	A		●	●	●
	Bentonite Slurry Cut-off Wall	A	X	●	●	●
	Fabric Form w/ Grout	C		●	●	●
"Low" Permeability Barriers						
	Clean 'Fine' Sediments	C		●	●	●
	Clogged Geotextile	C	X	○	●	N/A
	Graded Soil Filter	B	X	○	●	●
	Fabric Form w/Sand	C		●	●	N/A
	N/A NOT APPLICABLE      ● Good Application      ○ Maybe Difficult to Construct					

\* Barrier Locations



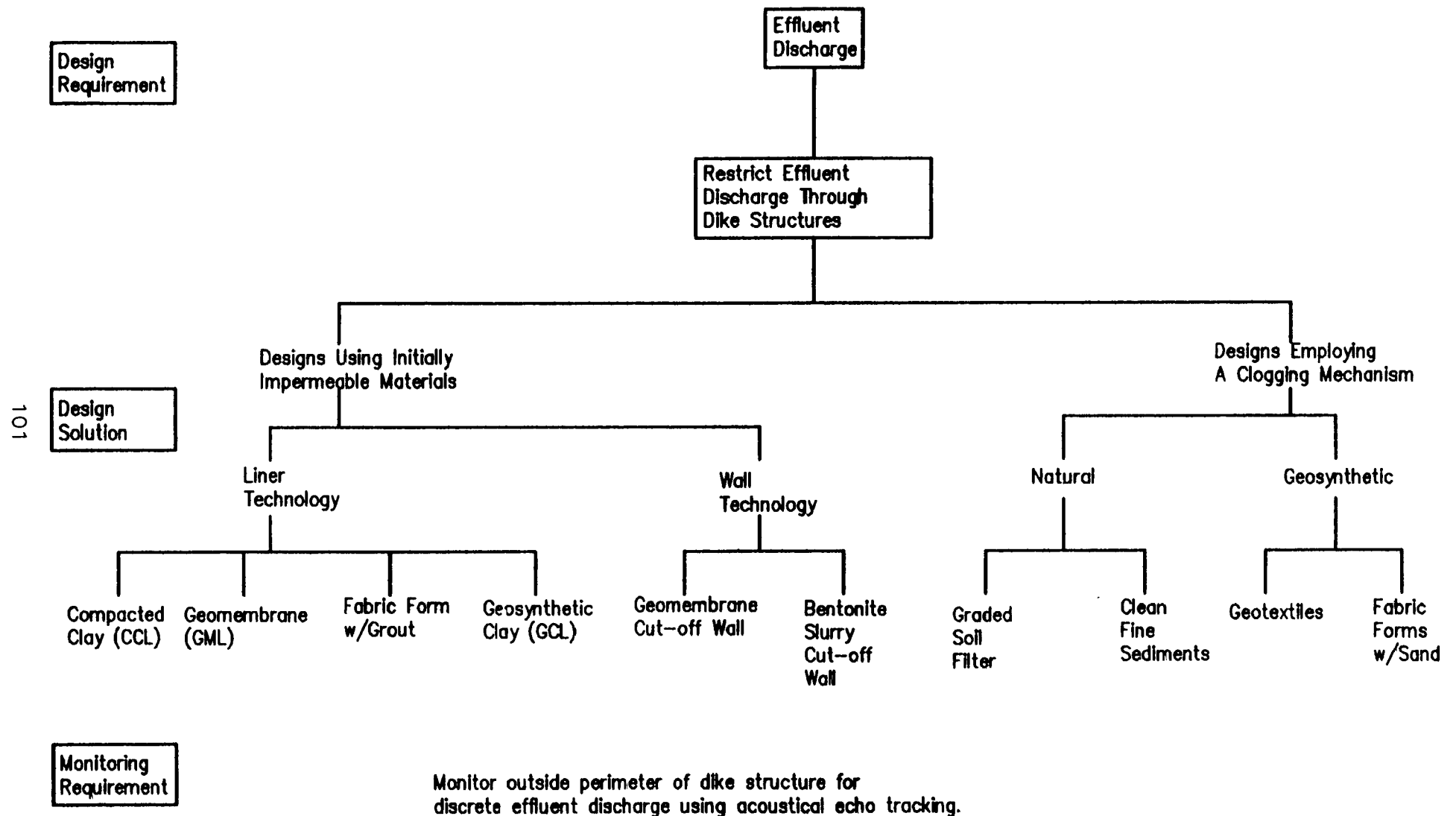


Figure 6.1 Effluent Dike Discharge Control

seepage along the entire dike structure. Such findings may require the use of an alternative mixing zone definition if the point discharges cannot be characterized or eliminated.

Effluent seepage through the dikes can be limited by controlling the level of effluent within the CDF or by designing an impermeable barrier layer into the dike as shown on Table 6.1 and Figure 6.1. The flow of water beneath the dike can be controlled using an impermeable basin liner or a dike vertical barrier that penetrates into a lower natural barrier layer. Note that, within Region 5, the COE has already used geomembranes, filter fabrics (geotextiles), and bentonite slurry cut-off walls in perimeter dikes, see Section 4. A more detailed discussion of geosynthetic components is presented in Appendix C. No one barrier system is suitable for all CDF applications as discussed below.

### 6.1.1 Dike Barrier Systems

**Compacted Clay Liner (CCL)** - A CCL barrier is a principle EPA containment element used in the design/construction of solid and hazardous wastes disposal facilities. It is well suited to most upland CDF applications. Construction of the CCL presents significant, if not insurmountable, problems in an aqueous environment. No current method of construction allows placement of a CCL beneath water. Use of a CCL in shoreline and in-lake CDFs would require a perimeter cut-off system and pump out that would allow placement of the CCL on a dry, prepared subgrade. Such construction requirements could be prohibitively expensive for structures such as CDFs because of their significant perimeter lengths.

Construction costs of CCLs are very dependent upon the availability of fine grained soils suitable for use as a barrier. If suitable soils are available on-site, the placement of the CCL will typically cost \$8 - \$16 per ton. Frequently the on-site soils are amended with bentonite to reduce their permeability. Amendment costs are approximately \$10 - \$15 per ton in addition to placement costs (Richardson, 1995).

**Geomembrane Liner (GML)** - A GML is the least expensive of the barrier alternatives and is also a principle EPA containment element for RCRA applications. The GML (see Appendix C) can be constructed with a flexible geomembrane such as PVC that allows factory fabrication of large panels or from high-crystalline thermoplastics such as HDPE that must be welded together in the field. GMLs such as HDPE offer greater service life and resistance to chemical attack of the polymer. While the resistance of a GML to chemical attack can be evaluated using the EPA 9090 test, the low contaminant concentration levels associated with problematic sediment should not impact most commercial GMLs. As with CCLs, the placement of GMLs has commonly been done only in dry site conditions. Several significant problems are possible if installation of a GML is attempted below water:

1. The polymers have specific gravities less than 1.0 and will float, necessitating the use of counterweights;

2. The presence of moisture on the geomembrane reduces the quality of a field seam; and
3. Soil or stone placed over the GML can easily puncture the geomembrane and inspection or repair of the geomembrane is not feasible under water.

In addition to aqueous application problems, the design of a GML must address problems associated even with 'dry' applications. The most significant conventional problem generated by the GML is sliding stability due to the slick surface of the GML. The COE experienced a sliding failure during their placement of a GML during the construction of the Chicago CDF. Interface friction tests under saturated conditions must be performed as part of the design process.

Installed costs of GMLs range from \$0.40 to \$0.80 per square foot depending upon the type of geomembrane and difficulty of installation (Richardson, 1995).

**Geosynthetic Clay Liner (GCL)** - GCLs use a thin layer of bentonite attached to a geotextile to form a barrier layer. GCLs must be placed in dry site conditions to prevent premature hydration of the bentonite granules. This wetting-up of the GCL dramatically increases the weight and reduces the strength of the GCL. In upland CDFs, the GCL is an economical substitute for the CCL averaging approximately \$0.85 per square foot to install. The GCL is simply rolled out like carpeting to line dry installations. Commonly a 6-inch overlap is used between adjacent panels of GCL such that field welding or seaming of the panels is not required. The installed GCL would require protection from current or impact forces resulting from placement of the dredged material in the CDF.

Marine application of GCLs has never been attempted and would require a GCL manufactured for such an application. A marine GCL would require a significantly stronger carrier geotextile to survive the higher installation forces that could be anticipated due to hydration of the bentonite during placement. Once submerged, the buoyant weight of the GCL would reduce the force in the geotextile. Alternatively, the bentonite would require treatment to retard the rate of hydration to limit swelling and subsequent loss of strength of the clay. If allowed to hydrate, the bentonite must be securely fastened between two layers of geotextile carrier. This may require stitching of the fabrics together. Such options are available from GCL manufacturers.

**Geomembrane Cut-off Wall (GCW)** - A GCW is constructed using HDPE panels that are attached by interlocking fittings at their edges. The interlocks are similar to that found on conventional sheet-piling but include a hydrophilic seal that swells when exposed to water. The GCW is installed in sandy soils using a vibrated steel guide. In clays or loams, the GCW are typically installed using a bentonite-slurry trench to penetrate the confining clay layer and

seal the toe of the cutoff wall. The GCW provides increased chemical resistance and longevity when compared to conventional steel sheet-pile barrier walls.

The cost of GCW installation is dependent on the soil type that it must penetrate and the depth of penetration required. In favorable soils, GCWs have been installed to depths exceeding 20 meters at costs less than \$2.00/square foot. Field construction quality assurance procedures have been established to verify the integrity of the interlocked joints (EPA/540/R-92/073).

**Bentonite Slurry Cut-Off Wall** - The bentonite cut-off wall system has been extensively used to laterally contain Superfund remediation sites. A water-bentonite slurry is used to maintain a trench excavated with a backhoe or clamshell. The permanent barrier is made using either a soil-bentonite blend or a soil-cement-bentonite blend. This soil-bentonite blend is placed into the trench and displaces the lighter bentonite-water slurry. Construction of the slurry wall must be performed under dry conditions but can easily extend below the groundwater elevation. Thus, aquatic CDFs could use this cut-off method if their dikes were, at least initially, built with a portion above the water elevation and impermeable enough to contain the slurry.

Bentonite cut-off walls require no special construction equipment for depths less than 30 feet. Greater depths can be accomplished, but will typically require the services of an experienced specialty contractor. Slurry wall construction costs are heavily dependent upon the depth of the wall. Costs in 1991 dollars, range from \$7.00 per square foot for a 30-foot deep walls to \$15.00 per square foot for a 75+ foot deep wall (EPA, 1992).

**Fabric Form with Grout** - While more commonly associated with erosion control, the use of geotextile forms and a bentonite enriched grout can produce a hydraulic barrier blanket. The fabric form uses two woven fabrics that are connected by threads at regular increments such that a blanket of controlled thickness is produced when grout is pumped between the fabrics. The fabric forms can be placed beneath water if weighted to reduce their buoyancy.

Installed cost of grout-filled fabric forms in conventional applications is approximately \$2.00 per square foot. The addition of bentonite to the grout and the need for counterweights will probably raise this cost significantly in aquatic applications (Richardson, 1995).

**Clean 'Fine' Sediments** - A moderately low permeable barrier can be formed using silty sediments that have been hydraulically dredged. As these sediments consolidate under their own weight, their permeability will decrease. This operations-based liner offers significant economy for sealing CDF bottoms (see Section 6.2) but may be difficult to use for dike lining. The lining of a dike using this method would require using a dredge, earthmover or dragline bucket to move the consolidated sediments from the CDF bottom to the dike sidewall and use of a graded natural filter or geotextile to prevent the piping of the sediment through the dike. This process may have to be repeated if erosional forces act on the side slopes prior to



placement of dredged material against the dike. The use of clean fine-grained dredged materials to line the CDF is an example of a containment alternative that can be implemented with a simple change in operational practice.

**Clogged Geotextile** - Filter design criteria and laboratory tests are available (see Appendix C) to select a geotextile that will not clog when used to filter a soil/water slurry. Conversely these same methods allow a geotextile to be selected that will intentionally clog when exposed to the sediment slurry. Such a barrier may require an initial clean slurry to develop clogging if an initial small release of contaminants is unacceptable. As the geotextile clogs, a soil cake can build up on the fabric and act as a flow barrier.

Geotextiles are the least expensive of the geosynthetic components and are commonly installed for \$0.10 to \$0.15 per square foot. Counterweighted to resist floating and installed in a aquatic application, the geotextile installed costs will be significantly higher (Richardson, 1995).

**Graded Soil Filter** - From the early works of Terzaghi, geotechnical engineers have known how to design layered soil filter systems that allow movement of water with minimal loss of soil particles. The COE relies on these very principles in the design of conventional CDFs. As in the case of the geotextiles, these same relationships allow the design of a layered soil system that will clog and prevent the flow of water.

The design for clogging requires only a slight modification of the COE design procedure for dikes. As with the geotextiles, the use of an initial clean slurry may be necessary to clog the system without allowing the escape of contaminants. While such a barrier would not provide the very low permeability of CCLs or GMLs, they may provide an increase longevity without any change in CDF construction costs.

**Fabric Forms with Sand** - Fabric forms could be filled with a fine sand (e.g. sugar sand) to produce a soil layer that is readily clogged by fine sediments. A promising variation is the use of a coating to seal the lower geotextile such that it acts like a geomembrane. The coated fabric form could then be installed by counterweighting the fabric form panels, sinking and then filling the forms with sand. Adjacent form panels could be sewn together in a manner similar to the construction methods used by the COE to place reinforcement geotextiles at sea for the construction of embankments on soft foundations. This method has been used already to reinforce CDF perimeter dikes. Such a system would provide a sand cushion to protect the barrier membrane, and could be installed in all categories of CDFs.

Addition of a coating to the fabric form will add \$0.30 to \$0.80 per square foot to the cost of the uncoated geotextile form. This increase in form cost may, however, be offset by a decrease in the cost of the sand filling as compared to a bentonite grout filling.

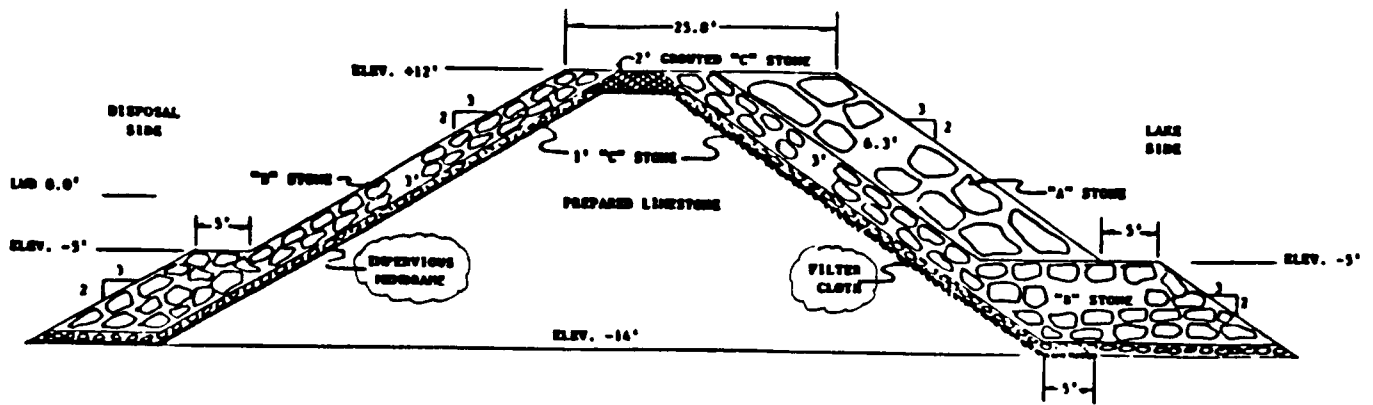
### 6.1.2 Design Considerations for Dike Barrier Systems

Integration of barrier systems into CDF dike sections must (1) not impair the stability of the dike, (2) allow construction of the barrier using conventional construction technology, and (3) key into a lower low permeable layer to minimize effluent discharge beneath the dike.

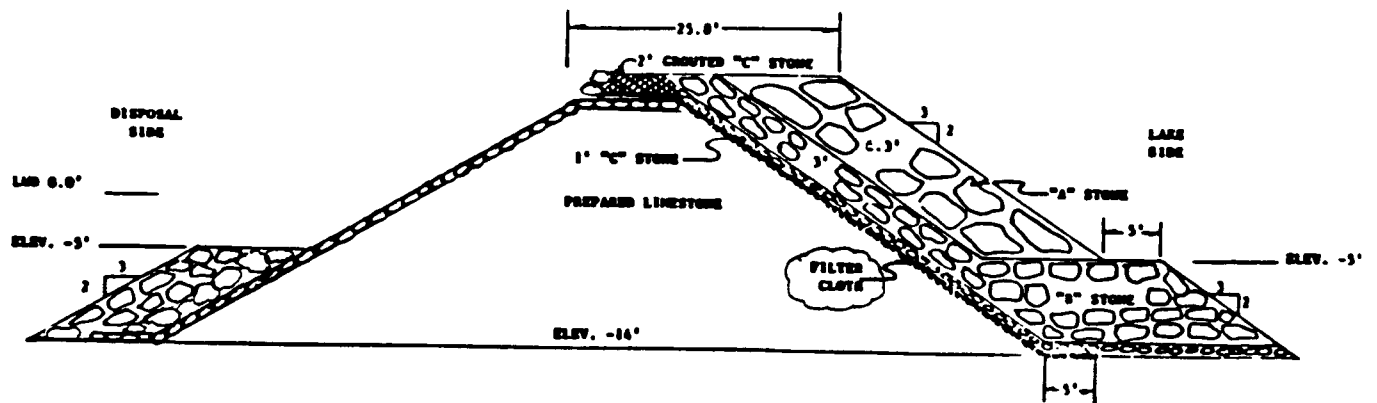
**Stability of the Dike** - The importance of barrier element stability within a dike has been demonstrated at the Chicago CDF. The design dike section, shown on Figure 6.2a, incorporates an impervious membrane beneath the armor stone on the disposal side of the dike. Placed on the 3H:2V slope (33.8° slope angle), the membrane creates a sliding failure plane due to its surface smoothness. Typical interface friction angles for various membranes range from as low as 8 degrees for smooth sheet to as much as 28 degrees for textured sheet. A prior knowledge of the low interface friction values for such membranes would have alerted the designer to the eventual sliding failure that developed.

The membrane stability problem at the Chicago CDF could have been eliminated by using a barrier system that has a higher interface friction angle, by reducing the slope angle of the membrane, or by increasing the thickness of the disposal side armor stone such that it would have been self buttressing. Note that the prepared limestone had up to 6½ inch stones that would preclude placement of a vertical barrier system and presented a major threat to membrane survivability during construction. Barrier systems offering higher interface friction angles include a non-woven geotextile or graded soil filters. Such systems can be designed to be clogged by the effluent. Alternatively, the layers of "B" and "C" stone on the disposal side could have been replaced with a grout filled fabricform barrier that provides both erosion control and a low permeability barrier, see Figure 6.2b. Alternatively, the slope stability can be increased by reducing the slope angle of the geomembrane or increasing the thickness of the interior stone. However, these design changes would significantly increase the cost of the dike.

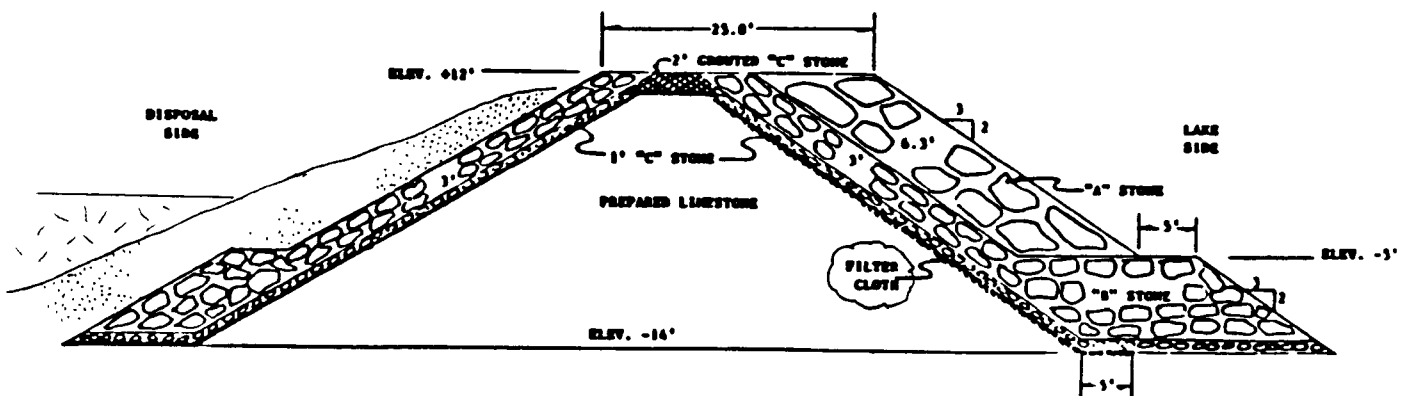
Following failure of the membrane, the COE opted for an 'operations' solution that should be considered in future design alternatives. This operations solution simply called for the placement of a stable wedge of clean sand against the interior of the dike prior to placement of dredged materials within the CDF, Figure 6.2c. This alternative is both acceptable and economical but does require providing a means of limiting the piping of the sand through the large stone and renourishment of sand that has eroded prior to placement of additional dredged materials. This sand layer may provide a sufficient filter layer to provide for "solid retention" of problematic dredged materials. To increase the degree of "hydraulic isolation," a layer of clean dredged material high in fines could be placed over the sand. As discussed in Section 6.2, many dredged materials, once consolidated, produce very low permeabilities and make excellent environmental liners.



A. Chicago CDF Dike Section



B. Grout Filled Fabric Form Barrier



C. Clean Sand Effluent Barrier

Figure 6.2 Alternative Dike Section Barriers

**Construction of the Dike** - The dike barrier selected must be compatible with the proposed dike zone materials. For the Chicago CDF dike section shown on Figure 6.1a, the gradation specifications for the prepared limestone core zone provide for up to 6½ inch stones and less than 5 percent fines. This produces a high permeable core that would not lend itself to slurry wall excavation or the use of vibratory hammer installation techniques. Thus the construction of a vertical barrier through the prepared limestone would be very difficult and require unusual construction techniques.

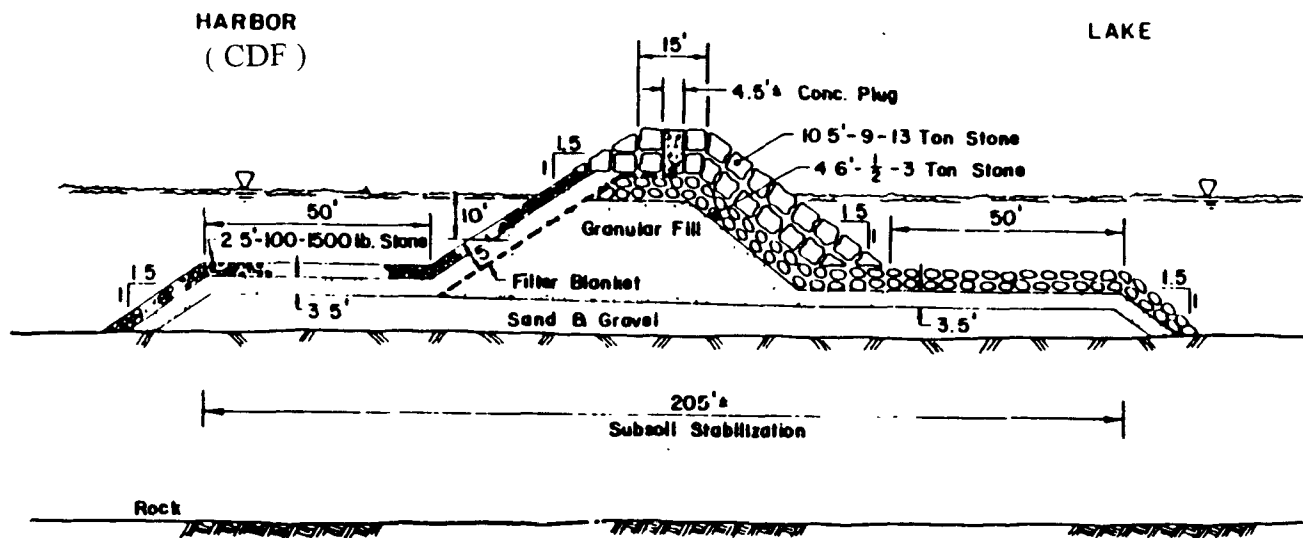
Integration of a barrier system within a conventional CDF dike is complicated by the zoned construction that typifies such structure. The Buffalo CDF dike section shown on Figure 6.3a is not unusual in its use of layered zones that range from sand and gravel to 13-ton stone. Penetrating vertically through such layers is very difficult and suggests that the barrier layer must be added between existing zone layers. For example, the filter blanket (geotextile) used on the Buffalo Dike could be extended to the low-permeable subsoil as shown on Figure 6.3b. This 'filter' layer could then be intentionally clogged by placing a layer of clean, hydraulically dredged silts and clays within the CDF. After clogging the filter fabric, contaminated dredged materials could be placed within the CDF.

**Leachate Flow Beneath/Under the Dike** - A low permeability barrier in the dike is effective in presenting off-site seepage of leachate only if the natural subsoil under the dike is also of low permeability soils or if the site is within a region of groundwater discharge. If this is not the case, the flow through the permeable lower strata can be stopped by either lining the floor of the CDF, see Section 6.2, or by placing a vertical cutoff wall through the strata. The flow of seepage from beneath the CDF is of particular concern since the contaminant concentrations in seepage waters will be at equilibrium concentrations. Depending upon the potential for partitioning of the contaminants to water, such concentrations can be significantly higher than those predicted by the elutriate tests, see previous discussion in Section 1.

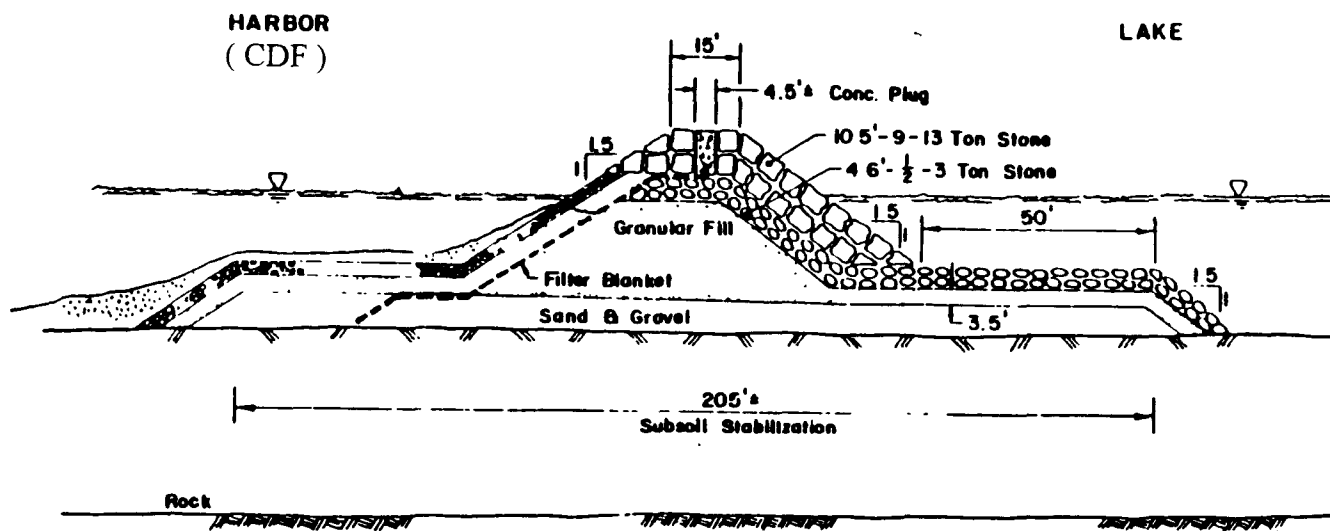
Construction of a vertical cutoff wall through a surficial marine sand layer requires the use of conventional sheet pile walls or placement of a dike section that can be penetrated by a driven or vibrated steel guide or mandrel. Such a penetrable dike section would be constructed of sands or sandy-gravels that lend themselves to slurry wall construction techniques or the use of a vibratory mandrel for insertion of the barrier sections. The Buffalo CDF dike section shown on Figure 6.3a may lend itself to both slurry wall and vibratory mandrel construction depending upon the grain size distribution of the granular fill making up the core.

## **6.2 Leachate Discharge to the Groundwater**

The possible flow of contaminated waters into the environment through the bottom of the CDF is site dependent. Shoreline CDFs may be located in areas of groundwater discharge such that groundwater flows into the CDF and limits outward leachate movement into the environment. For CDFs located where unacceptably contaminated leachate from dredged materials can move



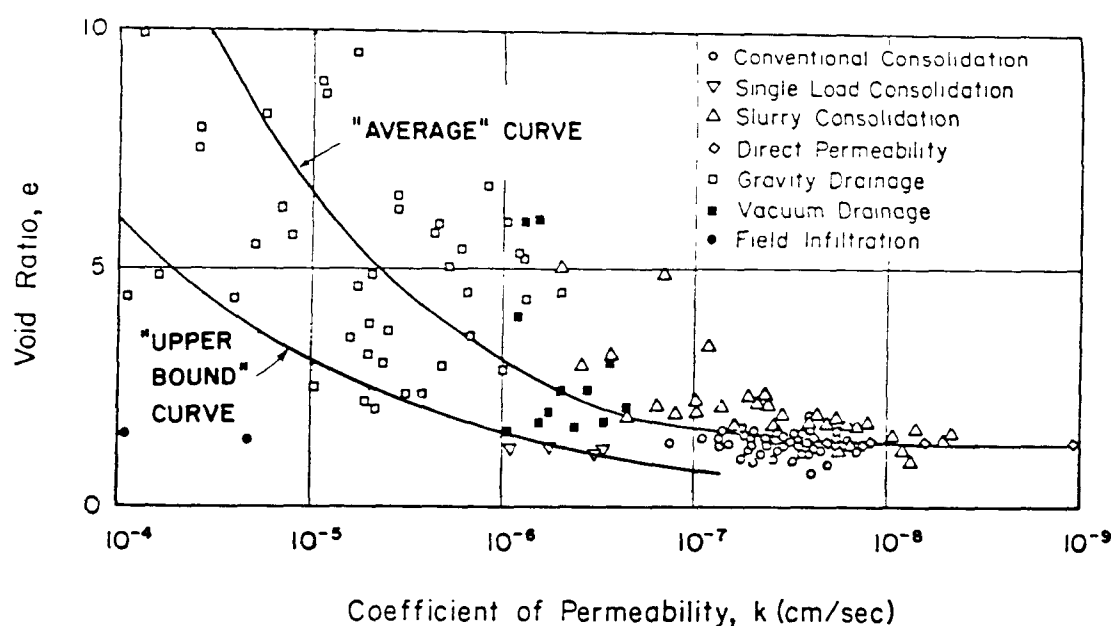
A. COE Buffalo CDF Dike Section



B. Clogged Filter Fabric Barrier

Figure 6.3 Alternative Dike Section Barrier

into the underlying soils, a barrier is required to seal the bottom. The basic barrier systems previously discussed in Section 6.1 can serve this function, with the exception of those appropriate only for vertical cut-off wall type systems. These barrier systems include compacted clay liners (CCL), geomembrane liners (GML), geosynthetic clay liners (GCL), clogged geotextiles, and graded soil filters. Figure 6.5 provides a guide to the selection of a barrier to limit the release of leachate.



( after Krizek and Salem, 1974)

Figure 6.4 Summary of Permeability Data for Toledo Dredgings

Construction of a bottom liner system in shoreline or in-lake CDFs would appear to significantly favor the use of a clean fine-grained slurry placed into the CDF initially to intentionally clog the native underlying soils. Extensive geotechnical data for dredged materials exists that clearly shows they are capable of achieving field permeabilities low enough to equal the other natural material barriers. Data shown on Figure 6.4 shows that dredged materials from the Toledo CDF can have long-term permeabilities less than  $1 \times 10^{-7}$  cm/sec. The actual permeability achieved is influenced by the plasticity of the dredged material and the loading that it experiences. This slurry could be hydraulically dredged silty sediments selected to seal the CDF and not specifically selected to meet a given dredging need. Operationally such a sealing layer would only require an initial dredging operation contract that is specific about the type of dredging to be performed (hydraulic), the type of sediments to be moved (fine grained), and a period of time for placement and limited consolidation of the sediments. Ongoing placement of sediments within the CDF increases the vertical effective stress acting on the sealing layer. This increase in vertical stress further consolidates the sealing sediments and reduces their permeability.

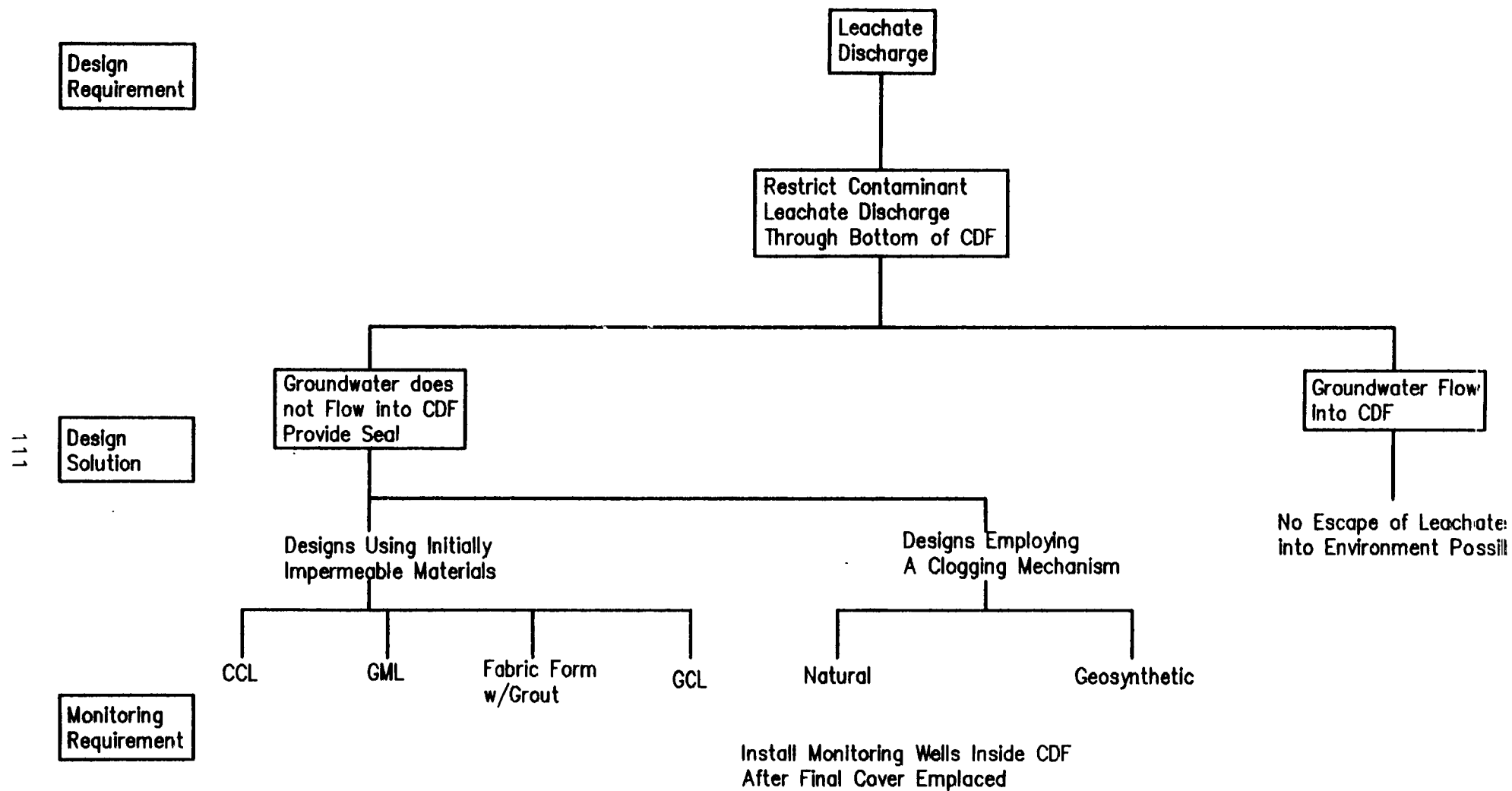


Figure 6.5 Leachate Discharge Control

### 6.3 Impoundment Basin Design Guide

The type of low permeable dike or ground water barrier required can be selected using Figure 6.6 based on criteria previously presented on Table 1.2. Such barriers are required if the concentrations or potential for partitioning of the contaminants to water are high. The economics of construction will favor those barriers commonly placed in nonaqueous site conditions. Such barrier layers include CCL, GCL, and GML systems. A dike barrier layer is required in shoreline or intake CDFs only if the WQS of the dike discharge exceeds applicable WQS beyond the zone of dilution. The zone of dilution should be estimated assuming random point discharge through the dike unless the designed dike section is specifically designed to prevent this occurrence.

A low-permeability barrier may be required between the dredged material and groundwater if both significant mobile contamination exists within the dredged material and significant potential for contamination of the groundwater exists. For example, a CDF sited on low-permeability glacial tills would not require a groundwater barrier even if the problematic dredged sediments were close to regulatory limits of contamination. This is applicable to all CDF types and ground water discharge/recharge zones.



<u>CDF Characteristic*</u>	<u>Dike Barrier Alternatives**</u>	<u>Groundwater Barrier Alternatives**</u>
Minimum Cont. in DM Minimum Potential Cont. of GW	UP-CCL,GCL,GML SL or IL – None Required	None Required
Minimum Cont. in DM Maximum Potential Cont. of GW	UP-CCL,GCL,GML SL or IL – None Required	UP-CCL,GCL,GML SL or IL – Layer of Clean, Fine Grained DM
Minimum Cont. in DM Existing Cont. of GW	UP-CCL,GCL,GML SL or IL – None Required	None Required
Maximum Cont. in DM Minimum Potential Cont. of GW	UP-CCL,GCL,GML SL or IL – WQS OK – None Required WQS Exceeded – See Table 6.1	None Required
Maximum Cont. in DM Maximum Potential Cont. of GW	UP-CCL,GCL,GML SL or IL – WQS OK – None Required WQS Exceeded – See Table 6.1	UP-CCL,GCL,GML SL or IL – Layer of Clean, Fine Grained DM
Maximum Cont. in DM Existing Cont. of GW	UP-CCL,GCL,GML SL or IL – WQS OK – None Required WQS Exceeded – See Table 6.1	None Required

\* Cont = Contamination  
DM = Dredged Material  
GW = Ground Water

\*\* UP = Upland CDF, SL = Shoreline CDF, IL = Inlake CDF

Figure 6.6 Impoundment Basin Design Guide

## SECTION 7

### INTERIM AND FINAL CLOSURE OF CDFs

The role played by the interim and final covers of a CDF is heavily dependent upon the nature of the contaminant(s) of concern, particularly its partitioning potential, and the type of CDF environment. For example, acidic rains common to the midwest can leach metals from the sediments and mobilize them. Specific design objectives for the cover must therefore consider the potential partitioning of the contaminants present, the impact of precipitation generated infiltration and run-off, and the long-term environment at the CDF. The need for a "hydraulic isolation" cover can be based on the criteria previously discussed in Section 1, see Table 1.2, and on AEPP criteria presented in Section 2.

The cover system selected for a CDF can influence all of the contaminant pathways that have been evaluated in this document, with the exception of the effluent discharge during filling operations. As such, the design of a cover system for a CDF must focus on minimizing the impact of such pathways when required. It is assumed in this document that final CDF covers will be constructed above adjacent water surfaces, e.g. no submarine final covers are considered. However, permit reviewers should consider the full operational life of the CDF and ensure that the need for interim covers/pathway control is evaluated. This is particularly important in proposed hybrid sitings of CDFs that would couple the CDF design with the remedial needs of the proposed disposal site. Figure 7.1 lists cover related pathway control systems.

Cover systems must also be designed to ensure low maintenance, be easily monitored, and be economical to construct. Final covers are placed once the CDF is full and the dredged material is stable enough that future settlements will not damage the cover. Interim covers may be required when the facility is either inactive for a prolonged period of time or when the dredged material is unstable and future subsidence could impair the function of a final cover. This section reviews the existing cover criteria used by USACE and EPA for CDFs or waste containment systems and concludes with a review of alternate cover systems that use geosynthetic components and/or sediment disposal strategies.

#### 7.1 USACE Closure Objectives

The long term use for a CDF closure is commonly selected by the local sponsor. Local sponsors are typically a City, County, or State governmental agency. The local sponsor is required to provide all lands, easements, and rights of way to the USACE for the CDF. Under the Diked Disposal Program (PL 91-611, Section 123) for constructing CDFs on the Great Lakes a local government sponsor is required. The local sponsor may have planned or implemented productive and beneficial uses for CDFs. These uses include the development of recreational areas, new or expanded marinas, wildlife refuges, etc. The planned development must be compatible with the structural integrity of the facility and the types of sediments contained. These lands cannot be transferred from the local sponsor without the approval of the USACE. In recent years, the USACE has phased out the construction

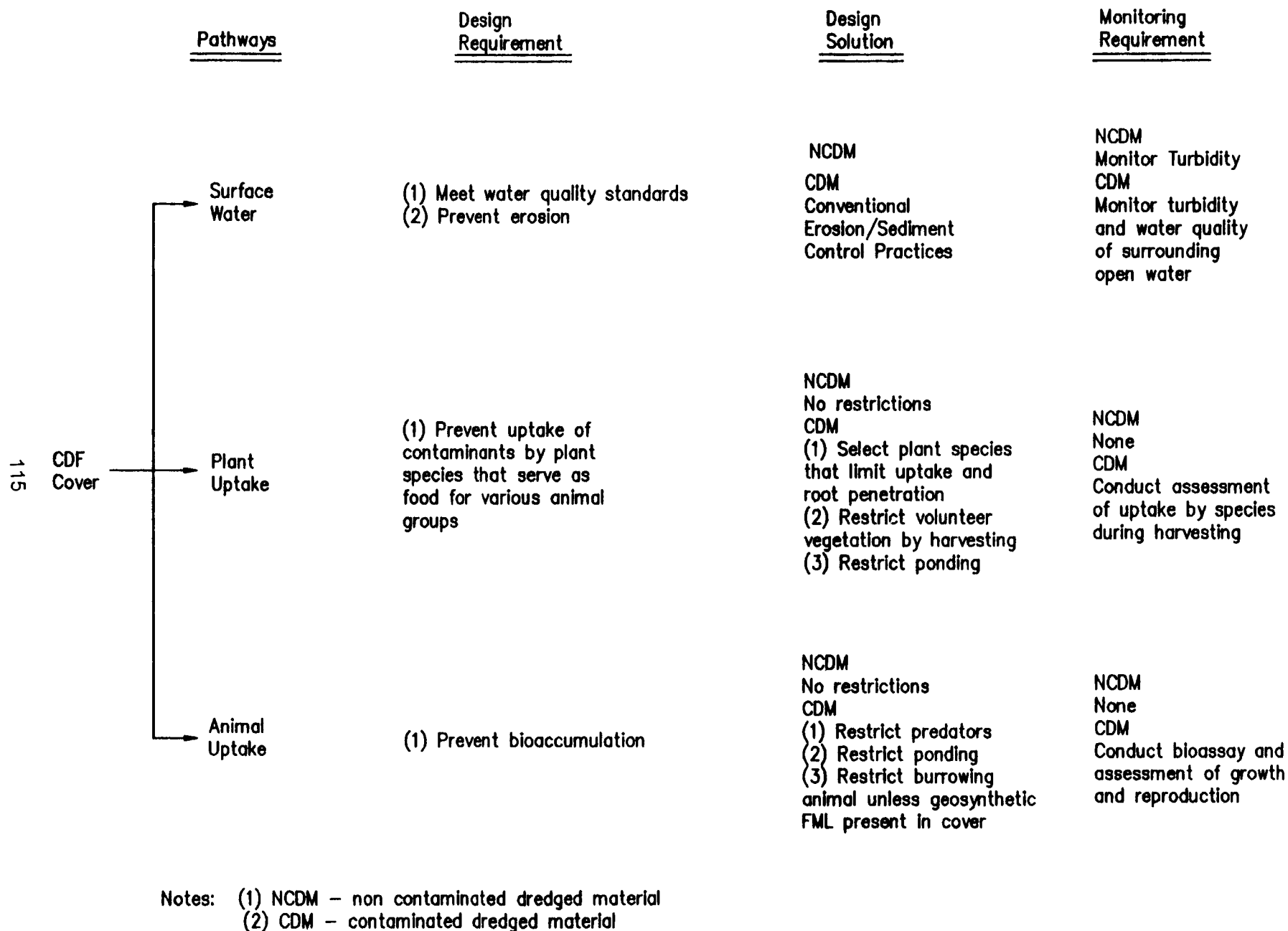


Figure 7.1 Cover Related Contaminant Pathway Control

of CDFs under the authority of PL 91-611. Future maintenance dredging will, however, still require confined disposal. Future CDFs will be constructed under the operation and maintenance (O and M) authorities of individual navigational projects. The extent of local participation and cost-sharing for such projects will vary on a project by project basis. A summary of filled CDFs with local sponsor, cap design, and intended use is given on Table 7.1. A review of this table illustrates that closure procedures are very site specific. Additionally, unlike a typical upland landfill, a CDF does not typically receive either a temporary cover or removable cover during the actual sediment placement operation. Final uses of the CDFs range from wildlife habitats to municipal landfill sites.

Current USACE design guidance for CDFs (EM 1110-2-5027) is to maximize the volume of CDF available for sediment disposal by promoting consolidation and drying of the contained dredge materials. Interim soil covers are not typically used because they are difficult to install, interfere with the drying process and reduce storage capacity.

## **7.2 EPA Closure Objectives**

The USACE has played a significant role in the development of the current EPA hydraulic isolation based closure programs under RCRA. The USACE involvement has ranged from assistance in the development of design guidance documents ( e.g. EPA, 1979 ) to development and continued support of the HELP (Hydrologic Evaluation of Landfill Performance) computer model. The HELP model evaluates the effectiveness of hydraulic barriers and has played a major role in the EPA closure program. This USACE technical assistance in establishing EPA closure criteria should aid in establishing applicable closure technologies for CDFs.

### **7.2.1 RCRA Subtitle C Hazardous Waste Landfills**

A significant impetus in the development of the basic EPA cover system resulted from the need to meet requirements for RCRA facilities and Superfund sites under RCRA 40 CFR 264.310. Such covers are applicable for the worst-case sediments identified previously on Table 1.2. RCRA specifies that a final cover be designed and constructed to:

- 1) promote long-term minimization of liquids migration through the closed cap;
- 2) function with minimal maintenance;
- 3) promote drainage and minimize erosion or abrasion of the cover;
- 4) accommodate settling and subsidence so that the cover's integrity is maintained; and
- 5) have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

**Table 7.1 - Summary of Closed CDFs in the Great Lakes (adapted from EPA, 1990)**

<b>Facilities</b>	<b>Years of Operation</b>	<b>Capacity (cubic yards)</b>	<b>Local Sponsor</b>	<b>Cap Design</b>	<b>Ultimate Use</b>
Cleveland Dike #12	1974-1979	2,760,000	Cleveland-Cuyahoga County Port Authority	None	Waterfront Development
Small Boat Harbor, Buffalo	1968-1972	1,500,000	Niagara Frontier Transportation Authority	6 ft of soil	Wildlife area/parking
Toledo (Grassy Island)	1967-1978	5,000,000	Toledo-Lucas Port Authority	None	Wildlife/recycle as top soil
Michigan City	1978-1987	50,000	City of Michigan City	Clay cap with top soil cover	Park Land ( <i>now undetermined</i> )
Bayport (Green Bay)	1965-1979	650,000	City of Green Bay	City of Green Bay plans to cap site	Industrial development/marine terminal facility
Clinton River	1978-1990 (98% filled)	370,000	State of Michigan	Clay	Public access site and MDNR field station
Frankfort Harbor	1982-1990	30,000	State of Michigan	Site to be seeded when completed	Cherry orchard
Grassy Island (Detroit River)	1960-1984	4,320,000	none, U.S. Fish and Wildlife Service owns land	none	Wildlife area

Table 7.1(Continued) - Summary of Closed CDFs in the Great Lakes (EPA, 1990)

Facilities	Years of Operation	Capacity (cubic yards)	Local Sponsor	Cap Design	Ultimate Use
Harbor Island (Grand Haven)	1974-1985	310,000	State of Michigan	none	Public use
Harsen's Island	1975-?	100,000	State of Michigan	restored to former soil level and revegetated	Upland nesting habitat for waterfowl
Kawkawlin River	n/a	n/a	Bay County, MI	none	n/a
Kidney Island (Green Bay)	1979-1986	1,200,000	City of Green Bay	none	Wildlife habitat
Monroe (Edison)	-1984	n/a	n/a - private site	none	Detroit Edison
Port Sanilac Village	1979-1983	143,300	Village of Port Sanilac	none	Municipal Landfill
Verplank	1974-n/a	134,000	Verplank Coal and Dock Company	none	Not available
Whirlpool (St. Joseph Harbor)	1978-1990	25,000	State of Michigan	none	n/a
Windmill Island	1978-1988	160,000	State of Michigan	none	Park facility

USACE assisted in preparing a technical guidance manual for EPA to assist in implementation of the RCRA requirements (EPA, 1985).

Under RCRA guidance, final covers as a minimum include a vegetated top cover, a middle drainage layer, and a composite barrier that consists of a geomembrane over a 2-ft clay layer. The vegetated layer must minimize the impact of erosion on the cover. The middle drainage layer serves to reduce the hydraulic head acting on the barrier system, and the composite barrier prevents infiltration of surface waters to the waste. The minimal cover configuration is shown on Figure 7.1a.

Supplemental layers to the RCRA cover were proposed by USACE to provide for the collection and removal of gases generated by the waste, and for biotic barriers to prevent intrusion into the cover by burrowing animals. The full RCRA cover with these supplemental layers is shown on Figure 7.1b. EPA has issued final Minimum Technical Guidance (MTG) on RCRA covers (EPA/530/SW-89/047) that agree with the above USACE interpretation.

### **7.2.2 RCRA Subtitle D Non-Hazardous Waste Landfill Covers**

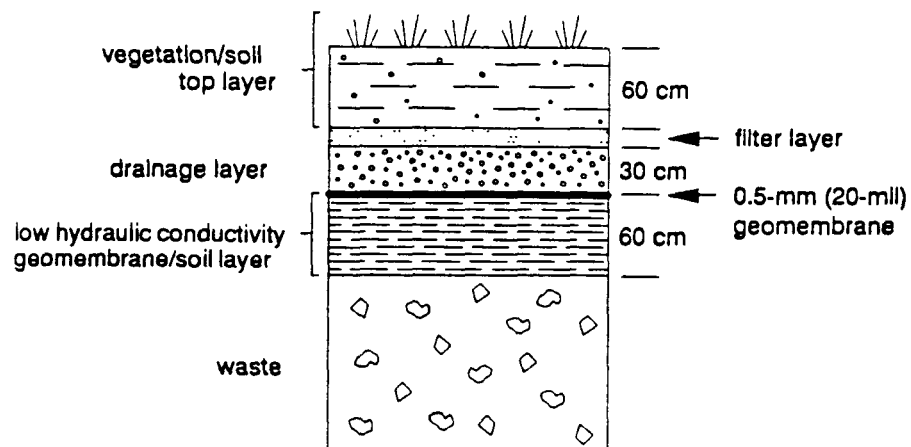
EPA closure criteria for RCRA-D nonhazardous waste landfills were established on October 9, 1991. The promulgated regulations require that final covers for non-hazardous waste landfills have a permeability less than or equal to the liner or natural soils beneath the waste. A minimal cover under RCRA-D for an existing unlined facility consists of the following:

- a 6-inch layer of top soil with vegetation; and an
- 18 inches of  $10^{-5}$  cm/sec soil infiltration layer.

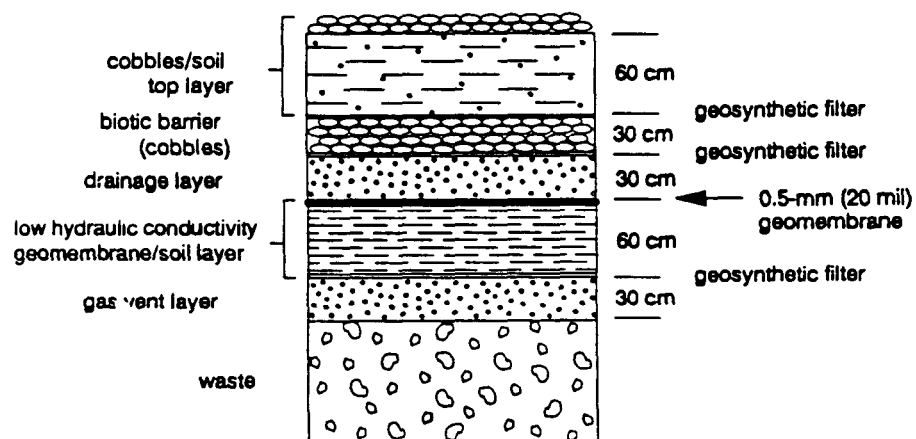
Such a cover profile may be appropriate for problematic sediments having moderate partitioning potential, see Table 1.2. For covers over landfills incorporating a composite liner, EPA has recently (Federal Register June 26, 1992) interpreted the closure criteria to simply require a geomembrane if a geomembrane is used in the liner system. Covers incorporating a composite barrier including a geomembrane are suitable for sediments having extensive partitioning potential, see Table 1.2. Thus a landfill that uses a liner barrier layer consisting of a geomembrane over a 2-ft clay layer having a permeability less than  $1 \times 10^{-7}$  cm/sec would only need a cover having a barrier layer consisting of a geomembrane over 18-inch of  $10^{-5}$  cm/sec soil.

The Subtitle D landfill cover for previously developed unlined landfills represents EPA's perspective on what minimum waste containment should include. The soil cover layer has a minimum thickness of 6-inches but must also be adequate to support required vegetation. This normally requires the use of substantially more than a 6-inch soil layer to achieve. The adequacy of the top soil layer must be verified using a long-term water balance model such as the HELP model developed by USACE for EPA (Schroeder, 1987, 1988, 1990).

### **7.2.3 Additional Regulatory Closure Criteria**



#### A. RCRA-C Minimum Technology Guidance Cover



#### B. RCRA Minimum Technology Guidance Cover With Supplemental Layers

Figure 7.2 EPA RCRA-C Final Cover Guidance



The low infiltration RCRA covers described in the previous two sections are required for facilities receiving waste that is typically recently generated. Covers for the closure of in-situ wastes have shown considerably more flexibility. This same flexibility may be appropriate for CDF closures since sediment contamination is typically both at very low concentrations and due to a historic event(s).

CERCLA closures comply with RCRA ARARs but vary significantly depending upon the potential exposure of the waste to either the groundwater or humans. This exposure concept is illustrated in Figure 7.3. Required CERCLA closures range from the full RCRA MTG cover for sites having a significant exposure of groundwater and humans, to a no action alternative for sites having no groundwater or human exposure potential (EPA/540/P-91/001). Such a risk-based cover selection is consistent with pathway control based design discussed in this document.

Under TSCA (40 CFR 761.65), a written closure plan for a PCB storage facility must be submitted and accepted by an EPA Regional Administrator. Closure criteria for chemical waste landfills used for disposal of contaminated soils with PCB concentrations equal to or greater than 50 WP (40 CFR 761.75) does not provide specific closure criteria. Within Region 5, the RCRA-C minimum technology closure guidance is commonly used as a basis for selecting the closure design components for TSCA facilities.

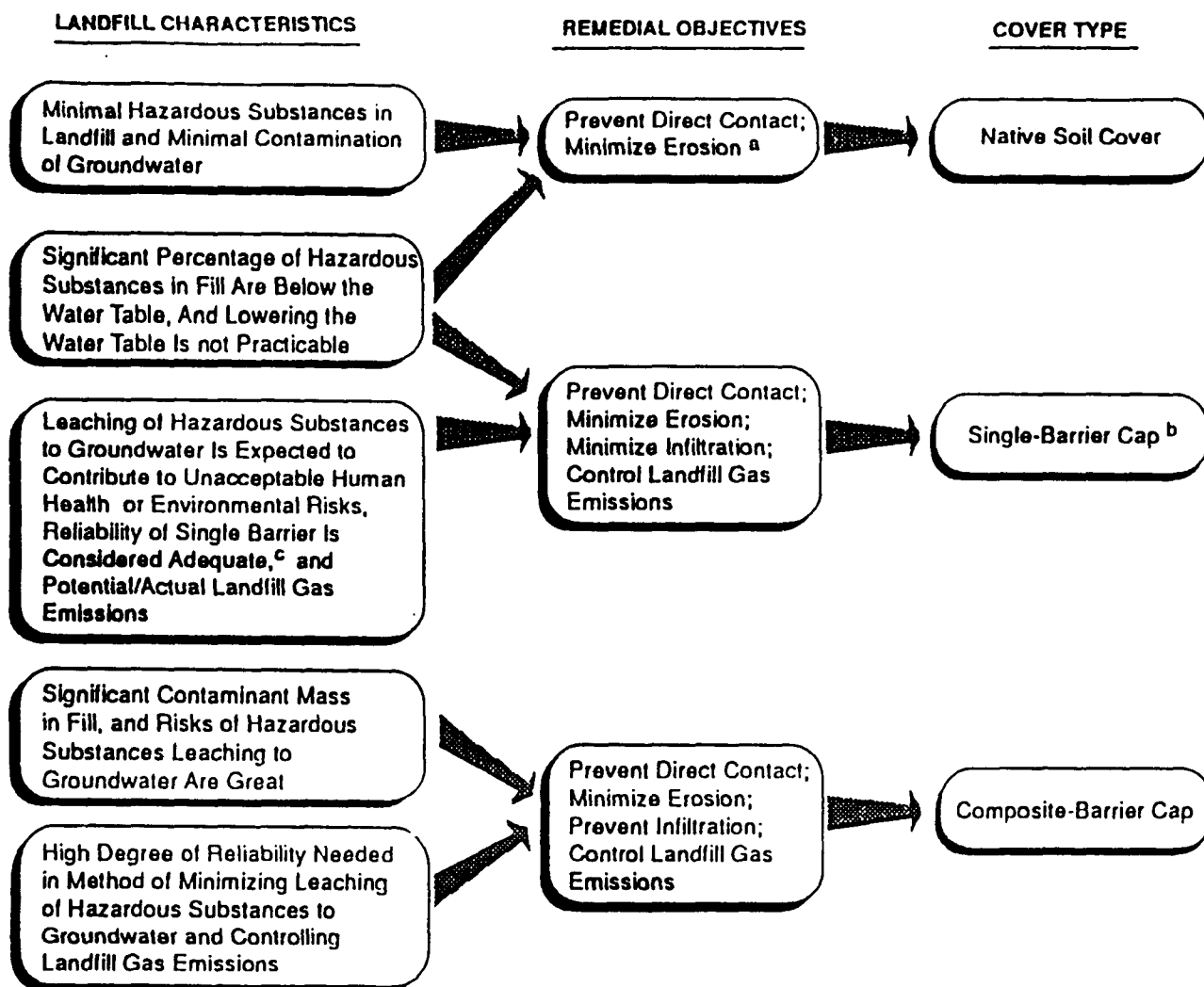
### **7.3 Design of Closures for CDFs**

Based on Table 7.1, existing closure of CDFs is commonly achieved by seeding grass or allowing volunteer vegetation to germinate in the last lift of dredged materials placed in the CDF. Typically, dredged materials are rich in phosphorous, nitrogen, and potash which promote rapid growth of vegetation. Only a limited number of closed CDFs incorporate a clay barrier layer in the cover. Only the Michigan City CDF cover has both a clay layer and a surface top soil layer. This section presents basic design concepts for closures that may be required when problematic dredged sediments are present.

#### **7.3.1 Barrier Layer Design**

For covers over contaminated dredged materials, the primary function of the closure is to limit the infiltration of precipitation and surface water run-on/off into the contaminated materials. A layer can be made to function as a barrier either due to its low permeability relative to the adjacent layers or as part of a water-balance system that balances infiltration and evapotranspiration. The design of the barrier layer must provide the following:

- A cover with a permeability less than or equal to that of the liner system placed beneath the dredged materials. This is to prevent a long-term buildup of water within the waste. Note that water-balance systems are not evaluated using this criteria since their performance is more related to vegetation induced evapotranspiration.



<sup>a</sup> Primary objective is to prevent direct contact, although the soil cover can be designed to reduce infiltration.

<sup>b</sup> Single-barrier caps may include additional layers that provide protection to that barrier.

<sup>c</sup> Examples include situations where infiltration is not the primary concern and may include sites containing a small volume of contaminant mass, regions with low annual precipitation, or sites where groundwater is not being used as a source of drinking water.

(EPA/540/P-91/001)

Figure 7.3 EPA CERCLA Landfill Cover Selection Guide

- Sufficient flexibility in the cover system to accommodate long-term settlements of the dredged materials.
- A design life that exceeds the projected life of the mobile contaminants.

Design considerations for barrier layers are presented in this section.

**Permeability Barrier ----** Low permeability barrier layers are typically constructed using compacted clay layers, geomembranes, geosynthetic clay layers, or a composite barrier consisting of a geomembrane over a compacted clay layer. The flow of water through a well constructed clay barrier is controlled by the permeability of the clay and the hydraulic gradient acting on the clay (Darcy's Law). Reduction in infiltration through this clay barrier requires either 1) reducing the permeability of the clay with admixtures or 2) reducing the hydraulic gradient by decreasing the height of water standing on the barrier or increasing the barrier thickness. Compacted clay layers must be protected against both desiccation and freezing to maintain their low permeability (Zimmie, 1990). In Region 5, this can require a minimum of 4 feet of soil cover over the clay barrier.

Flow through a geomembrane cover can be by diffusion of the liquid through the liner (Fick's First Law) or flow through holes or defects in the membrane. For most geomembranes, the rate of diffusion of liquids is very low. Significant flow can occur, however, through a hole in the membrane. Assuming a very permeable layer exists beneath the geomembrane, the flow through a defect in the geomembrane is given by (Giroud and Bonaparte, 1989) the equation:

$$Q = C_B a (2gh)^{0.5}$$

where Q is the flow rate (m<sup>3</sup>/s); C<sub>B</sub> is the flow coefficient with a value of approximately 0.6; a is the area (m<sup>2</sup>) of the hole; g is the acceleration due to gravity (9.81 m/s<sup>2</sup>); and h is the head (m) of water over the geomembrane. For example, for a single hole having an area of 1 cm<sup>2</sup> (0.0001 m<sup>2</sup>) acted on by a 30 cm head, the flow through the hole in a single day is 12,491 liters (3300 gallons).

A composite barrier reduces the flow rate through geomembrane penetrations by backing up the geomembrane with a low permeable soil layer. The flow through a hole in the geomembrane reduces to the following equation:

$$Q = 0.21 h^{0.9} a^{0.1} k_s^{0.74}$$

where k<sub>s</sub> is the permeability of the underlying soil. For the case of the 1 cm<sup>2</sup> hole having 30 cm of head acting on the geomembrane and backed by a soil with a permeability of 1x10<sup>-7</sup> cm/sec, the flow rate reduces to 0.06 liters/day (.016 gal/day). This is a dramatic reduction from the geomembrane alone.

**Water-Balance Barrier** ---- Infiltration through a water-balance barrier is minimized using a layered system that limits the penetration depth of infiltration while providing for maximum evapotranspiration removal of the infiltration. While the performance of the permeability barrier is wholly dependent upon the integrity of the barrier layer, the long-term performance of the water-balance system is dependent upon both its initial design and the maintenance of vegetation to provide evapotranspiration, and the weather. A water-balance cover layer currently proposed for long-term isolation of mixed wastes is shown on Figure 7.4. The upper layer of the cover is designed to support vegetation and to provide sufficient hydraulic storage capacity that infiltration during the wettest season will not saturate the system. The depth of penetration for the infiltration is limited to the upper layer using a physical phenomena referred to as "Richards Effect". The "Richards Effect" is due to capillary tension retaining the moisture in the fine grained surface layer. By placing a coarse grained layer (e.g. coarse sand or gravel) beneath the fine grained surface layer, infiltration will not move out of the surface layer until the surface layer is saturated and the surface tension overcome.

The long-term performance of a water-balance cover is therefore dependent upon the following:

- Providing sufficient hydraulic storage capacity in the upper layer to store maximum projected infiltration without saturating the layer;
- Planting and maintaining sufficient vegetation on the cover to remove, via evapotranspiration, moisture held in the upper layer; and
- Limiting the depth of infiltration penetration through the Richards Effect.
- Stability of the weather pattern.

For CDFs, the upper barrier layer could be constructed using clean, fine-grained dredged materials. The lower, coarse layer could be constructed using dredged materials composed of coarse sand. Site specific evaluation of a water-balance cover can be done within Region 5 using the HELP computer model previously discussed.

**Settlement Criteria** ---- The barrier layer must be able to conform to settlements of the sediments and still function. As with settlement criteria of engineered structures, the most significant challenge to the barrier layer is due to large differential settlements that occur over relatively short lengths. In conventional landfills the design model for differential settlement might be the development of a void immediately beneath the cap due to the rusting out of a refrigerator, etc. Large differential settlements within a CDF are not anticipated unless zones of dredged materials having significantly different properties are present. An example would be a zone of clam shell excavated sediments having high unit weights surrounded by low strength and density hydraulic-dredged material. Normal density gradients associated with hydraulically-placed sediments should not impact the performance of the barrier layer. An additional zone of potential high differential settlements occurs

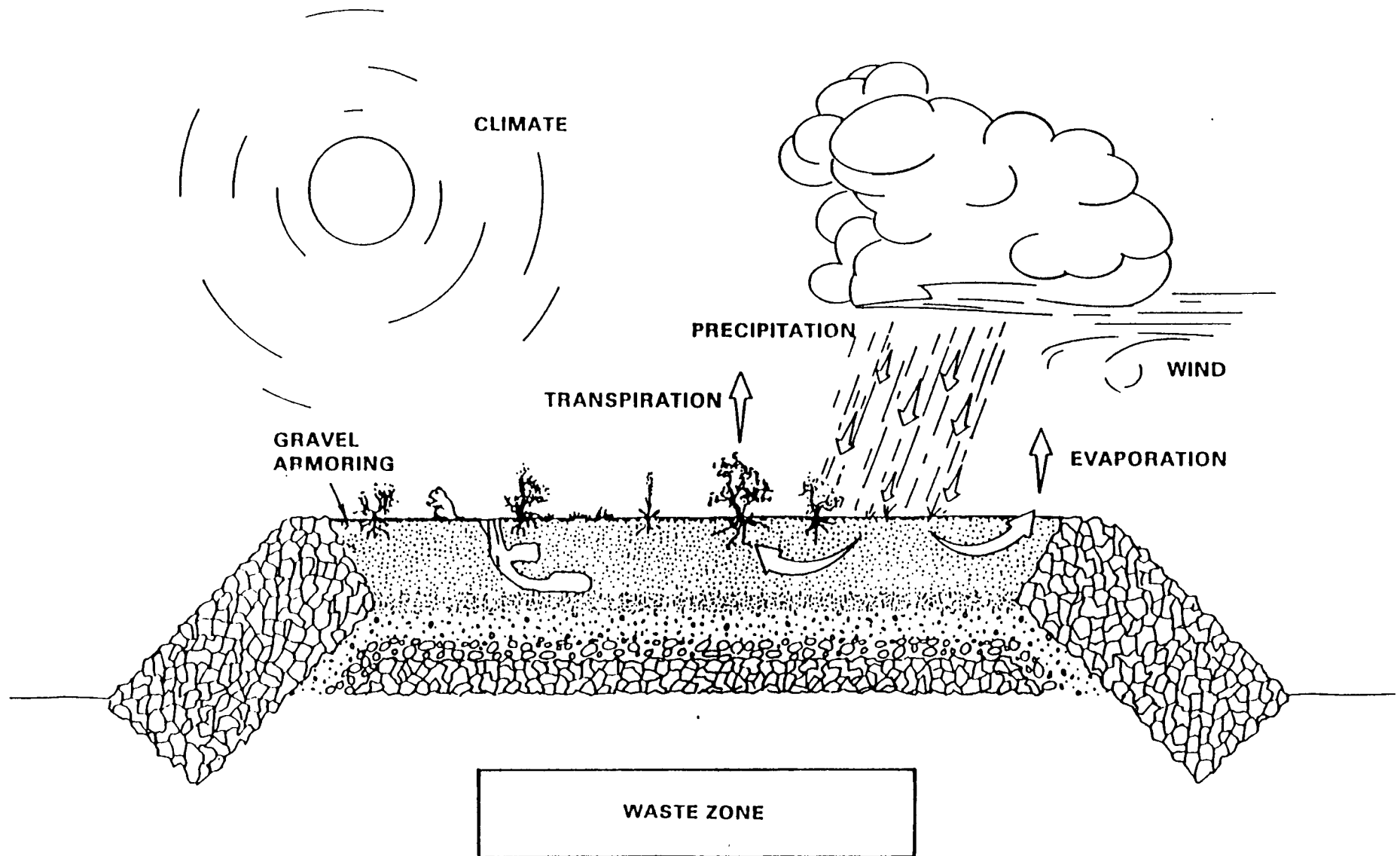


Figure 7.4 DOE Water-Balance Cover

at the perimeter of the CDF where the soft compressible sediments are deposited directly against the containment dikes. If the barrier layer extends over the dikes, then it must bridge large localized zones of differential settlements that occur between the rigid dikes and the softer dredged material.

Research into allowable differential settlements for barrier layers has been performed by COE for EPA (Murphy and Gilbert, 1987). Figure 7.5a shows the strain in the barrier elements as a function of localized differential settlements. Common geomembranes such as high density polyethylene (HDPE) can tolerate less than 10% of such biaxial strains prior to failure. Compacted soil liners have an even lower tolerance for strains from differential settlements. Figure 7.5b shows ultimate tensile strains in soils before formation of cracks verses their plasticity index. The ultimate tensile strain for typical soil liners prior to failure will be typically less than .25%. Composite liners using a conventional compacted soil layer are not recommended for zones of high differential settlement.

### 7.3.2 Surface Water Control Layer Design

Precipitation run-off from the CDF cover must meet water quality standards (see AEPP criteria in Section 2.2.2) and should not produce excessive erosion of the cover. Each of these two design criteria require an independent design evaluation.

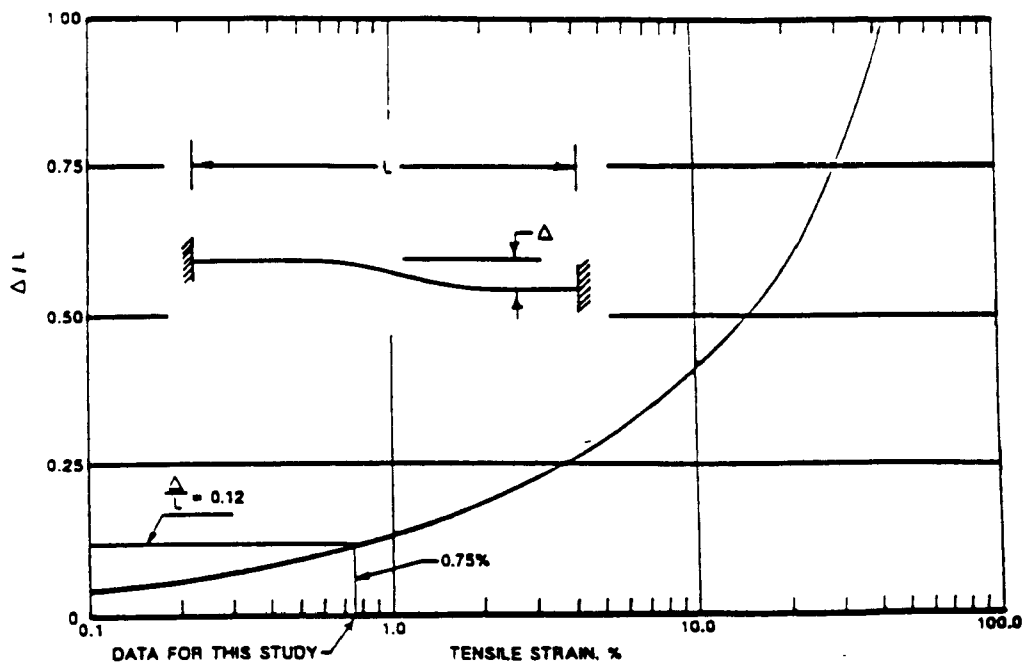
The water quality of the run-off will be a function of the contaminants available in the sediments and the partitioning capacity of the water. If field or laboratory tests (Lee, 1991) indicate a water quality problem due to the contaminants in the sediments, then either the contaminants in the run-off must be removed, or the contaminants in the dredged material must be chemically fixed (see Appendix A), or the sediment must be isolated from the run-off by a cover barrier layer.

The surface erosion potential of CDF covers is typically low because of the small slopes associated with these covers and the reality that the cover is still contained at the perimeter by the CDF dikes. These geometric constraints for the cover are the result of the initial low shear strength of dredged materials placed with the CDF. However, the erosion potential is increased due to the silty nature of much of the dredged materials. Based on criteria developed for RCRA/CERCLA final covers (EPA, 1991a), the annual soil loss from erosion must be limited to less than 2 tons/acre/year.

Annual soil loss due to erosion is estimated using the Universal Soil Loss Equation (USLE) given by

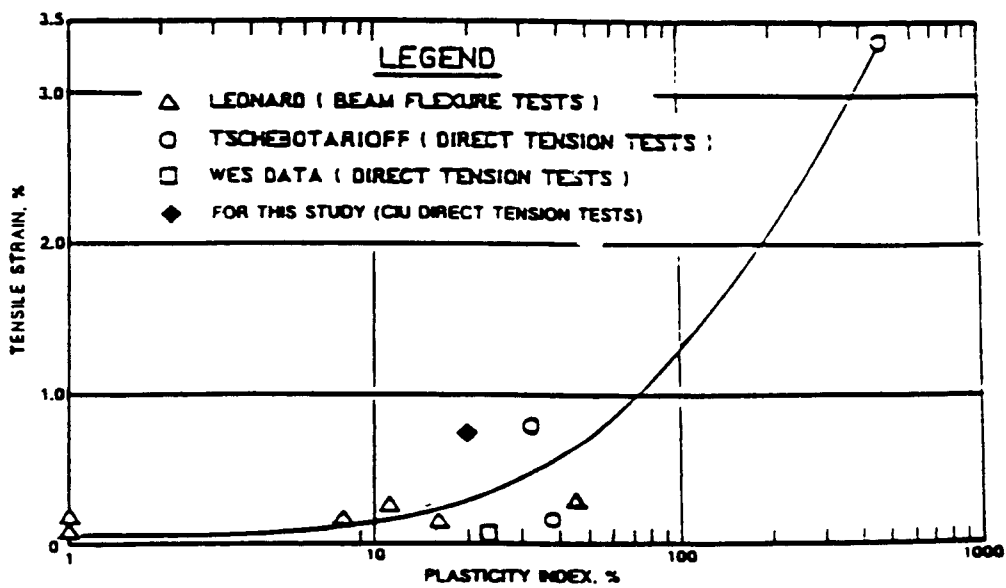
$$A = R K L S C P$$

where      R = Rainfall and Run-Off Index,  
              K = Soil Erosion Factor,  
              LS = Slope Constant,  
              C = Crop Management Factor, and  
              P = Field Practice Factor.



Index of maximum settlement  $\Delta/L$  vs tensile strain (after Gilbert and Murphy, 1987)

### A. Strain vs. Differential Settlement



Tensile strain vs plasticity index (after Gilbert and Murphy, 1987)

### B. Ultimate Strain vs. Plasticity for Clays

Figure 7.5 Soil Barrier Performance

### 7.3.3 Airborne Emissions Control Design

As discussed in Section 5.3, air borne contaminant emissions from a CDF result from the direct volatilization of contaminants to the atmosphere and as the result of wind erosion of contaminated surface sediments. Control of airborne emissions to satisfy the AEPP criteria developed in Section 2.2.7 is required during the interim operational phase of the CDF and during the post-closure life of the CDF. Such air borne emissions control requires both specific operational practices and design considerations.

Thibodeaux (Brannon, 1990) identified four primary vapor phase emission pathways related to dredged materials as follows:

- during sediment handling while dredging;
- from sediments devoid of vegetation and exposed and drying;
- from that portion of the CDF that contains surface water; and
- from sediment that is covered with vegetation.

The greatest volatile emissions are thought to occur when the CDF is receiving dredged materials and when the dredged material is exposed to the air. The volatilization of contaminants occurs prior to closure of the CDF from dredged materials that are devoid of vegetation, exposed above the surface water level, and drying. Two operational practices can be used to limit volatilization losses prior to closure: (1) maintain the surface of the confined dredged material below water, or (2) place a layer of clean soil or dredged material on the surface of the contaminated material. The selection of a clean material for use as a volatilization barrier must also consider wind related soil particle loss (see discussion of PM-10s in Section 5.3). It is important to remember that air borne emissions include both volatilized chemicals and wind blown particulate matter.

From the long-term final cover design perspective, the control of airborne emissions may include filtering emissions from gas venting systems. The need for a gas venting system in the final cover must be evaluated for each CDF. In conventional RCRA C and D landfill closures, a gas collection layer and venting system, see Figure 7.2b, is commonly provided in the final cover to minimize the build up of gases within the waste. Proposed air quality regulations, see Section 5.3, may require processing of vented gases to limit the quantity of non-methane organic compounds (NMOC). Such regulations are focused on MSW landfills that, by the very nature of household wastes, contain significant quantities of organic materials. Such high levels of organic wastes degrade and even produce commercially attractive quantities of gas. Dredged materials, however, are primarily composed of inert solids containing lesser amounts of volatile organics. Additionally, gas venting systems are used to limit the lateral movement of waste generated gases. Such lateral movements of gas have posed a significant danger to structures adjacent to landfills. Thus the need for a gas venting system must consider the gas generating potential of the dredged sediments and the potential exposure of adjacent structures.



Limiting the long-term wind blown loss of particulate matter may require design considerations that are subtly different than required for water related erosion. The large, flat final covers associated with CDFs do not promote water run-off erosion but are ideal for wind blown loss of particulate material. The final cover design must therefore ensure that a healthy vegetated surface layer survives or must incorporate a surface layer of soil having a grain size distribution that limits wind blown erosion.

#### **7.3.4 Plant and Animal Uptake Control Design**

The need for control of contaminant uptake by plants or animals is dependent upon both the degree of contamination in the dredged material, operational practices during the active life of the CDF, and the presence of a barrier layer in the final cover. Plant and animal uptake potentials can be estimated using the BioConcentration Factors (BCF) discussed in Sections 5.2.1 and 5.2.2 and presented in Tables 5-1 and 5-2. The acceptable levels of uptake or AEPP can be determined from Section 2.2.3 for plants and Section 2.2.4 for animals. A dredged material containing a contaminant that has a high BCF may require measures to be incorporated in operational procedures, and into the final cover to restrict the exposure of animals via the food chain. Operational measures to restrict plant and animal uptake may include placing an interim clean layer of dredged material over the problematic dredged material and the elimination of surface depressions that form ponds. The effectiveness of a clean buffer layer to limit uptake, e.g. its minimum required thickness, must be validated using laboratory bioassay tests like those shown on Figures 2-7 and 2-8.

Control of plant uptake of contaminants from CDF sediments can be accomplished by the critical selection of plant species and/or the control of root penetration. Work by (Lee, C.R. et al, 1991) has shown that many grasses are selective in their ability to uptake contaminants such that plant uptake can be limited by correctly matching sediment contaminant presence and availability to plant intake preference. The long-term success of such an approach, however, is limited by the degree of invasion by volunteer vegetation. Limiting the growth of trees and grasses with more aggressive root systems requires long-term maintenance of the cover. Tree growth is best limited by annual mowing of the cover. Such practices are not commonly part of historical CDF closure plans.

To minimize long-term maintenance requirements, covers need to be designed to limit root penetration of volunteer trees, large shrubs, and many wild grasses. Root penetration can be limited by the use of a geomembrane or a herbicide-impregnated geotextile. The geomembrane provides a simple physical barrier to the roots (and moisture infiltration) at a typical installed cost of \$0.30 to \$0.70 per square foot. The herbicide barrier kills the plant to limit root penetration but cost \$2.00 to \$2.80 per square foot. Having a service life of less than 20 years and significant cost, the herbicide barrier may be suitable only for limited applications where water flow must be allowed but root penetration limited.

Designed control measures to limit animal uptake of contaminants must reflect the level of long-term maintenance of the cover and the nature of the contaminants. Ponding of water on the interim and

final covers must be prevented to limit a potential chain that can uptake contaminants. In the case of surface ponds, fish within the ponds readily uptake metals from adjacent sediments and provide a vehicle for contaminant movement up the food chain. If ponds are proposed on a cover, then a barrier system could be incorporated between the pond water and the dredged material if necessary.

Long-term maintenance may require that animals be limited to grazers who do not burrow. The presence of grazers should be restricted (fencing, etc.) if plant intake of contaminants is possible. Ongoing work by the Department of Energy ( Landeen, 1990 ) has shown that burrowing animals can readily penetrate 3-meters into a cover but do not penetrate even flexible geomembranes.

A low permeability layer may be incorporated into the final cover system for other closure objectives, e.g. to limit infiltration. The presence of a soil or geomembrane low permeable layer in the final cover will limit the uptake of contaminants by plants or animals by restricting access of roots or benthic organisms to the dredged materials.

#### **7.4 CDF Final Cover Selection Guide**

The final closure objectives and final closure component design considerations previously discussed in this Section are consolidated to the CDF cover selection guide shown on Figure 7.6. Six scenarios are used to characterize a CDF based on three criteria: 1 - level of contamination in the dredged material (minimum(less than problematic) or maximum (problematic)), 2 - the potential for contamination of the groundwater underlying the CDF. The six CDF characteristics scenarios can be reduced to four distinct groupings of final closure objectives as shown on Figure 7.6.

Closer examination of the individual final closure objectives shows that they are not independent objectives. For example, placement of a barrier layer in the cover to limit infiltration will also limit air emissions and plant or animal uptake. This overlap of closure objectives allows the potential final cover profiles to be reduce to only three in number. These three cover profiles are shown on Figure 7.6. All three cover profiles incorporate a surface layer of vegetated dredge material to reduce surface erosion. Such erosion is suspected to be very limited due to the flat topography that characterizes the placed CDF waste.

Two of the final cover profiles utilize a layer of clean dredged material. In one profile, a clean dredged sand is used to provide infiltration storage capacity so that the erosion limiting plants will survive droughts. The thickness of the sand layer is evaluated based on water balance criteria to ensure the availability of moisture to plants during times of drought. The water balance evaluation can be performed using EPAs HELP (Hydrologic Evaluation Landfill Performance) computer model. The remaining clean dredged material cover uses low-permeability dredge material that forms a low permeability barrier layer to limit infiltration, air emissions, and plant or animal uptake. The thickness of this layer must be greater than required by any of the criteria.

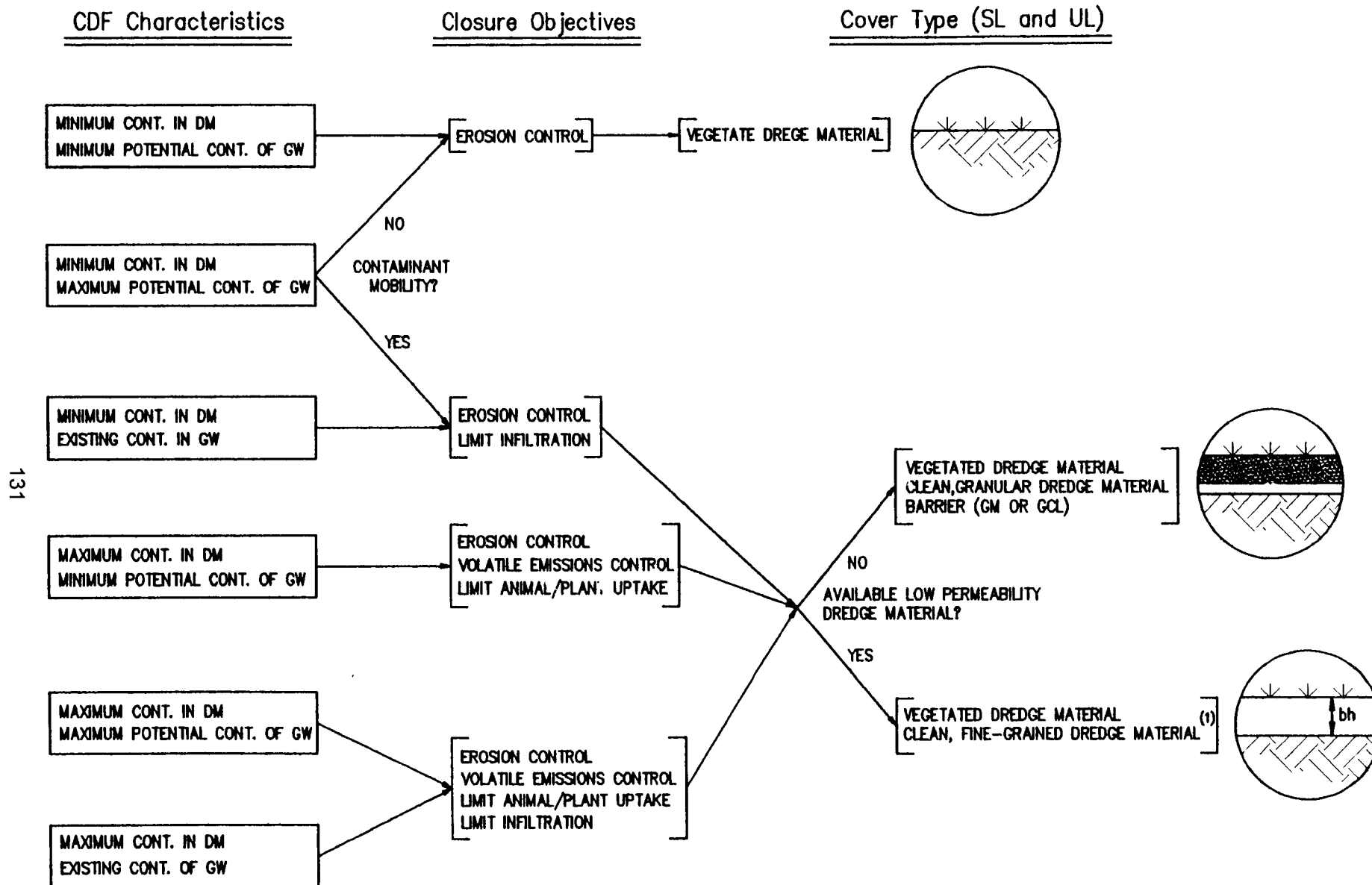


Figure 7.6 CDF Cover Selection Guide

CONT = CONTAMINATION  
DM = DREGE MATERIAL  
GW = GROUND WATER

(1) THICKNESS DETERMINED BY INFILTRATION OR UPTAKE CRITERIA

Unit costs for the components making up three cover profile are estimated as follows:

• Vegetative erosion control	(\$1500/acre)	\$0.04/ft <sup>2</sup>
• Clean dredged material	(\$10/ton)	\$0.50/ft <sup>2</sup> /ft thickness
• Barrier layer	(GCL or GM)	\$0.65/ft <sup>2</sup>

The total unit costs for the three cover profiles range from \$0.04/ft<sup>2</sup> for the vegetative cover only, to \$1.04/ft<sup>2</sup> for the vegetative cover plus two feet of clean dredged material, to \$1.69/ft<sup>2</sup> for the latter plus a geosynthetic barrier layer. The full barrier will increase disposal costs approximately \$1.20 per ton (assuming a 20-foot average dredge material thickness).

## **SECTION 8**

### **OPERATIONAL AND POST-CLOSURE MONITORING**

Each of six contaminant pathways discussed in this document may require monitoring during the actual placement of dredged sediments in the CDF, during the interim between placement of dredged materials in the operational life of the CDF, or during the post-closure period required for the CDF to reach an equilibrium state. Recalling from Section 1, the long-term equilibrium state must reflect potential contaminant partitioning mechanisms and resulting transport mechanisms. Current monitoring programs tend to be short-term focused and predicated on the solids retention philosophy of contaminant containment. Such monitoring programs are appropriate during operations. Post-closure monitoring programs must be able to detect secondary pathways not related to solids retention. Specific monitoring requirements will be influenced by the type and degree of contamination, the setting, type of CDF (e.g. upland, in-lake), the site specific hydrogeology, and the design details of the specific CDF contaminant system.

Both the operational and post-closure monitoring programs are intended to track and document the influence of the CDF on the surrounding ecosystem. As such, the effectiveness of these monitoring systems is predicated on a clear identification of the background environmental conditions that exist prior to construction of the CDF. Such background ambient site data includes surface water quality on or adjacent to the site, ground water quality beneath and down gradient of the site, and air quality at the site.

#### **8.1 Monitoring During Operations**

During the actual placement of dredged sediments within the CDF, the potential for volatilization of contaminants and the loss of free water (or supernatant) are at a maximum. The specific contaminant pathways that may require monitoring during placement of dredged sediments include the impact of contaminant volatilization on air quality in the vicinity of the CDF, and the impact of the free water on effluent quality and site groundwater quality. As discussed in Section 5.3, the level of contaminant volatilization during placement of dredged sediments is significantly influenced by the dredging process used to dredge the sediments. For example, hydraulic dredging is commonly preferred at environmentally sensitive dredge sites because it limits the turbidity resulting from the dredging process. Hydraulic dredging does, however, fluidize the dredged sediments, resulting in an increased percentage of sediments in suspension and a significant increase in the quantity of supernatant. At the point of discharge within the CDF, the contaminants are more mobile so that the potential for volatilization or advective transport of the contaminants is increased.

As the level of the dredged material rises above the level of the supernatant, the exposed dredged material becomes exposed to direct sunlight and free oxygen. The resulting heating and drying of the dredged material can lead to an increase in the volatilization of contaminants. Additionally, the differential subsidence of the dredged material can produce surface ponds that support both fish and a benthic community. In this fashion, the interim exposed surface of the dredged material can foster both plant and animal uptake of contaminants. Monitoring for potential volatilization and plant or animal uptake is required to determine if an interim cover of clean dredged material is required to limit contaminant loss.

#### **8.1.1 Effluent Quality Monitoring**

Effluent can leave the CDF through a designed weir point discharge system or via seepage through the perimeter dike. Water quality monitoring of the effluent discharge from the point discharge system or at the fringe of a mixing zone is conventional and does not require clarification in this manual. Effluent seepage through the perimeter dikes is more difficult to monitor because of uncertainties related to potential seepage pathways and the potential impact of the dike on effluent quality. These factors are discussed in Section 6.1. For example, the monitoring of seepage through dikes is complicated by dye studies (e.g. Pranger, 1986) that have shown that seepage in shoreline and in-lake CDFs is not uniform, but rather occurs at discrete points. Traditional monitoring wells placed within the perimeter dikes can easily miss such fingers of contaminant flow and therefore do not provide effective monitoring. The development of discrete plumes leaving the marine dikes can be detected using dye studies or geophysical techniques such as acoustical echo tracking. This method measures the sonar backscatter intensity that can be correlated to chemical turbidity concentrations (ref). Additional monitoring methods can include satellite imaging if the effluent produces sufficient change in the physical environment at the point of seepage.

#### **8.1.2 Leachate Discharge Monitoring**

Downward flow of water-carried contaminants from within the CDF can be detected by the installation of monitoring wells within the CDF. Such wells will require proper screening and sealing to prevent direct contamination from the supernatant. Such sealing typically requires initially placing a conductor casing through the dredged material and into an aquitard beneath the dredged material. After sealing the conductor casing to the aquitard, the deeper monitoring well is placed through the conductor casing. Such considerations are clearly reviewed in existing manuals (see EPA, 1987). Such monitoring wells are easily damaged during operation of the CDF. Protection of monitoring wells placed within perimeter dike system is conventional and may simply require use of steel locking caps and traffic barriers. Protection of monitoring wells placed within the CDF is much more difficult and may require construction of "islands" of clean dredged sediments, through which the wells are placed, to protect the wells during placement of dredged sediments or placement of the wells after closure.

### **8.1.3 Air Quality Monitoring**

At CDF sites where dredged materials are exposed above the waterline, the air quality at the point of discharge of the dredged sediments may require air quality monitoring for the specific volatile contaminants present in the dredged sediments. It should be noted that such monitoring differs from "odor" monitoring in that specific volatile compounds should be targeted.

## **8.2 Post-Closure Monitoring**

The level of monitoring required after placement of the final cover over the CDF is significantly influenced by the type of cover used. General guidelines for post-closure monitoring are given on Table 8.1. In general, the monitoring of contaminant pathways related to effluent and leachate discharge remain the same as previously developed for the operational conditions. The influence of the final cover on contaminant pathway control is impacted by both the contaminant type and the type of barrier system incorporated in the cover as shown on Figure 7.6.

### **8.2.1 Surface Water Run-Off Monitoring**

A monitoring and sampling program should be established for both the water and sediments carried off the CDF final cover to ensure the cover is a secure barrier. Note that in many CDF closures the run-off from the final cover is still contained by the perimeter dikes such that a uncontrolled discharge is avoided. Surface water run-off monitoring is commonly performed on an annual basis for MSW landfills adjacent to sensitive waters.

### **8.2.2 Plant Uptake Monitoring**

Lacking a secure barrier in the final cover, an annual harvest of surface vegetation should be performed. This harvest limits the growth of trees and volunteer vegetation that may be deep rooted and provides vegetation samples for assaying of specific chemical uptake. The guidelines for the assaying program should be established based on the specific target contaminants in the dredged sediments.

### **8.2.3 Animal Uptake Monitoring**

Fish and benthic organisms present both immediately outside the CDF and above the final cover should subject to regular bioassays if a secure contaminant barrier is not designed into the final cover. The suitability of the final cover to serve as a nesting ground should be minimized if contaminant transport through the final cover is possible. This may include removal of surface ponds that form on the final cover and the elimination of vegetation required for nesting. The development of ponds on the final cover can be inexpensively tracked and

**Table 8.1**  
**Monitoring Requirements for Contaminant Pathways**

Contaminant Pathway						
CDF Characteristics	Effluent	Leachate	Surface Water*	Plant Uptake*	Animal Uptake*	Volatilization*
Minimum Cont. in DM Minimum Potential Cont. of GW	NR	NR	NR	NR	NR	NR
Minimum Cont. in DM Maximum Potential Cont. of GW	NR	Minimal Perimeter Monitoring Wells	NR	NR	NR	NR
Minimum Cont. in DM Existing Cont. in GW	NR	Extensive Monitoring Wells**	NR	NR	NR	NR
Maximum Cont. in DM Minimum Potential Cont. of GW	All-Weir Discharge WQ SL,IL-Dike Seepage WQ	Minimal Perimeter Monitoring Wells	Annual Sampling of Run-off	Annual Harvest and Analysis	Limit Ponding and Grazing Animals	Annual Inspection for Distressed Vegetation
Maximum Cont. in DM Maximum Potential Cont. of GW	All-Weir Discharge WQ SL,IL-Dike Seepage WQ	Extensive Monitoring Wells**	Annual Sampling of Run-off	Annual Harvest and Analysis	Limit Ponding and Grazing Animals	Annual Inspection for Distressed Vegetation
Maximum Cont. in DM Existing Cont. of GW	All-Weir Discharge WQ SL,IL-Dike Seepage WQ	Expanded Perimeter Monitoring Wells*	Annual Sampling of Run-off	Annual Harvest and Analysis	Limit Ponding and Grazing Animals	Annual Inspection for Distressed Vegetation

SL - Shore Line  
 IL - In Lake  
 UL - Upland

\* No Post-Closure Monitoring Required if Geomembrane is Incorporated in Final Cover.  
 \*\* Include Both Interior and Perimeter Monitoring Wells



predicted by the collection and interpretation of colored infrared and thermal infrared imagery of the CDF cover (Stohr et al, 1987). This simple technique simply detects vegetation stressed by saturation of the root zone. Such saturation only occurring within regions of ponding. Indication of contaminant uptake in plants (Section 8.2.1) should trigger a increased program of animal uptake monitoring.

#### **8.2.4 Volatilization Monitoring**

While it is acknowledged that the maximum rate of volatilization of contaminants occurs during placement of the dredged sediments into the CDF (See Section 5.3), gases generated by the dredged sediments could have a detrimental impact on the final cover vegetation. Lacking an adequate barrier system in the final cover, volatilization of the contaminants can cause the localized distress of the vegetation at the point of discharge. The presence of distressed vegetation can be evaluated using the same colored infrared and thermal imagery used to track the development of ponds. Provisions should be made to install passive gas venting systems if it is shown that the vegetative distress is related to emission of volatile contaminants.

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## **APPENDIX A**

### **CONTAMINATED SEDIMENT TREATMENT**

#### **A.1. Introduction**

Treatment of contaminated sediment will usually involve combining several appropriate technologies into an overall scheme for achieving a cleanup objective. The treatment of dredged contaminated sediment and subsequent placement in a confined disposal facility (CDF) typically include the following steps: removal, transport, interim storage, pretreatment, treatment, disposal, and effluent (including surface runoff) or leachate treatment. In this section the pretreatment and treatment steps will be discussed. All processes in this chapter were recommended for study in the ARCS program (Averett *et al.*, 1990).

#### **A.2. Soil Chemistry**

##### **A.2.1 Properties of Sediments Affecting Contaminants**

Sediments requiring remediation can vary widely in terms of physical and chemical properties. The primary physical characteristic is texture (i.e. the distribution of sand, silt, and clay sized particles). In general, sandy sediments have little attraction for either toxic metals or synthetic organics (pesticides and industrial organics). In contrast, fine textured sediments such as silt and clay have a much greater affinity for all classes of contaminants. Fine-textured material at the sediment-water interface and suspended silt and clay particles effectively remove contaminants from the water column. These fine textured materials have large surface areas when compared to either their volume or mass (e.g. specific surface). This large surface area serves as a site for colloidal chemistry to occur. These particles tend to accumulate in more quiescent reaches of waterways. Separation of the less contaminated gravel and sandy fractions from contaminated sediments may be possible, yielding material clean enough for disposal without restriction, while also reducing the volume of the contaminated sediment requiring treatment.

A second very important physical property is the organic matter content. Fine textured sediments generally contain from one to several percent naturally occurring humic material derived from microbial transformation of plant and animal detritus. Sandy sediments typically have less than one percent humic material. Humic material may be present as discrete particulates or as coatings on either clay or fine sandy sediments particles and is important in two respects: (1) the humic material greatly increases the affinity of sediments for metals (e.g. bind, chelate and complex) and nonpolar organic contaminants and (2) it serves as an energy source for sediment microbial populations.

Measurement of in situ water content is a third physical property of sediments usually important to remediation decisions because it is a measure of the amount of void space present in the sediment and as a result the density.

The chemical properties of sediments also greatly affect the mobility and biological availability of contaminants. Sediment acidity and oxidation/reduction status are two very important chemical parameters. Strongly acidic (low pH) sediments can in general slow microbial activity and increase the soluble levels of toxic metals. Weakly acidic, neutral, and slightly alkaline conditions (higher pH) favor metal immobilization processes. The oxidation-reduction status of a sediment, measured as redox potential, has a major effect on the retention or release of a number of metals, either directly or as a result of the different reactions of metals with oxidized and reduced sediment constituents. Changes in pH and redox potential of contaminated sediments from their initial in-situ condition at a dredging site to different conditions at a disposal site can substantially affect contaminant mobilization/immobilization processes. Other important chemical properties of sediments include salinity conditions, sulfide content, the amount and type of cations and anions, and the amount of potentially reactive iron and manganese.

Clay minerals have a high specific surface and associated electrical charge. Specific surface is defined as the surface area of a particle divided by either its mass or volume. The electrical charge on this surface is predominately negative with some positive sites on the ends of the clay mineral. The charge distribution is created by the atomic lattice structure that makes up the clay mineral. The behavior of water-cation systems adjacent to this surface can be described by the Gouy-Chapman theory developed from colloidal chemistry. The distribution of these cations in terms of distance from the colloid surface is termed the double layer. These cations distribute themselves along the surface of the clay platlet but are not permanently attached to minerals. The effect of various parameters on the double layer thickness and resulting soil structures is presented in Table A-1. The Gouy-Chapman Theory developed an equation for the double layer thickness that can be expressed as follows:

$$t = \frac{eKT}{8\pi ne^2v^2}$$

- where
- t = double layered thickness
  - ε = dielectric constant
  - k = boltsman constant
  - T = temperature
  - n = electrolyte concentration
  - e = elementary charge
  - v = cationic valance

The dielectric constant as utilized in the Gouy-Chapman equation is a measure of the pore fluids ability to act like an insulator and influence the strength of the clay minerals electric field. A reduction of the clay minerals electric field reduces the thickness of the double layer and hence, the colloidal clay behavior. As the dielectric constant increases, the thickness of the double layer increases causing a tendency for particle dispersion and the pore fluid acts more like a polar molecule. Therefore, if the liquid within the pore spaces is not polar (such as a petroleum product),

then the diffuse double layer will not develop. A table of typical values of dielectric constant for a variety of different fluids is presented in Table A-2.

### **A.2.2 Forms and Reactions of Contaminants**

Typical trace and toxic metal contaminants in dredged sediments commonly include copper, zinc, cadmium, lead, chromium, nickel, arsenic, mercury. These elements are usually present in soils and sediments at low concentrations from natural sources. It is when one or more of these contaminants is present in elevated concentrations that they pose a potential problem. Toxicity may be experienced if these excess metals are released to the water column or are present in forms readily available to plants and animals that come in contact with the sediment material.

Metals dissolved in the water column or pore water are available to most aquatic organisms. Metals bound to clay minerals and humic material by cation exchange processes are available due to equilibrium partitioning between these bound metals and dissolved metals. On the opposite extreme, metals bound within the crystal lattice structure of clay minerals are generally much less bioavailable.

Metals may be mobilized or immobilized if the chemical environment (e.g. pH and Eh) of the sediment or dredged material changes. Therefore, understanding the influence of the in-situ sediment chemical environment, and the potential of alteration in these parameters at the disposal site are important to the selection of disposal alternatives for contaminated sediments. The fate of potentially available metals as sediment conditions change is presented in Table A-3. In addition there may be a complex interaction between some of these processes as the pH or oxidation status of a sediment is altered. As metals are released from one form, they may be immobilized again by another process.

Organic contaminants can vary widely in water solubility depending on their molecular composition and functional groups. Like metals in a sediment-water system, most organic contaminants tend to become strongly associated with the sediment solid phase, particularly the humic fraction. Thus, at most sites, the distribution of organic contaminants between dissolved and solid phases is a function of their water solubility and the percent of naturally occurring humic materials in the sediment. However, at heavily contaminated sites, organic contaminants may also be highly associated with petroleum-based or sewage-based organics.

Unlike metals, however, organic contaminants do degrade. Though all organic contaminants degrade at some rate, some have half-lives on the order of several decades. Chemical half lives are measures of persistence, or how long a chemical will remain in various environmental media. The half lives are the result of all removal processes (e.g. phase transfer, chemical transformation, and biological transformation) acting together. A summary of typical half lives of organic contaminants found in contaminated sediments is presented in Table A-4. Some organics are subject to enhanced degradation rates under certain sediment chemical conditions.

### A.2.3 Sediment Toxicity Assessment

Assessing the toxicity of sediments and any potential threat they pose to human health and the environment is an important step in the remediation process. Presently, several different kinds of tools are available to use in making decisions concerning sediment assessment and desired levels of remediation. The primary tools include environmental regulations based on bioaccumulating contaminants and sediment assessment methods. Environmental regulations are the most important and have previously been covered in Section 1.1 Regulation of Dredging Activity. In the following sediment assessment methods will be discussed.

Although sediments are an extension of the water column, assessment of sediment toxicity is much more complex than assessment of water quality. Due to the nature of sediment chemistry, presence of contaminants does not necessarily mean that the sediment is toxic. For example, contaminants may be present but complexed by humic material in the sediment and thus relatively unavailable.

The EPA has developed a "Sediment Classification Methods Compendium" (EPA, 1991) to serve as a reference for methods that could be used to assess the quality of contaminated sediments. This compendium describes the various methods, as well as their advantages, limitations, and existing applications. The sediment quality assessment methods are presented in Table A.5. Each method either directly or indirectly attempts to delimit levels of contamination within sediments such that above those levels either (1) acute and/or chronic toxicological effects become manifest or (2) some amount of bioaccumulation occurs. The sediment quality assessment methods described can be classified into two basic types: quantitative or qualitative (refer to Table A.6). Quantitative methods are chemical-specific and can be used to generate numerical sediment quality values. Descriptive methods are qualitative and cannot be used alone to generate numerical sediment quality values for particular chemicals.

Currently, the EPA is working toward the development of nationally applicable sediment quality criteria (SQC). The SQC represents the best recommendation of sediment contaminant concentrations that will not unacceptably affect benthic organisms or their uses. SQC would eventually be developed for each high priority contaminant of concern.

Equilibrium partitioning (EqP) theory is the EPA's selected method to establish national SQC. The EqP approach relies on established water quality criteria to assess sediment toxicity. The first basic assumption of the EqP approach is that sediment toxicity is correlated to the concentration of the contaminants in the interstitial water and not to the total sediment concentration. The second basic assumption is that contaminants partitioned between the interstitial water and the sediment sorbents (e.g. organic carbon) are in equilibrium. Therefore, for a given contaminant, if the total sediment concentration, the concentration of sorbent(s), and the partitioning coefficient are known, then the interstitial contaminant concentration can be calculated. The interstitial contaminant concentration can then be compared to established water quality criteria to assess sediment toxicity. A flow chart describing the process is presented in Figure A-1.

Due to variation in the specific sediment sorbent(s) that different classes of contaminants sorb to, methodologies for deriving SQC vary with different classes of compounds. For non-ionic organic chemicals the methodology requires normalization to organic carbon. For metal contaminants a methodology has been developed that is based upon normalization to acid volatile sulfide. A flow chart describing the process is presented in Figure A-2.

### **A.3. Pretreatment**

Pretreatment technologies prepare dredged material for treatment or disposal. Objectives of pretreatment processes are largely dependent on the treatment or disposal options following in the treatment process train. The objectives of this step are usually one or more of the following:

- A. To provide a suitable material for further treatment and/or disposal operations;
- B. To enhance or accelerate settling of the dredged materials solids;
- C. To reduce the water content of the dredged materials solids;
- D. To separate coarser, potentially cleaner, solids from the fine-grained, more contaminated solids (particle classification);
- E. To reduce the overall cost for the remedial action.

Pretreatment technology processes include the following: (1) dewatering, (2) particle classification (separation), and (3) slurry injection.

#### **A.3.1 Dewatering**

Dewatering technologies are processes used to reduce the moisture content of slurries or sludges to expedite the handling and to prepare the material for further treatment or disposal. The water generated during dewatering generally contains contaminants as well as suspended solids. Types of dewatering processes include mechanical, evaporative and settling ponds. Dredged material dewatering has traditionally been accomplished in ponds or CDF's, which rely on a combination of seepage, drainage, consolidation and evaporation. Evaporative processes by themselves alone are not considered a viable alternative for use in the Great Lakes region due to the climate. Most mechanical dewatering processes reduce the moisture of the feed material to a level comparable to in situ sediment (about 50 percent by weight) and work best on homogeneous waste streams.

Implementability for dewatering processes other than settling ponds is poor primarily because of the high processing rates required for most dredging operations. The primary purpose for dewatering to minimize the loss of leachate through the dikes and bottom of the CDF. A summary of recommended dewatering techniques for use in the ARCS program (Averett *et al.*, 1990) is presented in Table A-6.



### **A.3.2 Particle Classification**

Separation by grain size is important in the management of soils and sediments contaminated with toxic materials since the contaminants tend to sorb primarily onto fine-grain clay and organic matter. The most appropriate solids separation technology for a given site depends on the volume of contaminated sediments; composition of the sediments (particle size distribution of the feed); specific gravity and chemical analysis of the soil; mineralogical composition; characteristics of the soil; percentage of sand, humus, clay or silt; composition of the organics in each soil fraction; moisture content; pH; characterization of the contaminants; types of dredging or excavation equipment employed; site location and site surroundings, (refer to Figure A-3). Particle classification options include screening processes that depend on size, processes that depend on a combination of size and density or density alone, and processes that depend on conductive or magnetic properties of the particles. A summary of recommended particle classification technologies evaluated by the ARCS program (Averett et al., 1990) is presented in Table A-7.

### **A.3.3 Slurry Injection**

Slurry injection technologies are used as a pretreatment step either to add chemicals that condition the sediment for further treatment and/or accelerate the settling of the suspended solids or to provide nutrients or microbes that will enhance biodegradation of organics. The process involves the injection of chemicals or microorganisms into the dredged material slurry to take advantage of the mixing process available in the pipeline from a hydraulic dredge. A summary of recommended slurry injection techniques for use in the ARCS program (Averett et al., 1990) is presented in Table A-8.

## **A.4. Treatment**

This section discusses the various treatment technologies available for the decontamination/detoxification of contaminated sediment. Many of the process options are not stand alone processes, but are components of a system that may involve multiple treatment steps to address multiple contaminant problems. Specific treatment objectives include the following:

- A. Destruction of toxic organic contaminants by conversion to nontoxic end products;
- B. Removal of heavy metal or organic contaminants from contaminated dredged material, thereby concentrating toxic material into a media of smaller volume (extraction), and/or to reduce the volume of solids for further treatment or disposal;
- C. Reduction of the mobility of contaminants in dredged material to a level compatible with acceptable risks;
- D. Compatibility with removal and final disposal options;
- E. Compliance with acceptable capital and operating costs;
- F. Minimization contamination of other environmental media;

- G. Avoidance of the addition of potentially toxic materials or the production of toxic materials during the treatment process.

In addition, most of the processes outlined below will also require one or more pretreatment processes. A summary of treatment options available for selected contaminants present in CDF's is presented in Table A-10.

#### **A.4.1 Biological Treatment**

Biological degradation technologies use bacteria, fungi, or enzymes to breakdown PCB's, pesticides, and other organic constituents into less toxic compounds. The micro-organisms may be indigenous microbes, conventional mutants, or recombinant DNA products. Biological degradation proceeds with slower reaction rates than thermal or chemical techniques. A summary of recommended biological techniques evaluated by the ARCS program (Averett *et al.*, 1990) is presented in Table A-9.

#### **A.4.2 Chemical Technologies**

The objective of chemical processes, such as chelation, oxidation, or reduction, is to change the form of a toxic material to render it less toxic or to change its solubility, stability, separability, or other properties affecting handling or disposal. Chemical treatment technologies use chelating agents, acid or base addition, chlorine displacement, oxidation, or reduction in the destruction, detoxification, or removal of contaminants found in contaminated sediments. A summary of recommended chemical technologies reviewed/evaluated by the ARCS program (Averett *et al.*, 1990) is presented in Table A-10.

#### **A.4.3 Extraction Technologies**

Extraction is the removal of a contaminant (organic/inorganic) from soils or sediment by dissolving it in a fluid that is later recovered and subsequently treated to remove the contaminant or recycled. Extraction is often used to remove volatile organics from permeable soils and can also be used to treat soils and sludges contaminated with the following: metals, inorganics, organics (PCB's, TPH, halogenated solvents, aromatics), amines, ethers, and anilines. Extracting agents that are employed vary according to the contaminants to be treated. They include water, acids, bases, complexing and chelating agents, surfactants, and certain reducing agents.

There are two basic methodologies employed utilizing extraction processes. These methodologies are the following: (1) containerized extraction, and (2) in situ extraction. In the containerized extraction process soil/sediment is excavated and placed in a container to allow contact with the extracting liquor. The extracting liquor is then injected into the soil, and contaminants are extracted from the soil and concentrated in the washing solution. The washing solution leaches the contaminants out of the soil and is collected and recycled by a specific treatment technology

appropriate for the type of contaminants involved. For in situ extraction processes, the contaminated site is typically flooded with an appropriate extraction solution and the elutriate leaching from the site is collected either by a series of shallow well points or subsurface drains. The leachate is then treated and recycled back into the site.

A summary of recommended extraction technologies reviewed/evaluated by the ARCS program (Averett et al., 1990) is presented in Table A-11. The technologies presented in Table A-12 are the following: (1) acid leaching, (2) B.E.S.T., (3) C. F. Systems-Propane, (4) Low Energy (acetone/kerosene), and (5) surfactants.

#### **A.4.4 Immobilization Technologies**

The purpose of immobilization technologies is to limit the mobility of contaminants that are present in sediments. Most immobilization techniques take the form of solidification or stabilization (S/S) processes performed prior to placement of the dredged material in the CDF. The objectives of S/S are generally to improve the handling and physical characteristics of the material, decrease the surface area of the sediment mass across which transfer or loss of contaminants can occur, and/or limit the solubility of contaminants by pH adjustment or sorption phenomena. Immobilization techniques are typically used for heavy metal contaminants because they cannot be destroyed and extraction from soils is a difficult process. Solidification or stabilization is also effective for limiting the volume of leachate leaving the site. It should be noted that placement of contaminated dredged material in a low-permeability landfill covered with a low-permeability cap is in itself a physical immobilization technique. Thus immobilization techniques can include chemical techniques that modify the dredged materials and containment techniques that simply prevent the movement of water to or from the waste. A summary of immobilization techniques for use in the ARCS program (Averett et al., 1990) is presented in Table A-12.

#### **A.4.5 Thermal Technologies**

Thermal technology processes include incineration, pyrolytic, vitrification, supercritical and wet air oxidation, and other processes that require heating the sediment several hundreds or thousands of degrees above the ambient temperature. Thermal processes are generally the most effective options for destroying organic contaminants. Incineration typically achieves destruction/removal efficiencies greater than 99 percent for organic contaminants. Heavy metals in the incineration processes generally pass through the process, except that some of the most volatile metals (such as lead and mercury) can volatilize from the higher temperature processes. Pyrolysis in contrast involves heating the material in the absence of oxygen. Volatile materials are driven off and collected or destroyed by secondary processes, and metals, salts, and other nonvolatile materials melt into molten glass. Vitrification processes use high-voltage graphite electrodes to provide the primary heat source. A summary of thermal techniques reviewed/evaluated by the ARCS program (Averett et al., 1990) is presented in Table A-13.

**TABLE A-1**  
**EFFECT OF VARIOUS PARAMETERS ON DOUBLE LAYER**  
**THICKNESS AND RESULTING SOIL STRUCTURES**

PARAMETER	DOUBLE LAYER THICKNESS		SOIL STRUCTURE	
	INCREASE	DECREASE	DISPERSE D	FLOCCULATED
Electrolyte Concentration	Decrease	Increase	Decrease	Increase
Ion Valence	Decrease	Increase	Decrease	Increase
Dielectric Constant	Increase	Decrease	Increase	Decrease
Temperature	High	Low	Increase	Decrease
Size of Hydrated Ion	Large	Small	Increase	Decrease
pH	High	Low	Increase	Decrease
Anion Adsorption	Increase	Decrease	Increase	Decrease

Note: As shown, a change in any particular parameter (increase or decrease has a related affect on the double layer thickness and the soil structure.

**TABLE A-2**  
**TYPICAL VALUES OF DIELECTRIC CONSTANTS**  
**FOR VARIOUS FLUIDS**

CHEMICAL NAME	DIELECTRIC CONSTANT
Cyclohexane	2
Xylene	2
Benzene	2
Aniline	6
Propanol	20
Acetone	22
Ethanol	26
Methanol	32
Water	80

**Table A-3 - Typical Fate of Potentially Available Metals In a Changing Chemical Environment**

<b>Metal Type</b>	<b>Initial Condition</b>	<b>Environmental Changes</b>	<b>Result</b>
carbonates, oxides, and hydroxides	salts in the sediment	reductions of pH	release of the metals as the salts dissolve
adsorbed on iron oxides	adsorbed in sediment	sediment becomes reducing or acidic	iron oxides become unstable and release metals
chelated to humic	chelated in sediment	strongly immobilizes metal in both reducing and oxidizing sediments (However, there is some indication that the process is less effective if a reduced sediment becomes oxidized)	
sulfides	very insoluble precipitate	sediment becomes oxidized	sulfides become unstable, oxidize to sulfates, and release the metals

Ref EPA, 1991

**Table A-4 - Half Life Range of Typical Contaminants**

<b>Half Life Range in Surface Water (days)</b>				
<u>Chemical Name</u>	<u>Low</u>	<u>High</u>	<u>Other Half Life Ranges</u>	<u>References</u>
PCBs	2	12.9		2
acenaphthene	--	--		2
acenaphthylene	0.125	--		2
anthracene	--	--		2
benzo(a)anthracene	0.10	5.00		2
benzo(a)pyrene	0.40	--		2
benzo(b)fluoranthene	1.00	2.00		2
benzo(ghi)perylene	--	--		2
benzo(k)fluoranthene	--	--		2
chrysene	0.20	--		2
dibenzo(a,h)anthracene	0.02	--		2
fluoranthene	1.00	2.00		2
fluorene	--	--		2
indeno(1,2,3-cd)pyrene	0.02	2.1		2
naphthalene	--	--		2
phenanthrene	0.38	2.00		2
pyrene	--	--		2
Dieldrin	723 days			1
Chlordane	very persistent			1
Vinyl Chloride	25 minutes			1
chloroform	15 months		blue gill	
1 day	1			
1,1,1-Trichloroethane	5-9 months			1
Carbon Tetrachloride			blue gill	
1 day	1			
Dibromochloromethane	274 years			1
Bromoform	686 years			1
Chlorobenzene	5.8 hours			1
bis(2-Chlorethyl)ether			blue gill	
4-7 days	1			
2-Chlorophenol			blue gill	
1 day	1			
2,4-Dimethylphenol	1-day			1
2,4-Dichlorophenol	8-9 days			1
Hexachlorocyclopentadiene	11 days			1
2,4,6-Trichlorophenol			rat blood	
20 hours	1			
2-Chloronaphthalene	biomagnified in water			
	1			
2,4-Dinitrophenol	no significant microbial degrdation in 64 days			
	1			
2,6-Dinitrotoluene	greater than 64 days			
	1			
Benzidine			dogs and rats: 68-88 hrs.	1
3,3'-Dichlorobenzidine			long life in soil	1

Note: 1. Reference No. 1, McNelis, D.N., et al., (1984). Exposure Assessment Methodolgies for Hazardous Waste Sites", University of Nevada, Las Vegas, Nevada, Environmental Monitoring Systems Laboratory, Office of Research and Development, Cooperative Agreement No. CR 810550-01.

2. Superfund Public Health Evaluation Manual, EPA 540/1-86/060, Office of Emergency and Remedial Response, U.S.E.P.A., Washington, D.C.

**TABLE A-5 — Sediment Quality Assessment Methods**

Method	Type			Concept
	Numeric	Descriptive	Combination	
Bulk Sediment Toxicity	x			Test organisms are exposed to sediments that contain unknown quantities of potentially toxic chemicals. At the end of a specific time period, the response of the test organisms is examined in relation to a specified biological endpoint.
Spiked-Sediment Toxicity	x			Dose-response relationships are established by exposing test organisms to sediments that have been spiked with known amounts of chemicals or mixtures of chemicals.
Interstitial Water Toxicity	x			Toxicity of Interstitial water is quantified and Identification evaluation procedures are applied to identify and quantify chemical components responsible for sediment toxicity. The procedures are implemented in three phases: 1) characterization of interstitial water toxicity, 2) Identification of the suspected toxicants, and 3) confirmation of toxicant identification.
Equilibrium Partitioning	x			A sediment quality value for a given contaminant is determined by calculating the sediment concentration of the contaminant that would correspond to an interstitial water concentration equivalent to the EPA water quality criterion for the contaminant.
Tissue Residue	x			Safe sediment concentrations of specific chemicals are established by determining the sediment chemical concentration that will result in acceptable tissue residues. Methods to derive unacceptable tissue residue are based on chronic water quality criteria and bioconcentration factors, chronic dose response experiments or field correlations, and human health risk levels from the consumption of fresh water fish or seafood.
Freshwater Benthic Community Structure		x		Environmental degradation is measured by evaluating alterations in freshwater benthic community structure
Marine Benthic Community Structure		x		Environmental degradation is measured by evaluating alterations in marine benthic community structure.
Sediment Quality Triad	x	x	x	Sediment chemical contamination, sediment toxicity, and benthic infauna community structure are measured on the same sediment. Correspondence between sediment chemistry, toxicity, and biological effects is used to determine sediment concentrations that discriminate conditions of minimal, uncertain, and major biological effect.
Apparent Effects Threshold	x		x	An AET is the sediment concentration of a contaminant above which statistically significant biological effects (e.g., amphipod mortality in bioassays, depressions in the abundance of benthic infauna) would always be expected. AET values are empirically derived from paired field data for sediment chemistry and a range of biological effects indicators.

Ref. EPA, 1991

**Table A-6 — PRETREATMENT COMPONENT — DEWATERING**

Process Option	Treatment Methodology	Factors Controlling Performance	Minimum Input Slurry Range (% solids by wt.)	Output Slurry Range (% solids by wt.)	Cost
Belt Filter Press	Belt filter presses use single or double moving belts to dewater sludges. Consists of three stages. (1) conditioning by adding of flocculent to thickening drum; (2) gravity drainage of free water, and (3) compression zone. Compression zone is provided by the top belt pressing against the bottom belt which serves as a filter.	Sediment solids feed concentration, flocculent, amount of pressure between rollers, filter opening size	1-40	50-60	Capital cost for 500,000 yd <sup>3</sup> facility \$6 million; operation and maintenance \$20-\$100 per yd <sup>3</sup>
Carver-Greenfield Evaporation	A food grade carrier oil is injected into the waste as a fluidizing agent to maintain the liquid phase as solids content increases. Oil-soluble contaminants are extracted from the waste by the carrier oil, and volatile compounds are stripped out and condensed with the carrier oil and water. Water is removed by thermal treatment. The carrier oil is removed by evaporation and stream stripping, and the contaminants are removed for distillation. Useful for sediments and wastes containing oil-soluble contaminants such as PCB's, dioxins	Temperature, carrier oil	8	--	
Centrifugation	Technology that uses rapid rotation of a fluid mixture inside a rigid vessel to separate the components based on their mass. Types are solid bowl, basket and disc. Concentrates soil/sediments from fine gravel to silt.	Particle size; efficiency drops drastically for particles smaller than 10 microns.	-- -- Disc = 1	Solid basket = 15-40 Basket = 9-25 Disc = 6	Capital cost for 50 lb/hr dry \$500,000. Operation and maintenance \$20 to \$100 per yd <sup>3</sup> .



Table A-6 (Continued)

Process Option	Treatment Methodology	Factors Controlling Performance	Minimum Input Slurry Range (% solids by wt.)	Output Slurry Range (% solids by wt.)	Cost
Chamber Filtration	Utilizes rigid individual filtration chambers operated in parallel under high pressure to dewater a slurry. Used in situations requiring a large area of filtration in minimal area	Pressure plate warpage and deterioration of plate gasket.	--	>50	Operation and maintenance cost \$20 to \$100/yd <sup>3</sup>
Gravity Thickening	Operates on differences in specific gravity between solids and water to accomplish separation. Process accomplished in circular vessel similar to a conventional clarifier.	Maximum flow, waste type, volume of solids per day, percent solids, specific gravity, surface chemistry, maximum particle size, percent solids required in the underflow.	--	--	Operation and maintenance \$20 to \$100 per yd <sup>3</sup>
Primary Settling (CDF)	CDF functions like large settling ponds. Effective settling area reduced by wind, turbulence and short circuiting.	Efficiency controlled by hydraulic characteristics of the settling pond and drainage mechanism.	--	Approximately 50	Operation and maintenance less than \$20 per yd <sup>3</sup>
Subsurface Drainage (CDF)	System consists of a network of perforated pipes or filter material placed under or around the perimeter of a CDF. These pipes or filter material drain to a series of sumps where water is withdrawn.	Permeability of dredge and filter material, time.	--	--	Operation and maintenance less than \$20 per yd <sup>3</sup>

Table A-6 (Continued)

Process Option	Treatment Methodology	Factors Controlling Performance	Minimum Input Slurry Range (% solids by wt.)	Output Slurry Range (% solids by wt.)	Cost
Vacuum Filtration	Vacuum filter unit consists of a rotating cylindrical drum mounted horizontally and partially submerged in trough containing a slurry. A vacuum supply applies negative pressure to the inside of the drum while the moist solids adhere to the filter.	Vacuum, degree of drum submergence, drum speed, filter media, porosity, feed type, solids, concentration, chemical conditioning, management.	--	20 to 40	Operation and maintenance \$20 to \$100 per yd <sup>3</sup>
Wick Drains (CDF)	High permeability polymeric strips to promote both radial and vertical drainage. Normally placed on 5 ft. centers to depths of 40 ft. Surcharge used to promote dewatering. Have been used on CDFs.	Wick spacing, depth of CDF, material type, amount of surcharge.	--	--	Operation and maintenance cost \$20 to \$100 per yd <sup>3</sup>

**Table A-7 — PRETREATMENT PARTICLE CLASSIFICATION TECHNOLOGIES**

Process Option	Size of Particle Handled	Treatment Methodology	Equipment Requirements	Advantages	Limitations	Size Requirement	Cost
Flotation	Fines	Physiochemical process to concentrate contaminants. Material is ground finer than 48 to 65 mesh so that the contaminants will be able to be floated by air bubbles. After grinding suspended particles are treated with chemicals to cause the particles to be air-avid and water repellent. The mixture is agitated with air and the contaminants attached to the air bubbles float to the surface, forming froth. This concentrated froth is skimmed off leaving a clean product.	Mechanical flotation device uses an upright impeller for agitation and aeration. Pneumatic device uses air blowers.	Corrosion resistance	Dependent upon surface chemistry, particles size, shape distribution of feed, contaminant distribution with particle size, characteristic of the soil, specific gravity and chemical analysis of the soil, mineralogical analysis, solids to liquids ratio, pH.		Capital cost \$24K to \$160K. Operation and Maintenance \$20 to \$100 yd <sup>2</sup>
Grizzlies	Debris to Gravel > 1.0 in.	Vibrating or fixed separation units used to remove oversized material and reduce slurry velocity prior to subsequent processing.	Device consists of parallel frame mounted bars spaced 1 to 5 in. apart. Units can be used in series or parallel.	Improves the reliability and efficiency of separation technologies. Maintenance costs minimal.	None.	Typically 6 to 9 ft. wide and 12 to 18 ft. long.	Operation and maintenance cost less than \$20 per yd <sup>3</sup>
Hydraulic Classifiers	Gravel to fine sand	Physical separation and classification by grain size of sand and gravel from fines by settling velocity through water.	Typically V-shaped rectangular trough or cone in which slurry of a dredge material is directed. Sand and gravel particles fall to bottom and are recovered through discharge valves while fine-grained material is carried off by water flow.	Units typically designed for mobile system application with quick startup and shutdown time. Fairly simple maintenance requirements	Removal and classification of solids from 3/8 in. to approx. 74 microns. Some fines will be removed with sand and gravel		Capital cost varies with size and capacity. Typical range \$30K to \$76K. Operation and maintenance \$20 to \$100 per yd <sup>3</sup>

**Table A-7 – PRETREATMENT PARTICLE CLASSIFICATION TECHNOLOGIES (Continued)**

Process Option	Size of Particle Handled	Treatment Methodology	Equipment Requirements	Advantages	Limitations	Size Requirement	Cost
Hydrocyclones	Separates clay/silt from coarser particles	Separates solids (gravels and sands) from slurry by vortex-generated centrifugal forces.	Cone-shaped vessel with tangential feed inlet at top. Discharge pipe located short distance into vessel to form vortex.	Applicable to sites with limited space. Wide variety of sizes and can be operated in series or parallel.	Not effective with highly viscous, high-clay content slurries, slurries with solids concentration greater than 30% or particles with specific gravity of approx. 2.5 to 3.2.	Small size	Capital cost varies according to size and number. Typical range \$1K - \$5K. Operation and Maintenance less than \$20 per yd <sup>3</sup> .
Impoundment Basins	Gravel to fine silt	Physical separation and classification by grain size of gravel to fine silt by settling velocity through water	Diked area or CDF	Handles large dredging operations	Requires large area. No solids removal system. Needs backhoe or clamshell dredge. Minimal control when used employed as a particle separator	Large area	Operation and Maintenance less than \$20 per yd <sup>3</sup>
Magnetic/ Electrostatic	100 micron or less	Separates slurry based on difference in magnetic and conductive properties between contaminant and the soil.	Slurry is forced through magnetized steel wool containing 95% void space. Intensity of the magnetic field can vary from 1 to 100 kilogauss.	Soils may be dry or in slurry form.	Particles have to be less than 100 micron in size. If contaminants finely disseminated throughout soil unlikely to work.		Operation and Maintenance \$20 to \$100 yd <sup>3</sup>
Moving screens	1/8 in. to 6 in.	Plain screening surface in a rectangular frame. Typically nested from coarse to fine at a slope of 20 degrees to allow for a cascading effect. Screens may be vibrated, revolving or gyrated. Vibrated most common.	Vibrated rectangular framed screen arranged in nest. Usually placed at 20 degrees slope to allow particles to cascade from one screen to the next.	Can typically handle 300 to 950 tons of material per hour.	Soil has to be dry or washed through screen with water. Screen replacement frequent.	3 to 10 ft wide and 6 to 30 ft long.	Capital cost for screen 10' long, 5' wide, 5' deep with a capacity of 200 ton/hr approx. \$25K. Operation and Maintenance cost \$20 to \$100 per yd <sup>3</sup> .

**Table A-7 — PRETREATMENT PARTICLE CLASSIFICATION TECHNOLOGIES (Continued)**

Process Option	Size of Particle Handled	Treatment Methodology	Equipment Requirements	Advantages	Limitations	Size Requirement	Cost
Shaking Table	Wide range from slimes to rocks	Feed enters a long upper edge of table. Wash water and shaking action spread the feed over the table. Particles are sorted according to size by the arrangement of riffles that decrease in height along their length toward the discharge end.	Rectangular table with a slope of 0 to 6 degrees. Surface is smooth with riffles. Table capable of being shaken.	Versatile gravity separation.			Operation and Maintenance cost \$20 to \$100 per yd <sup>3</sup> .
Spiral Classifiers	Sand and gravels up to 3/8 in.	Settled solids are fed from the hydraulic classifier into the spiral classifier by a rotating screw placed on an incline. Fines carried to bottom of incline while sand and gravel carried up incline by screw.	Rotating screws mounted in an inclined rectangular vessel with capability of washing, dewatering, and sediment. Require pretreatment by hydraulic classifier.	Removes clay and silt adhering to sand and gravel. Designed for mobile systems. Capable of processing up to 950 tons per hour.		Typically 22 to 34 feet long, 8 to 19 feet wide and 8 to 12 feet deep.	\$14K to \$77K for single screw; \$37K to \$150K for double screw. Operation and Maintenance cost range from \$20 to \$100 per yd <sup>3</sup> .
Stationary Screens	Separates fines from sands and gravels.	The screen surface is continuously curved. A slurry is passed over the screen with a velocity high enough to produce a centrifugal force to keep the slurry in the contact with the screen.	A curved screen surface. The screen consist of frame mounted parallel bars spaced close together for a finer particle separation. A pressurized water spray can be added to increase efficiency.	No more moving parts; wedge bar screen is more resistant to abrasion.	Less efficient than vibrating screen.	Small size.	Operation and Maintenance \$20 to \$100 per yd <sup>3</sup> .

TABLE A-8 — PRETREATMENT — SLURRY INJECTION						
Process Option	Size of Particle Handled	Treatment Methodology	Equipment Requirement	Advantages	Limitations	Costs
Chemical Clarification	Silt and clays	Use of conditioners to promote coagulation or flocculation of the smaller size colloidal size particles. Process increases rate of sedimentation. Coagulants include inorganic chemicals (salts of iron and aluminum), and organic polyelectrolytes. Polyelectrolytes recommended for dredged material.	Pipeline transport of dredged material slurry required to mix conditioner to mix conditioner. Method to inject conditioner required.	Polyelectrolytes are less dependent on pH and require lower dosages compared to inorganic chemicals.	Settling process required after injection of conditioners. Prolonged periods of mixing reduce effectiveness.	Operation and maintenance less than \$20 per yd <sup>3</sup> .
Microbe Addition	Silt and clays	Use of microorganisms that are acclimated to degrade toxic materials. Microorganisms are injected into pipeline slurry, mixing them through the sediment mass.	Pipeline transport of dredged material slurry required to mix microorganisms. Method to inject microorganisms required.	—	Different microorganisms required for different types of toxics.	Operation and maintenance \$20 to \$100 per yd <sup>3</sup>

TABLE A-9 — CONTAMINANT SEDIMENT TREATMENT/BIOLOGICAL						
Process	Applicable Contaminants	Mechanism	Factors Affecting	Demonstrated for Remediation of Sediments	Typical Cost	Comments
Aerobic Bioreclamation	Organic materials	Microorganism are encouraged to grow in an aerobic environment utilizing the organic contaminant as a source of food.	Nutrients for growth of microorganisms, oxygen, temperature, soil moisture, pH.	Bench	Operation and maintenance \$20 to \$100 per yd <sup>3</sup>	Methodology can be used to treat soils and groundwater contaminated with organic materials
Anaerobic Bioreclamation	Organic contaminants such as halogenated compounds, various aromatics, some pesticides.	Process uses anaerobic metabolism that includes anaerobic respiration using nitrate or sulfate as a terminal electron acceptor and fermenting methanogenic processes using a methanogenic consortium (strictly anaerobic bacteria).	Temperature, redox potential of -250 mv or less, no oxygen, nitrates or sulfates can be present.	Bench	Operation and maintenance \$20 to \$100 per yd <sup>3</sup> .	Process is slower and fewer compounds can be degraded in comparison to aerobic bioreclamation.
Bioreactors	Organic materials	An aerobic biodegradation technology that functions to increase the availability of contaminants and nutrients to microbes within a tank. Slurry is dewatered and results in water treated, if necessary.	Nutrients, oxygen, pH.	No	Operation and maintenance \$20 to \$100 per yd <sup>3</sup> .	Limitations of technology include inhibition of microbial metabolism by chloride substitution and heavy metals, and temperatures outside the optimum range.

TABLE A-10— CONTAMINANT SEDIMENT TREATMENT/CHEMICAL						
Process	Applicable Contaminants	Mechanism	Factors Affecting	Demonstrated for Remediation of Sediments	Cost	Comments
Chelation	Metals	Chelating molecule (ligand) forms multiple bonds with metal ions resulting in a heterocyclic (ringed) structure. The chelating agents either increase metal mobility for removal or immobilize by sorbing onto clay materials.	pH, chelate dosage, chelating agent, type of metal.	No	Operation and maintenance of \$100 to \$200 per yd <sup>3</sup> .	Chelating agents must be used according to their affinity for particular metals.
Nucleophilic Substitution	PCB's, acids, oils, thiols, dioxins, chlorobenzenes.	Chemically removes chlorine from organic (aromatic) compounds using the electron donator principle.	Requires alkaline conditions, (high pH level, temperature, reaction time, reagent dose, moisture content.	Yes	Operation and maintenance \$150 to \$200 per yd <sup>3</sup> .	Two primary processes: APEG, alkali metal hydroxides in polyethylene glycol: KPEG, potassium - polyethylene glycol.
Oxidation of Organics	Oxidation organics such as aldehydes, phenols and benzidine. Limited applications for slurries, tar and sludge.	Oxidation state of atom is increased by removal of electrons. Oxidation transforms, degrades or immobilizes contaminants in the soil system.	Oxidant concentration, pH, oxidation potential.	Yes	Operation and maintenance \$150 to \$200 per yd <sup>3</sup> .	Toxic products may form if reaction is not complete. Process is not applicable for high strength complex waste systems, nor highly halogenic organics. Methodology can be employed in situ.



TABLE A-11 — CONTAMINANT SEDIMENT TREATMENT/EXTRACTION						
Process	Applicable Contaminants	Mechanism	Factors Affecting	Remediation of Sediments, Dredged Materials	Typical Cost	Comments
Acid Leaching	Metals, amines, anilines, ethers, phenols.	Steam and/or weak acids such as aqueous solutions of sulfuric, hydrochloric, nitric, phosphoric and carbonic acid are used as dissolving agents for basic metal salts, amines, anilines and ethers processes. In situ treatment may be performed using weak acid solutions such as acetic acid and sodium hydrogen phosphate. Basic solutions such as NaOH are used as flushing agents for soils contaminated with metals such as zinc, tin, lead and phenols.		Pilot, No	Operation and maintenance \$63 to \$200 per yd <sup>3</sup> .	
B.E.S.T. (Basic Extraction Sludge Treatment)	PCB's oils, creosote	Mixture of one part free water sediment and 1 to 7 parts amine-based solvent, usually triethylamine (TEA). A single liquid phase forms and solid matter is removed by centrifugation and dried to remove residual TEA. TEA is then processed to remove contaminants.	Treatment must be sealed from atmosphere and operated under a nitrogen blanket. Temperature must be below critical solution temperature. Alkaline conditions (pH 10) are required.	Demonstrated, Bench	Operation and maintenance \$60 to \$300 per yd <sup>3</sup> .	
C.F. Systems - Propane	PCB's and organics.	Contaminated sediment is fed to the top of the extractor and makes non-reactive contact with condensed propane solvent flowing up through the extractor at a pressure of 250 psi. Typically used in a series of three extractors. Contaminated propane is fed to a separator where it is vaporized and recycled by recompression.	Propane, pressure, temperature.	Pilot/Pilot	Operation and maintenance \$100 to \$200 per yd <sup>3</sup> .	
Low-Energy Acetone - Kerosene	PCB's and organics.	This process separates the sediment into a liquid and a solid, then leaches the solid portion with a hydrophilic solvent (acetone). The acetone is steam stripped from the sediment. The PCB's are treated with a hydrophobic solvent (kerosene).	Water content > 50 percent.	Conceptual, Bench	Operation and maintenance \$41 to \$200 per yd <sup>3</sup> .	

TABLE A-11 – CONTAMINANT SEDIMENT TREATMENT/EXTRACTION (Continued)						
Process	Applicable Contaminants	Mechanism	Factors Affecting	Remediation of Sediments, Dredged Materials	Typical Cost	Comments
Surfactants	Hydrophobic organics, non-soluble organics (PCB's, crude oil, tertiary oils).	Surfactants are injected into the soil to flush contaminants. Typically use mixture of anionic and nonanionic surfactants.		Demonstrated, No.	Operation and maintainance \$100 to \$200 per yd <sup>3</sup> .	Field and laboratory have exhibited mixed results.

TABLE A-12 – CONTAMINANT SEDIMENT TREATMENT/IMMOBILIZATION						
Process	Applicable Contaminants	Mechanism	Factors Affecting	Remediation of Sediments, Dredged Materials	Typical Cost	Comments
Chloranan Encapsulation	Organic compounds, heavy metals, oil and grease.	Process involves the injection of cement, water and an additive chloranan into contaminated solids or sludges. Chloranan encapsulates the organic contaminants to prevent their interference with the solidification process. Contaminants are immobilized from soils in a concrete-like matrix that's leach resistant.	Water content, type of solid/slurry density of soil.	Demonstrated, No	Operation and maintenance \$100 to \$200 per yd <sup>3</sup> .	
In Situ Encapsulation	Organic and inorganic materials such as metals, esticides, phenols and PCB's.	Process involving injection and/or mixing of solidification/stabilization reagents with contaminated material. Mixing can be accomplished using agricultural spreaders and tillers, special augers, backhoes or clamshells.	Type of material, contaminant and reagent. Water content.	Demonstrated, No	Operation and maintenance \$100 to \$200 per yd <sup>3</sup> .	
Lime-Based Pozzolan	Organics and low levels of metals.	Contaminated materials are mixed with a carefully selected reactive, pozzolanic additive (typically bituminous coal fly ash) to a pasty consistency and subsequently blended with hydrated lime to form a solid mass.		Demonstrated, bench scale testing for dredged material	Operation and maintenance \$100 to \$200 per yd <sup>3</sup> .	Process only tolerates low levels of mercury and moderate levels of lead. Greater leachability than cement-based processes.
Portland Cement - Based	Arsenic, lead, zinc, copper, cadmium, nickel, PCB's.	Portland cement is added as a binding agent along with a pozzolanic product (fly ash) to react with any free calcium hydroxide and thus improve the strength, handling characteristics, and chemical resistance of stabilized sediment.	Type of contaminant, water content.	Demonstrated, bench scale testing for dredged material	Operation and maintenance \$100 to \$200 per yd.	Cement reduces the mobility of heavy metals due to their conversion to insoluble hydroxides or carbonates because of the elevated pH of cement. Other sorbents are added to improve characteristics.
Proprietary Processes	Typically metals and higher molecular weight organics.	A proprietary reagent is typically mixed with contaminant, then combined with a cement product to form a stabilized mass. There are a large number of these types of processes on the market.	Type of contaminant, soil type, reagent type.	Demonstrated, bench scale testing for dredged material	Operation and maintenance \$100 to \$200 per yd.	

TABLE A-12 — CONTAMINANT SEDIMENT TREATMENT/IMMOBILIZATION (Continued)						
Process	Applicable Contaminants	Mechanism	Factors Affecting	Remediation of Sediments, Dredged Materials	Typical Cost	Comments
Sorption	Organic and inorganics.	Process typically involves adding a solids material to soak up the free liquid in a soil or waste to produce a product that is easier to handle. Sorbents include natural materials such as fly ash, kiln dust, vermiculite and bentonite, as well as synthetic materials such as activated carbon, resins, Hazorb, Locksorb, etc.	Quantity of sorbent for removal of liquid varies according to the nature of the liquid, solids content of the waste and chemical reactions that may occur.	Demonstrated, No	Operation and maintenance \$100 to \$200 per yd.	Sorbents are inexpensive and plentiful, but are often required in large amounts, producing a problem of disposal.

TABLE A-13 – CONTAMINANT SEDIMENT TREATMENT/THERMAL						
Process	Applicable Contaminants	Mechanism	Factors Affecting	Remediation of Sediments, Dredged Materials	Typical Cost	Comments
Advanced Electric Reactor	PCBs, dioxins, heavily halogenated organics, nerve gas	Unit consists of a vessel with a porous carbon core surrounded by carbon electrides. A radiation heat shield surrounds the core and electrodes. Nitrogen acts as a gaseous blanket that isolates the reactants from the core and also acts as a heat transfer medium between the carbon electrodes and porous core. Two post reactor zones are connected in series.	Temperature, residence time	Pilot/No	Operation and maintenance greater than \$200 per yd <sup>3</sup> .	Transfers energy to the waste through radiation.
Circulating Bed Combustor	Halogenated, nonhalogenated hydrocarbons.	Process uses high air velocity to circulate solids and create a larger and more agitated combustion zone. Dry limestone is added to feed material to react with the acid gas so that a wet scrubber is not necessary.	Temperature, residence time	Demonstrated, yes	Operation and maintenance \$100 to \$200 per yd <sup>3</sup> .	Uses relatively low temperatures, 1600°F, due to the high degree of turbulence.
Eco-Logic	Chlorinated wastes, organic wastes containing PCBs, halogenated benzene, phenols, cycloalkane, alkanes, dioxin, dibenzofuran.	Thermochemical destruction process that relies on the ability of hydrogen to dechlorinate organic compounds at high temperatures.	Temperature, residence time	Pilot/Pilot	Operation and maintenance \$100 to \$200 per yd <sup>3</sup> .	Mobile unit
Fluidized-Bed Incineration	Halogenated and nonhalogenated organics, phenols, methyl methacrylate, oil refinery wastes.	Process consists of a cylindrical, vertical, refractory-lined vessel that contains an inert granular material, usually sand, on a perforated metal plate. Combustion air is introduced at the bottom of the incinerator and bubbles through the inert bedding material, causing the bedding material to become fluidized and agitated. The waste is pumped into the vessel and is combusted within the bubbling material.	Temperature, residence time	Demonstrated, No	Operation and maintenance greater than \$200 per yd <sup>3</sup> .	

**TABLE A-13 – CONTAMINANT SEDIMENT TREATMENT/THERMAL (Continued)**

Process	Applicable Contaminants	Mechanism	Factors Affecting	Remediation of Sediments, Dredged Materials	Typical Cost	Comments
High Temperature Slag Incineration	Waste including low-level radioactive wastes and most stable chlorinated aromatics.	Process transforms waste into a mechanically strong and chemically stable basalt-like material in granular or bulk form. A homogenous waste stream is fed into a combustion chamber. A burner then heats the top of the waste into a layer of molten slag. The slag droplets flow to a granulator where they are quenched, causing them to burst into granules.	Temperature, residence time	Demonstrated, No	Operation and maintenance greater than \$200 per yd <sup>3</sup> .	
Infrared incineration	Halogenated and nonhalogenated organics, dioxins, spent activated carbon.	Waste is prepared to the consistency and size required. Feed is then fed on a wire mesh conveyor belt into infrared primary chamber. Material is stirred gently by rotary rakes, or cake breakers.	Temperature, residence time, waste layer thickness, combustion air flow rate.	Pilot, No	Operation and maintenance greater than \$200 per yd <sup>3</sup> .	
In-Situ Vitrification	Organics, inorganics, heavy metals, PCBs	Process converts waste into a chemically inert and stable glass and crystalline product. Mechanism involves placing 4 large electrodes vertically inserted in a square arrangement in the soil. Graphite is placed on the surface to complete the circuit between electrodes. Sand, glass frit, or soda ash can be added to the soil to improve process. Combustion gases need to be processed.	Current, electrode spacing, water content.	Pilot, Bench	Operation and maintenance greater than \$200 per yd <sup>3</sup> .	
Low Temperature Thermal Stripping	Volatile organics and PCBs	Only enough heat is applied to volatilize contaminants.				

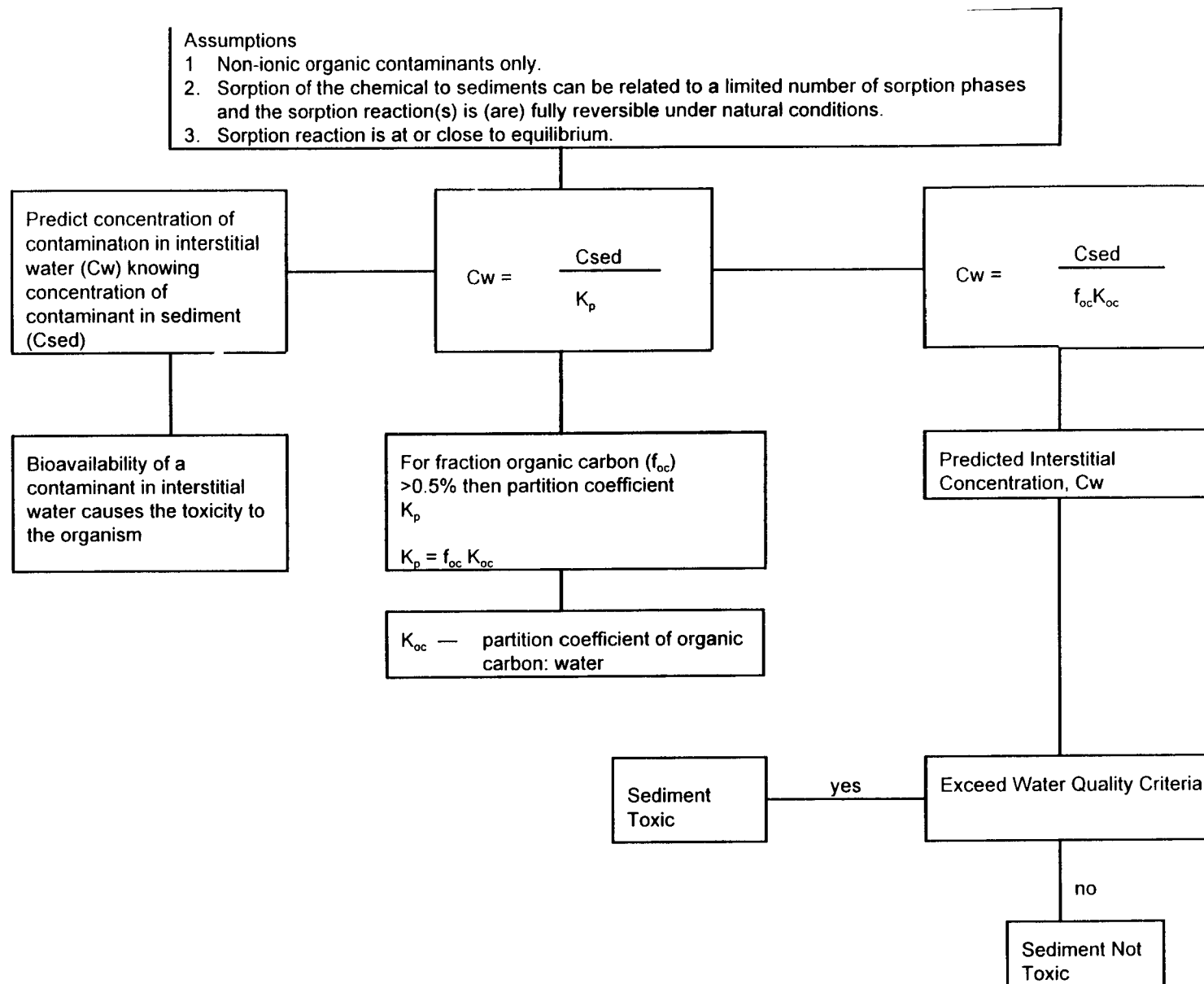


Figure A-1 -- Summary of EPA's -- EqP Model For Estimating Toxicity Of Non-Ionic Organic Chemicals in Sediments

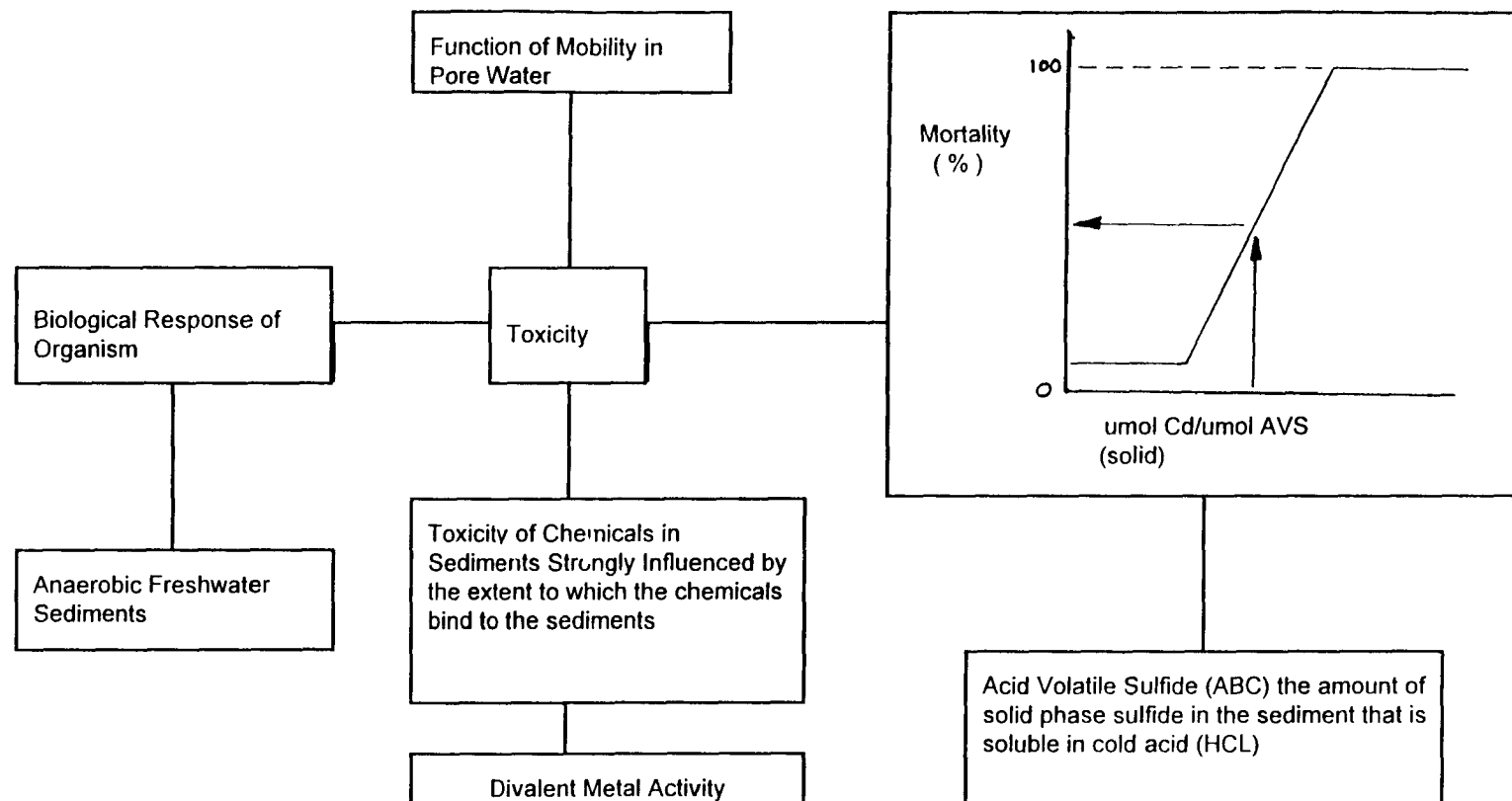
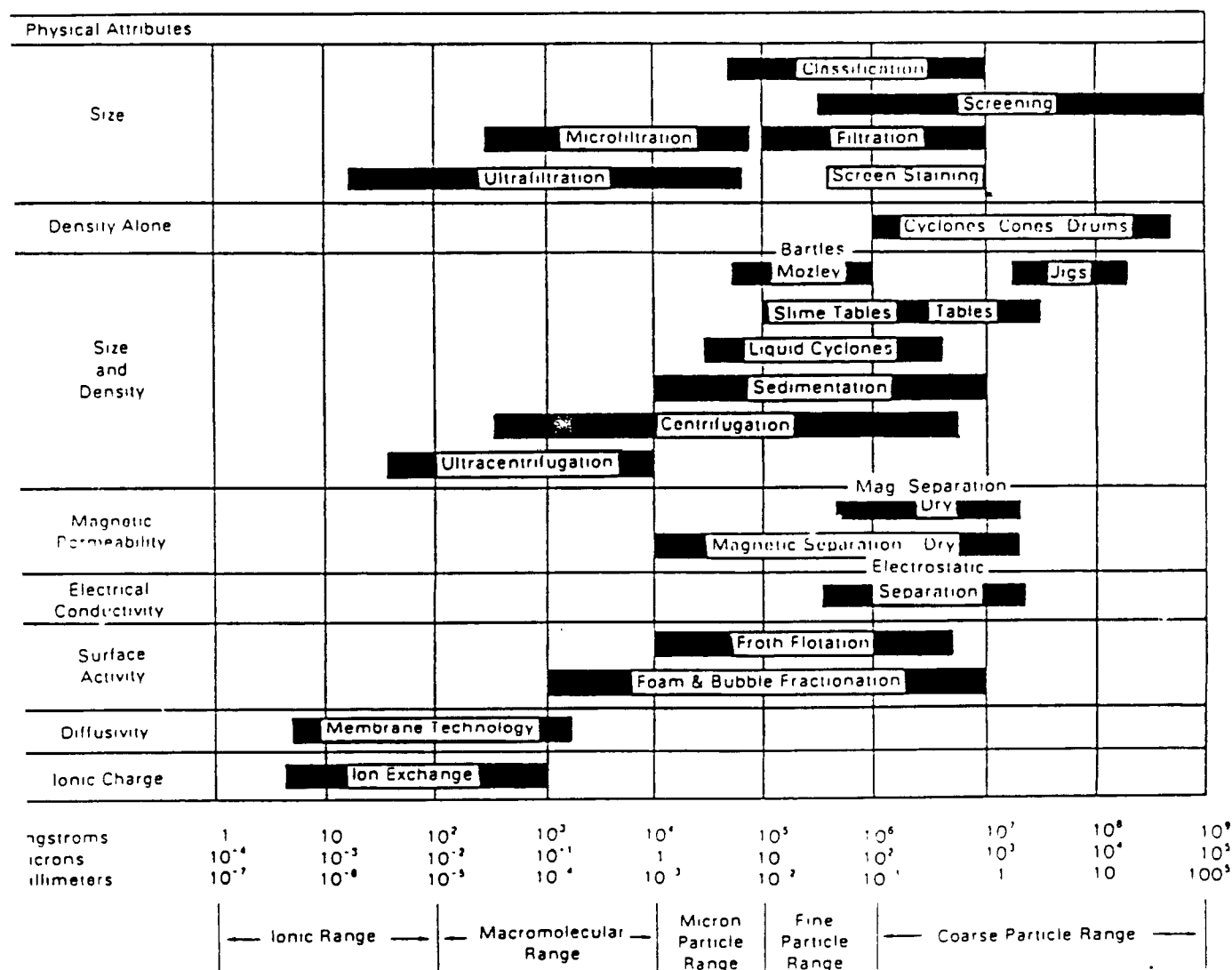


Figure A-2 - Summary of Acid Volatile Sulfide Method for Determination of Toxicity of Cadmium in Sediments



**Figure A-3 Physical Separation Technology and Particle Size**  
(Ref. EPA, 1988)



## **APPENDIX B**

### **ENVIRONMENTAL PERFORMANCE REQUIREMENTS**

**TABLE B1**      Summary of EPA Water Quality Criteria or Lowest Observed Effects Levels Where Criteria are Absent

**TABLE B2**      Standards for Contaminant Concentrations in Drinking Water

**TABLE B3**      Demonstrated Effects of Contaminants on Plants

**TABLE B4**      Additional Action Levels for Contaminants in Foodstuffs Used by Various Countries

**TABLE B5**      Action Levels for Various Heavy Metals and Pesticides in Plants and Foodstuffs

#### **REFERENCES**

Table B1

**Summary of EPA Water-Quality Criteria or Lowest Observed  
Effect Levels Where Criteria are Absent**

Pollutant	Priority Pollutant (Carcinogen)**	Type Criteria - Concentration, ug/l*			
		Fresh Water		Marine	
		Acute	Chronic	Acute	Chronic
Acenaphthalene	N				
Ancenaphthene	Y	1,700.000*	520.000*	970.0*	500*
Acrolein	Y	68.000	21.000	55.0	
Acrylonitrile	Y (Y)	7,500.000*	2,600.000*		
Aldrin	Y (Y)	3.000		1.3	
Aluminum	N				
Ammonia, total	N	15.700	3.900		
Ammonia, unionized	N	0.092	0.022		
Analine	N				
Antimony	Y	9,000.000*	1,600.000*		
Arsenic	N	360.000	190.000		
Arsenic (V)	N	850.00*	48.000*	2,319.0*	13*
Arsenic (III)	Y (Y)	360.000	190.000	69.00	36
Asbestos	Y (Y)				
Barium	N				
Benzene	Y	5,300.000*		5,100.0*	700*
Benzidine	Y (Y)	2,500.000*			
Beryllium	Y (Y)	130.000*	5.300*		
BHC	Y	100.000*	0.340*		
Bis-2-chloroethoxy methane	N				

(Continued)

- \* An asterisk (\*) following a number indicates that the value represents the lowest observed effect level (LOEL); when no asterisk appears, the value is an established EPA water-quality criterion.
- \*\* The first letter indicates that the compound is (Y) or is not (N) an EPA priority pollutant; the letter in parentheses designates a known carcinogen (Y) or a suspected carcinogen (S).

From Lee et al (1991)

Table B2

Standards for Contaminant Concentrations in Drinking Water

Parameter, mg/l (unless otherwise noted)	Drinking Water Standards	
	Federal	State of Washington
Arsenic	0.0500	0.0500
Barium	1.0000	1.0000
Cadmium	0.0100	0.0100
Chromium	0.0500	0.0500
Lead	0.0500	0.0500
Mercury	0.0020	0.0020
Selenium	0.0100	0.0100
Silver	0.0500	0.500
Fluoride	1.4-2.4000	1.4-2.4000
Nitrate (as N)	10.0000	10.0000
Endrin	0.0002	0.0002
Lindane	0.0040	0.0040
Methoxychlor	0.1000	0.1000
Toxaphene	0.0050	0.0050
2,4-D	0.1000	0.10000
2,4,5-TP Silvex	0.0100	0.0100
Trihalomethanes	0.1000	0.1000
Turbidity (JU)	1.0000	1.0000
Coliform bacteria membrane filter test (lb/100 ml)	1.0000	1.0000
Gross alpha (pCi/l)	15.0000	15.0000
Combined Radium 226 and Radium 228	5.0000	5.0000
Beta and photon particle activity (Mrem/yr)	4.0000	4.0000
Sodium	Monitor	250.0000
Chloride	250.0000	250.0000
Color (units)	15.0000	15.0000
Copper	1.0000	1.0000
Corrosivity	Noncorrosive	Noncorrosive
Foaming agents	0.5000	0.5000
Iron	0.3000	0.3000
Manganese	0.0500	0.0500
Odor (threshold number)	3.0000	3.0000
pH (units)	6.5-8.5000	6.5-8.5000
Sulfate	250.0000	250.0000
Total dissolved solids	500.0000	500.0000
Zinc	5.0000	5.0000

From Lee et al (1991)

Table B3

**Demonstrated Effects of Contaminants on Plants**

<u>Contaminant</u>	<u>Plant Growth Effect-Contaminant Content, mg/kg leaves</u>				
	<u>Normal*</u>	<u>Critical Content**</u>	<u>10% Yield Reduction**</u>	<u>25% Yield Reduction</u>	<u>Phytotoxic*</u>
Arsenic	0.1-1	--	--	--	3-10 75
Boron	775	--	--	--	5-700
Cadmium	0.1-1	8	15	Varies	25-100
Cobalt	0.01-0.3	--	--	--	20
Chromium (III), oxides	0.0-1	--	--	--	25-40
Copper	3-20	20	20	2040	--
Fluorine	1-5	--	--	--	--
Iron	30-300	--	--	--	--
Manganese	15-150	--	--	500	400-2,000
Molybdenum	0.1-3.0	--	--	--	100
Nickel	0.1-5	11	26	50-100	500-1,000
Lead	2-5	--	--	--	--
Selenium	0.1-2	--	--	--	100
Vanadium	0.1-1	--	--	--	10
Zinc	15-150	200	290	500	500-1,500

\* From Chaney (1983).

\*\* From Davis, Beckett, and Wollan (1978); Davis and Beckett (1978); Beckett and Davis (1977).  
From Chaney et al. (1978).

From Lee et al (1991)

**Table B4**  
**Additional Action Levels for Contaminants in Foodstuffs Used by Various Countries**

Source	Contaminant	Commodity	Content, mg/kg	References*
Britain	Lead	All foods	1.00 (fresh wt)	MAFF (1972)
World Health Organization (WHO)	Lead	Root vegetables	0.10 (fresh wt)	WHO (1972)
		Cereal	0.10 (fresh wt)	
		Leafy vegetables	1.20 (fresh wt)	
	Cadmium	Root vegetables	0.05 (fresh wt)	WHO (1972)
		Leafy vegetables	0.10 (fresh wt)	
		Potatoes, cereal	0.10 (fresh wt)	
Dutch	Copper	Animal feed	20.00 (dry wt)	DMAFCMN (1973)
Dutch (unofficial)	Cadmium	Single animal feed	0.50 (dry wt)	European Community (1974)
		Mixed animal feed	1.00 (dry wt)	
		Roughage	1.00-2.00 (fresh wt)	
European Economic Community	Lead	Single animal feed	10.00 (dry wt)	Van Driel, Smilde, and Van Luit (1983)
		Mixed animal feed	5.00 (dry wt)	
		Roughage	40.00 (fresh wt)	
FDA (as of Sep 82)	Mercury	Wheat seed	1.00 (dry wt)	FDA (1987)
	Various pesticides	Vegetables, grains, and feeds	0.03-0.10	

- \* MAFF      Ministry of Agriculture, Fisheries, and Food, United Kingdom  
WHO      World Health Organization  
DMAFCMN      Dutch Ministry of Agriculture and Fisheries, Committee on Mineral Nutrition  
FDA      U.S. Federal Drug Administration

**Table B5**  
**Action Levels for Various Heavy Metals and Pesticides in Plants and Foodstuffs**

Substance	Commodity	Data Source *	Action Level	Type of Limit **	Step	Reference
Aflatoxin	Cottonseed meal (non-dairy)	1	300.0000 ppb	--	--	CPG 7126.33
	Finished feeds	1	20.0000 ppb	--	--	CPG 7112.07
	Brazil nuts	1	20.0000 ppb	--	--	CPG 7112.02
	Peanuts	1	20.0000 ppb	--	--	CPG 7112.08
	Pistachio nuts	1	20.0000 ppb	--	--	
Aldrin and dieldrin	Grain (raw cereal)	2	0.0200 mg/kg	PRL	9	--
	Rice (in the husk)	2	0.0200 mg/kg	T	9	--
	Animal feed	1	0.0300 ppm	--	--	CPG 7141.01-B.1
	Vegetables	2	0.1000 mg/kg	T	9	--
	Artichokes	1	0.0500 ppm	--	--	CPG 7141.01-B.1
	Lettuce and carrots	2	0.1000 mg/kg	PRL	9	--
	Fruits	1	0.500 ppm	--	--	CPG 7141.01-B.1
	Melons	1	0.1000 ppm	--	--	CPG 7141.01-B.1
Arsenic	Non-pulpy black-currant nectar	3	0.2000 mg/kg	--	--	CAC/RS 101-1978
	Fructose	3	1.0000 mg/kg			CAC/RS 102-1978
	Cocoa powders and dry cocoa-sugar mixtures	3	1.0000 mg/kg			CAC/RS 105-1978
Benzene hexachloride (BHC)	Grain (animal feed)	1	0.0500 ppm	--	--	CPG 7141.01-B.2
	Grain (human food)	1	0.0500 ppm	--	--	CPG 7141.01-B.2
	Vegetables	1	0.5000 ppm	--	--	CPG 7141.01-B.2
	Fruits	1	0.5000 ppm	--	--	CPG 7141.01-B.2
Cadmium	Provisional weekly tolerance intake for humans	2	0.0067-			
			0.0083 mg/kg body weight			

(Continued)

\* Data source:

- 1 - FDA action levels for poisonous or deleterious substances in human food and animal feed, March 1987.
- 2 - (1982) Food and Agricultural Organization (FAO)/World Health Organization (WHO) Guide to Codex Maximum Limits for Pesticide Residues
- 3 - List of maximum levels recommended for contaminants by the joint FAO/WHO Codex Alimentarius Commission. Joint FAO/WHO food standards programme Codex Alimentarius Commission CAC/FAL 4-1978.

\*\* Type of limit:

- CPG - Compliance policy guidelines
- TT - Temporary codex tolerance
- T - Codex tolerance
- PRL - Practical residue limit

Step - Step in the procedure for the elaboration of Codex Maximum Limits for Pesticide Residue given in the FAO/WHO Guide to CODEX M

Reference - Refers to CPG number

Table B5 (Continued)

Substance	Commodity	Data Source *	Action Level	Type of Limit **	Step	Reference
Chlordane	Root and tuber vegetables	2	0.30 mg/kg	T	6	71(1)
	Sugar beet	2	0.30 mg/kg	T	9	--
	Leafy vegetables	2	0.20 mg/kg	T	6	71(1)
	Stem vegetables	2	0.20 mg/kg	T	6	71(1)
	Legume vegetables	2	0.02 mg/kg	T	9	--
	Fruiting vegetables	2	0.10 mg/kg	T	9	--
	Citrus fruits	2	0.02 mg/kg	T	9	--
	Assorted fruits	2	0.10 mg/kg	T	6	--
	Pineapple	2	0.10 mg/kg	T	9	--
	Passion fruit	2	0.10 mg/kg	T	6	72(1)
	Pome fruit	2	0.02 mg/kg	T	9	--
	Stone fruit	2	0.02 mg/kg	T	9	--
	Small fruits and berries	2	0.10 mg/kg	T	6	--
	Cottonseed oil, crude	2	0.10 mg/kg	T	9	--
	Cottonseed oil, edible	2	0.02 mg/kg	T	9	--
	Linseed oil, crude	2	0.50 mg/kg	T	9	--
	Soya bean oil, crude	2	0.50 mg/kg	T	9	--
	Soya bean oil, edible	2	0.02 mg/kg	T	9	--
	Grain, animal feed	1	0.10 ppm	--	--	CPG 7141.01-B.3
	Nuts	2	0.10 mg/kg	--	--	--
Copper	Non-pulpy black-currant nectar	3	5.00 mg/kg	--	--	CAC/RS 101-1978
	Fructose	3	2.0 mg/kg	--	--	CAC/RS 102-1978
	Cocoa powders and dry cocoa-sugar mixtures	3	50.00 mg/kg	--	--	CAC/RS 105-1978
	Edible acid casein	3	5.00 mg/kg	--	--	18th sessions-1976
	Edible caseinates	3	5.00 mg/kg	--	--	App. VI, CS 5/70 18th session-1976
Crotalaria Seeds	Grains and feeds	1	Avg of one whole seed/pound	--	--	CPG 7126.15
DDT, DDE, and TDE	Grain, animal feed	1	0.50 ppm	--	--	CPG 7141.01-B.5
	Grain, human food	1	0.50 ppm	--	--	CPG 7141.01-B.5
	Cocoa beans	1	1.00 ppm	--	--	CPG 7141.01-B.5
Endrin	Vegetables	1	0.05 ppm	--	--	CPG 7141.01-B.7
	Fruits	1	0.05 ppm	--	--	CPG 7141.01-B.7
	Oilseed meal, animal feed	1	0.03 ppm	--	--	CPG 7141.01-B.7
	Cottonseed oil, crude	2	0.10 mg/kg	T	9	--
	Cottonseed, oil, edible	2	0.02 mg/kg	T	9	--
	Linseed oil, crude	2	0.50 mg/kg	T	9	--

(Continued)

(Sheet 2 of 5)



Table B5 (Continued)

Substance	Commodity	Data Source*	Action Level	Type of Limit**	Step	Reference
Endrin (Continued)	Soya bean oil, crude	2	0.50 mg/kg	T	9	--
	Soya bean oil, edible	2	0.02 mg/kg	T	9	--
	Vegetable oils and fats	1	0.30 ppm	--	--	CPG-7141.01-B.7
	Nuts	2	0.10 mg/kg	T	6	72 (1)
Fenthion	Root and tuber vegetables	2	0.10 mg/kg	TT	3	JMPR 1977
	Bulb vegetables	2	0.10 mg/kg	TT	3	JMPR 1977
	Squash	2	0.20 mg/kg	TT	6	--
	Leafy vegetables	2	2.00 mg/kg	TT	6	--
	Brassica leafy vegetables	2	1.00 mg/kg	TT	6	--
	Legume vegetables	2	0.10 mg/kg	TT	3	--
	Assorted fruits	2	2.00 mg/kg	TT	6	--
	Bananas	2	1.00 mg/kg	TT	3	JMPR 1977
	Stone fruits	2	0.20 mg/kg	TT	6	--
	Plums	2	0.10 mg/kg	TT	3	JMPR 1977
	Small fruits and berries	2	0.20 mg/kg	TT	3	JMPR 1977
	Grapes	2	0.50 mg/kg	TT	6	--
	Cereal grains	2	0.10 mg/kg	TT	6	--
	Oilseed	2	0.10 mg/kg	TT	6	--
Heptachlor and heptachlorepoide	Vegetables	2	0.05 mg/kg	PRL	9	--
	Vegetables	1	0.01 ppm	--	--	CPG 7141.01-B.9
	Tomato	2	0.02 mg/kg	PRL	--	--
	Carrot	2	0.20 mg/kg	PRL	9	--
	Sugar beet	2	0.05 mg/kg	PRL	9	--
	Fruits	1	0.01 ppm	--	9	CPG 7141.01-B.9
	Fruits	2	0.01 mg/kg	PRL	--	--
	Grain, animal feed	1	0.01 ppm	--	9	CPG 7141.01-B.9
	Rice, human food	1	0.03 ppm	--	--	CPG 7141.01-B.9
	Raw cereal	2	0.02 mg/kg	PRL	--	--
	Soya bean oil, crude	2	0.50 mg/kg	PRL	9	--
	Soya bean oil, edible	2	0.02 mg/kg	PRL	9	--
	Cottonseed	2	0.02 mg/kg	PRL	9	--
Iron	Non-pulpy black currant nectar	3	15.00 mg/kg	--	--	CAC/RS 101-1978, App. V., CX 5/70
	Edible acid casein	3	20.00 mg/kg	--	--	18th session-1976
	Edible caseinates	3	50.00 mg/kg	--	--	App. VI, CX 5/70 18th session-1976
Kelthane (Dieldrin)	Animal feed	1	0.50 ppm	--	--	CPG 7141.01-B.6
Kepon (Chlordane)	--	--	--	--	--	CPG 7141.01-B.4

(Continued)

(Sheet 3 of 5)

Table B5 (Continued)

Substance	Commodity	Data Source*	Action Level	Type of Limit**	Step	Reference
Lead	Non-pulpy black currant nectar	3	0.300 mg/kg	--	--	CAC/RS 101-1978
	Cocoa powders and d.y cocoa-sugar mixtures	3	2.0000 mg/kg	--	--	CAC/RS 105-1978 App. V, CS 5/70
	Edible acid casein	3	2.0000	--	--	18th session
	Edible caseinates	3	2.0000	--	--	App. VI, CS 5/70 18th session
Lindane	Vegetables	1	0.5000 ppm	--	--	CPG 7141.01-B.10
	Root and tuber vegetables	2	0.0500 mg/kg	T	5	JMPR 1975
	Leafy vegetables	2	0.2000 mg/kg	T	3	JMPR 1975
	Brassica vegetables	2	0.5000 mg/kg	T	3	JMPR 1975
	Stem vegetables	2	0.5000 mg/kg	T	5	JMPR 1975
	Legume vegetables	2	0.1000 mg/kg	T	9	109 (1)
	Peas	2	0.1000 mg/kg	T	5	JMPR 1975
	Assorted fruits	2	0.5000 mg/kg	T	9	110 (1)
	Small fruits and berries	2	0.5000 mg/kg	T	3	111 (5)
	Cranberries	2	0.3000 mg/kg	T	5	
	Fruits	1	0.5000 ppm	--	--	CPG 7141.01-B.10
	Grain, animal feed	1	0.1000 ppm	--	--	CPG 7141.01-B.10
	Grain, human food	1	0.1000 ppm	--	--	CPG 7141.01-B.10
Mercury	Wheat (pink kernels only)	1	1.0000 ppm	--	--	CPG 7104.05
	Provisional tolerable weekly intake for humans	3	0.0050 mg total Hg/kg body weight 0.0033 mg methylmercury /kg body weight	--	--	
Methyl alcohol	Imported brandy	1	0.3500 percent	--	--	CPG 7119.09
Nitrosodimethylamine (NDMA)	Barley malt	1	10.0000 ppb	--	--	CPG 7104.07
	Malt beverages	1	5.0000 ppb	--	--	CPG 7101.07
Paralytic shellfish toxin	--	--	--	--	--	--
Polychlorinated biphenyls (PCB's)	Red meat fat		3.0000 ppm	--	--	21 CFR 109.30 (a) (9) and 509.30 (a) (9) tolerance used stayed on 8-24-73 (38 FR 22794) 21 CFR 109.6 (d) and 509.6 (d)

(Continued)

(Sheet 4 of 5)

Table B5 (Continued)

<u>Substance</u>	<u>Commodity</u>	<u>Data Source*</u>	<u>Action Level</u>	<u>Type of Limit**</u>	<u>Step</u>	<u>Reference</u>
Tin	Canned fruit cocktail	3	250.0 mg/kg	--	--	CAC/RS 78-1974
	Canned mature processed peas	3	250.0 mg/kg	--	--	CAC/RS 81-1976
	Canned tropical fruit salad	3	250.0 mg/kg	--	--	CAC/RS 99-1978
	Non-pulpy black currant nectar	3	150.0 mg/kg	--	--	CAC/RS 101-1978
Toxaphene	Animal feed, processed	1	0.5 ppm	--	--	CPG 7141.01-B.12
	Vegetables	1	1.0 ppm	--	--	CPG 7141.01-B.12
	Fruits	1	1.0 ppm	--	--	CPG 7141.01-B.12
Zinc	Non-pulpy black currant nectar	3	5.0 mg/kg	--	--	CAC/RS 101-1978

Table B6

**Action Levels and Maximum Concentrations for Contaminants in Aquatic  
Organisms for Human Consumption**

<u>Chemical</u>	<u>Food</u>	<u>Action Level* mg/kg (wet weight edible portions)</u>	<u>Maximum Concentration** mg/kg (wet Weight edible Portions)</u>
Aldrin	Fish and shellfish	0.3	
Antimony	All nonspecified foods (including seafood)		1.5
Arsenic	Fish, crustacea, molluscs		1.0
Cadmium	Fish Molluscs		0.2 1.0
Chlordane	Fish	0.3	
Copper	Molluscs All nonspecified foods (including seafood)		70.0 10.0
DDT, DDE, TDE	Fish	5.0	
Dieldrin	Fish and shellfish	0.3	
Endrin	Fish and shellfish	0.3	
Heptachlor, heptachlor epoxide	Fish and shellfish	0.3	
Hexachlorocyclohexane (Benzene hexachloride)	Frog legs		0.5
Kepona (Chlordecone)	Fish and shellfish Crabmeat	0.3 0.4	

(Continued)

- \* US Food and Drug Administration (FDA) action levels for poisonous or deleterious substances in human food, CPG 7141.01, 1987.
- \*\* Australian National Health and Medical Research Council Standards for metals in food, May 1980.
- Action level is for these chemicals individually or in combinations. However, in adding concentrations, do not count any concentrations below the following levels:

<u>Chemical</u>	<u>Minimum Level, mg/kg</u>
DDT, DDE, TDE	0.2
Heptachlor, heptachlor epoxide	0.3

**Table B6 (Concluded)**

<u>Chemical</u>	<u>Food</u>	<u>Action Level mg/kg (wet weight edible portions)</u>	<u>Maximum Concentration mg/kg (wet Weight edible Portions)</u>
Lead	Molluscs		2.5
	All nonspecified foods (including seafood)		1.5
Mercury	Fish, crustacea, molluscs		0.5
Methylmercury	Fish, shellfish, other aquatic animals	1.0	
Mirex	Fish	0.1	
PCB (total)	Fish and shellfish	2.0	
Selenium	All nonspecified foods (including seafood)		1.0
Tin	Fish		50.0
Toxaphene	Fish	5.0	
Zinc	Oysters		1,000.0
	All nonspecified foods (including seafood)		150.0

\* This is not an action level but is a tolerance limit established through the rulemaking process.

From Lee et al (1991)

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## APPENDIX C

### GEOSYNTHETICS IN WASTE CONTAINMENT SYSTEMS

In Section 1, six pathways that would potentially allow contaminants to escape a CDF were defined. These pathways included (1,2) loss of soluble contaminants in the dredge slurry via effluent discharge or leachate; (3) loss of contaminated dredge solids carried by surface water run-off; (4,5) loss of contaminants by plant or animal uptake; and (6) loss from volatilization of contaminants into the atmosphere. Geosynthetic components are key to the design and performance of traditional hazardous and solid waste containment systems. This appendix reviews applications of geosynthetic components in waste containment systems. Section 6 examines the use of these components for limiting contaminant pathways in the CDF contaminant basin. Section 7 presents the use of geosynthetic components in the final closure of a CDF.

Contaminant pathways in conventional waste containment systems are controlled using a system of barrier layers to limit the movement of liquids (leachates), drainage/collection layers that remove the liquids to minimize the hydraulic head acting on the barrier layer, and filter layers that prevent clogging of the drainage system and maintain separation of the layers. For hazardous wastes, EPA minimum technology guidance (MTG) is based on the waste containment system shown on Figure C.1. This system uses two lining systems, an upper geomembrane and a lower composite liner consisting of a geomembrane over a clay liner. Above each of the two liners is a leachate drainage/collection system that removes trapped leachate and prevents the development of a large hydraulic head on the liner. A minimum of one filter layer is required to ensure operation of the upper drainage system.

#### C.1 Barrier Systems

Barrier layers are designed to limit the movement of water and contaminants across the layer. Such barriers include compacted clay layers, asphalt layers, and geosynthetic layers. These layers limit the movement of contaminants by advective transport across the layer but do not completely limit diffusion of contaminants across the layer. For contaminants associated with CDFs and typical waste containment applications this limitation is acceptable.

Common synthetic barrier systems include geomembranes and geosynthetic clay liners (GCLs). Both barriers systems are commercially manufactured, delivered to the field in large rolls or panels, and are commonly used both alone and in conjunction with a conventional soil liner/barrier system. The geomembranes have been the subject of extensive EPA research. Technical guidance documents (TGDs) are available to aid in geomembrane selection, design, and installation. GCLs are relative new-comers to waste containment applications but have been evaluated in limited EPA workshops and are the subject of current EPA research. At present, EPA recommendations limiting the use of GCLs to covers and as a component in the primary liner of a RCRA C waste containment cell.

### 5.1.1 Geomembrane Barrier Systems

Proper application of a geomembrane to waste containment systems requires evaluation of the following: chemical compatibility of the geomembrane with the contaminants; proper design of the geomembrane to protect and limit stresses in the membrane; and construction quality assurance to ensure proper installation. Guidelines for all evaluations can be based on available technologies developed initially for hazardous waste containment:

**Chemical Compatibility of Geomembrane** ---- The chemical compatibility of a geomembrane with a waste leachate must be evaluated using the EPA Method 9090 test. This test requires a long test period, exceeding 120 days, and a quantity of the anticipated leachate. Most geomembranes will absorb constituents of the leachate and swell during exposure to leachates containing organics. Exceptions include PVCs that may lose plasticizer due to the organics and shrink. The chemical resistance of a geomembrane is related to the solubility of the polymer in the leachate, crosslinking of the polymer, degree of crystallinity, nature of the filler in the compound, and the molecular weight (MW) and MW distribution of the polymer. It is therefore difficult to generalize regarding chemical compatibility.

**Design of Geomembrane Liner** ---- Comprehensive design guidelines for geomembranes are available in the literature (Richardson and Koerner, 1988 and Koerner, 1991) and are beyond the scope of this document. General geomembrane design objectives and key design considerations are, however, reviewed in this section. The design of a geomembrane must ensure that the membrane experiences minimal tensile stresses in service and is not damaged by puncture during installation or service. Key design considerations include the following:

- |                  |   |
|------------------|---|
| <i>Puncture</i>  | A geomembrane must be protected from puncture during installation and as waste is placed in the facility. During placement, the geomembrane can be damaged by foreign objects such as sticks or large gravel particles or rocks within the adjacent soil. It is possible to protect the geomembrane from damage by using a cushion layer of sand or geotextile. Generally the soil adjacent to the geotextile must have a maximum particle size less than 1 inch. Placement of sediments directly on a geomembrane would be impacted by the dredging method used, e.g. slurry versus clamshell. |
| <i>Stability</i> | Common geomembranes, particularly HDPE, have a very slick surface that can create stability problems when used on slopes. The stability of dikes constructed with internal geomembrane barriers would have to be evaluated. Laboratory testing to determine interface friction angles is normally required on a site by site basis.   |
| <i>Anchorage</i> | Geomembranes must be anchored at their perimeters to prevent wind from blowing under the membrane. Such anchorage may be of temporary value if the membrane is to be buried within the system eventually. The anchorage system must be  |



designed so that the strength of the anchorage is less than the strength of the geomembrane. Thus failure of the anchorage should result in pullout and not tearing of the membrane.

**Weirs** Liquids contained by the geomembrane must be removed from the CDF through a weir or a sump. The connection of the geomembrane to a structural weir system requires the use of battens and consideration of potential differential settlements.

Additional design considerations unique to CDFs include evaluating the impact of the geomembrane of the consolidation of the sediments, placement of geomembranes having a specific gravity less than 1.0 in marine environments, and the potential for a partial barrier in the dike only. Specific design considerations for geomembranes are provided in the pathway evaluations provided in Sections 6 and 7.

In recent years, a commercial system of interlocking HDPE panels has been used to construct very low permeability vertical barriers (EPA, 1992a). These walls can be constructed within excavated trenches or in slurry trenches depending upon site conditions. Each HDPE panel interlocks with adjacent panels, see Figure C-3, similar to those used in conventional sheet pile walls. The vertical barriers can be used to restrict the outward migration of liquids or to restrict the inward migration of ground water.

**Construction Quality Assurance (CQA) ----** EPA has prepared specific recommendations for CQA programs developed to ensure that the geomembrane is properly installed (EPA/530/SW-91/051). CQA programs are a planned series of activities performed by the owner to ensure that the facility is constructed as specified in the design. There are five elements to a CQA program: (1) responsibility and authority, (2) CQA personnel qualifications, (3) inspection activities, (4) sampling strategies, and (5) documentation. Much of the CQA program for geomembranes focuses on the quality of field seams and detection construction damage. The end product of the CQA program is a certification document prepared by the CQA team to demonstrate that the geomembrane was installed as specified in the design. As-built drawings indicating field modifications, seam failures, patches, etc. are also part of the certification document.

### **C.1.2 GCL Barrier Systems**

GCLs are made by sandwiching bentonite granules between two geotextiles to form rolls or large panels of liner. The sandwich is held together using either a water soluble adhesive or by needling the two geotextiles together. Typical GCLs provide approximately one pound of bentonite per square foot and have a dry thickness of approximately 1/4 inch. GCL barrier layers have been used in CERCLA containment systems and covers over uranium mine tailings (e.g. UMTRA program) since 1988. They have the advantages of being easily placed in the field, inexpensive (especially if local clays are not available), and very tolerant of field abuse. During the past two years, the use of

GCLs in waste containment systems has been the subject of two EPA technical workshops. Ongoing research related to these workshops has focused on the following concerns:

<i>Stability</i>	As the bentonite in the GCL hydrates (absorbs water), the shear strength of the GCL can decrease significantly and create a plane of weakness within the facility;
<i>Seams</i>	GCL panels are joined by simply overlapping adjacent panels such that the integrity of the seam is dependent on the swelling and partial extrusion of the bentonite; and
<i>Chemical</i>	The permeability of the bentonite used in the GCLs can be significantly increased by the presence of leachate having a high ion exchange capacity.

GCLs may offer significant advantage for facilities such as CDFs where access for traditional construction equipment associated with clay liners is limited.

## **C.2 Drain/Collection Systems**

Waste containment systems that include barrier layers must also include adjacent layers that collect and remove the liquids retained by the barriers. Such drainage/collection drains traditionally have been constructed using sand or gravel layers. This same function can be performed by geonet drainage elements. Geonets are formed with a minimum of two layers of ribs oriented to produce a high planar flow capacity. The geonets are formed in a counter-rotating extruder and are typically 1/4 inch thick from the top of the upper rib to the bottom of the lower rib. Geonets can provide the same planar flow capacity as a 12 inch layer of sand having a permeability of  $10^{-2}$  cm/sec due to the high flow velocities within the net. The hydraulic flow capacity of a geonet is typically expressed as transmissivity (the product of layer thickness times layer permeability) as a function of gradient and normal pressure as shown on Figure C.2. The transmissivity of a geonet will decrease with increasing hydraulic gradient and normal stress.

There are two main concerns with geonets: first the crush strength at the intersection of the ribs must be sufficient to resist buckling and creep deformations during the service life of the geonet; and secondly adjacent layers must be prevented from intruding into the net voids when stressed by service loads. The latter problem is particularly important if the geonet is placed immediately adjacent to soft soils, such as dredge sediments, that can plastically flow between the ribs.

Geogrids are commonly available with a geotextile filter fabric bonded to one or two faces. Such products are called geocomposites and provide both drainage and filter systems in the same product. Geosynthetic filter systems are discussed in Section C.3.

One significant short coming of geonets compared to conventional sand drains is the reduced hydraulic storage capacity of the nets. Sand and gravel drainage layers can store a significant volume of water within their pore spaces. Geonets, however, are only a 1/4 inch thick and therefore

have almost no storage capacity. The use of geonet drains requires a liquid removal system that functions continually, but at possibly a very slow rate of removal.

### C.3 Filter Systems

Conventional filter systems are designed using graded layers of sands and gravel that increase the average particle size in the direction of flow. The filter criteria for natural soils follow basic criteria established by Terzaghi in 1922. The four main requirements of natural filters are:

- 1 - The filter material should be more pervious than the base material to ensure that no hydraulic pressure will build up to disrupt the filter and adjacent structures.
- 2 - The voids of the in-place filter material must be small enough to prevent base material particles from penetrating the filter and clogging the filter system.
- 3 - The layer of the protective filter must be sufficiently thick to provide a good distribution of all particle sizes throughout the filter.
- 4 - Filter particles must be prevented from movement into adjacent coarser layers or pipes.

Geotextile filter design parallels sand filter design with some modifications. Three of the above design elements remain the same: adequate flow, soil retention, and clogging.

Adequate flow through a geotextile is assessed by comparing the allowable permittivity ( permeability divided by thickness ) with that required to prevent build up of pressures within the base layer. Permittivity of a geotextile is obtained using the ASTM D4491 test method. Typical geotextile filters have sufficient permittivities when used adjacent to sands and fine grained soils.

Soil retention for a geotextile requires determining the effective opening size of the geotextile,  $O_{95}$ . The  $O_{95}$  of a geotextile is the opening size at which 5% of a given size glass bead will pass through the fabric. It is well established that the  $O_{95}$  of a geotextile is related to the particle size to be retained by the following type of relationship:

$$O_{95} < \text{fct.}(d_{50}, CU, D_R)$$

where  $O_{95}$  is the 95% opening size of the geotextile obtained using the COE CW 02215 test method,  $d_{50}$  is the 50% size of the particles to be retained, CU is the coefficient of uniformity of the particles to be retained, and  $D_R$  is the relative density of the particles to be retained.

The clogging potential of a geotextile can be evaluated using a the Gradient Ratio Test, COE test method CW 02215, or a long term flow reduction test as proposed by the Geosynthetic Research

Institute (GRI), test method GT1. Both tests place a sample of the actual soil to be retained against the geotextile and then flow water through the system. The test apparatus common to both the COE and GRI tests is shown on Figure C.3. The Gradient Ratio Test measures the increase in hydraulic gradient across the geotextile with an increase in gradient indicating increasing clogging. The GRI test simply monitors the flow rate out of the system under a constant system gradient. The flow rate should decrease slightly but then achieve an equilibrium flow rate. An ever decreasing flow rate indicates a clogging problem. The Gradient Ratio test can be performed in several days while the GRI test can require several months time.

Additional long term clogging of a geotextile may be caused by biological growth activity or from solids that precipitate from the water. Leachates rich in biological matter or potential precipitants should be tested using the GRI test.

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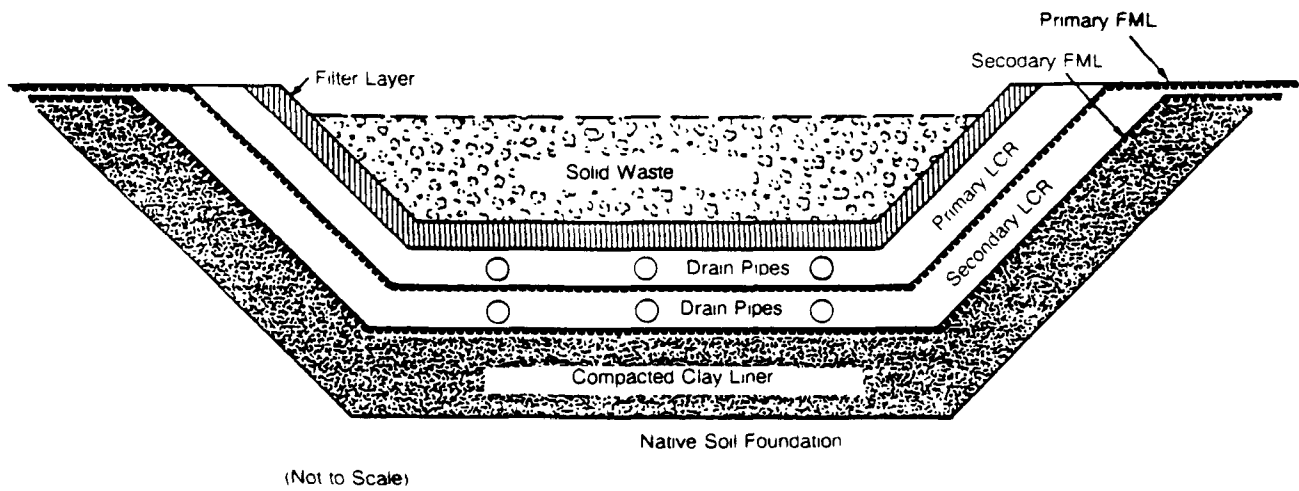
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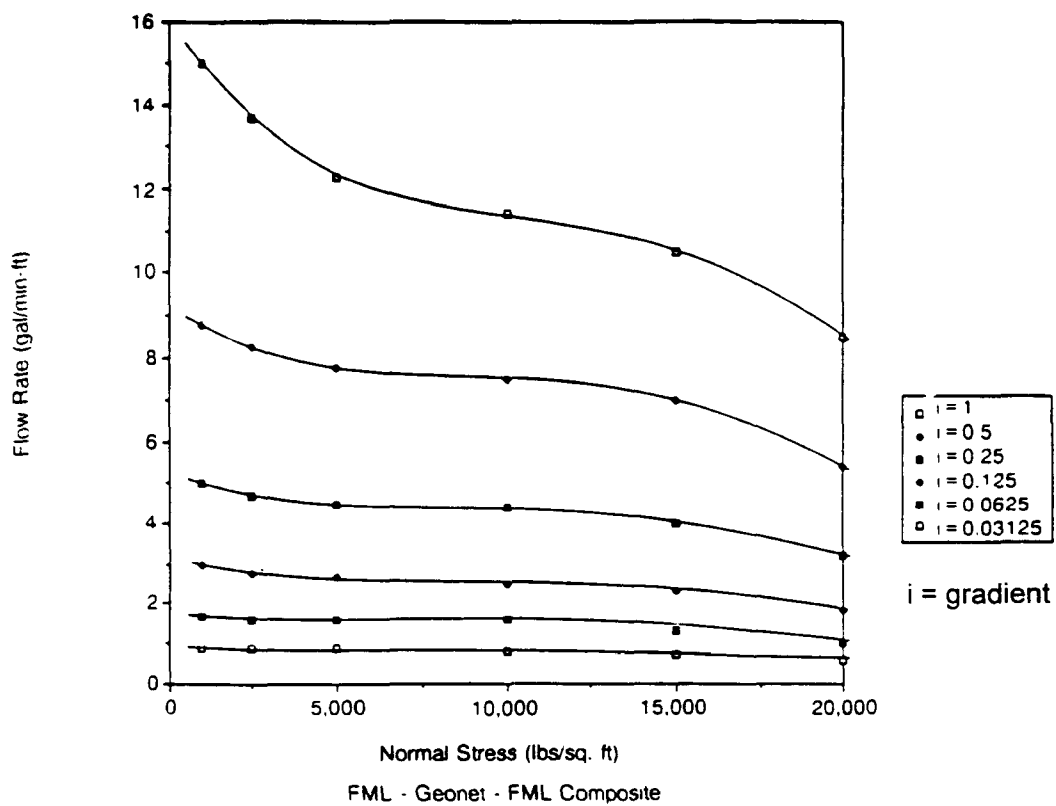
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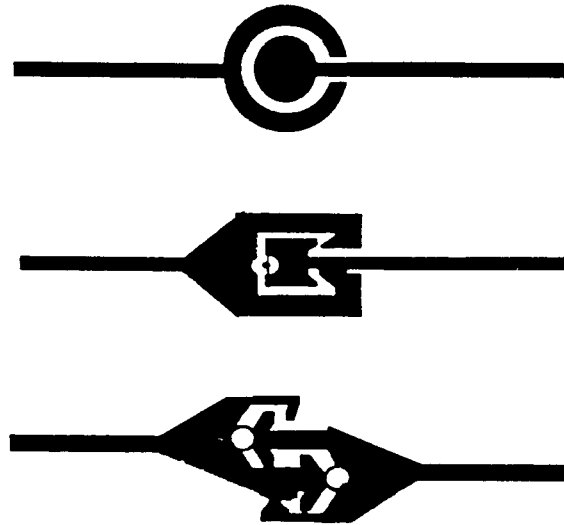
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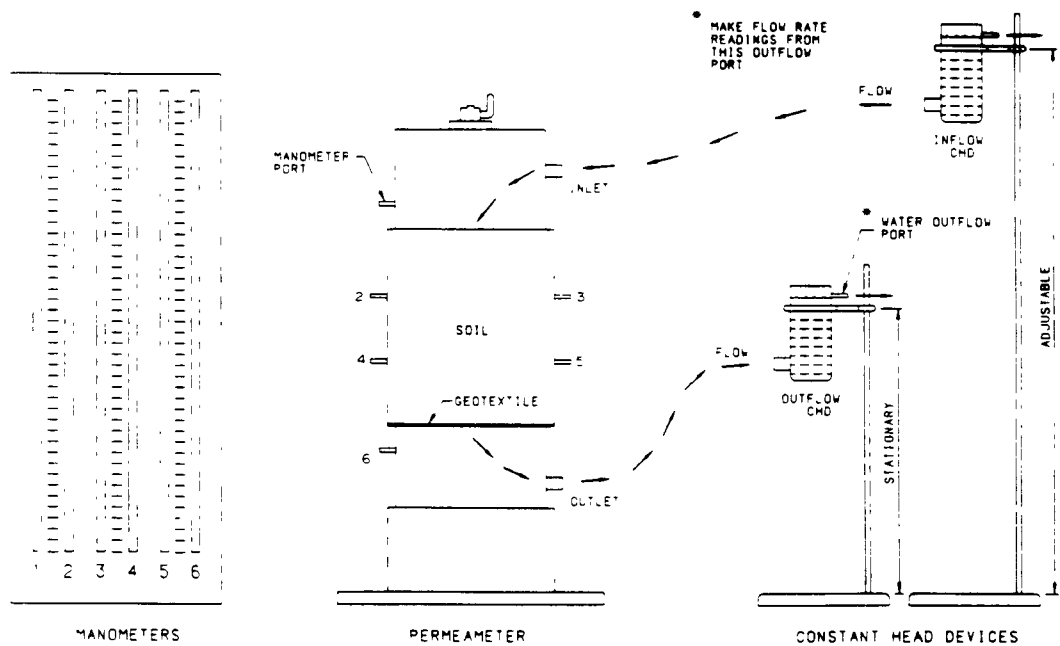
**Figure C-1 RCRA Minimum Technology Guidance Landfill**



**Figure C-2 Hydraulic Flow Capacity of Geonets**



**Figure C-3 Geomembrane Vertical Cutoff Wall Joints**



**Figure C-4 Gradient Ratio Test Device**

## **APPENDIX D**

### **CDF - REGION 5 SUMMARY TABLES**

**Table D-1**  
**Technical Specifications for In-Lake CDFs**

<b>Facility</b>	<b>Capacity (MCY)/ % Filled</b>	<b>Acres Area</b>	<b>Dike Construction</b>	<b>Liner/ Cap Design</b>	<b>Dewaterin g System</b>	<b>Effluent Treatmen t</b>
Cleveland Dike #12 (1974-1979)	2.8/100	56	Rubble mound	None/None	None	Natural settling
Cleveland Dike #14 (1979- )	6.1/40	88	Rubble mound with sheetpile cutoff	None/None	2 overflow weirs	Natural & granular dike filter - 2 oil skimmers
Lackawanna Dike #4 (1974- )	6.9/40	100	Rubble mound	None/None	Thru dike and overflow weir	Dike filter - natural settling
Erie (1979- )	1.640	22	Rubble mound. & sheetpile each face	None/None	Overflow weir - dike filter	Dike filter & natural settling
Huron (island) (1975- )	2.1/70	63	Rubble mound & cellular sheetpile & filter cloth	None/None	Thru dike/ pumping/ weirs	1-hour settling before pumping to lake
Lorain (1977- )	1.9/70	58	Rubble mound & sheetpile	None/None	Weir	Dike filter & settling
Buffalo (1968-1972)	1.5/100	33	Soil & slag core & limestone riprap	None/6 feet & construction ddbris	Thru dike	Natural setting
Times Beach (1972- )	1.5/45	45	Layered slag & rubble mound	None/None	Thru dike	Dike filter/ natural settling

MCY = million cubic yards  
mCY = thousand cubic yards



Table D-1 (Continued)

Facility	Capacity (MCY)/ % Filled	Acres Area	Dike Construction	Liner/ Cap Design	Dewaterin g System	Effluent Treatmen t
Toledo/ Facility #4 (1976- )	10/65	242	Limestone base with clay dike	Clay core/None	Overflow weir	Natural settling with oil skimmer
Toledo/ Grassy Island (1967- ? )	5.0/100	150	Granular fill (sandy loam)	None/None	Overflow weir	Natural settling
<u>CHICAGO DISTRICT</u>  Chicago/ Calumet Harbor (1984- )	1.3/20	42	Stone filled with limestone core	Plastic liner (30 mil)/2-foot clay liner & topsoil at closure	Pump thru filter cells	Primary and secondar y settling/sa nd-carbon filtration
<u>DETROIT DISTRICT</u>  Bayport/ Green Bay (1965-1979)	5.5/100	400	On-site material	None/cap planned	Overflow weir	Natural settling
Bolles Harbor (1978- )	0.33/25	25	Limestone with clay core, sheetpile revetments & filter cloth	None/None	Overflow weir	Natural settling & oil skimmer
Clinton River (1978- ? )	0.37/98	30	Dredged material from Clinton River channel, includes rip- rap	On-site clay/clay	None	Natural settling & oil skimmer
Erie Pier/Duluth (1979- )	1.1/65	82	On-site and dredged material with stone rip-rap-- 300' steel bulkhead on S.E. side	20 mil PVC liner/None	None	None--no outlet for effluent

Table D-1 (Continued)

Facility	Capacity (MCY)/ % Filled	Acres Area	Dike Construction	Liner/ Cap Design	Dewaterin g System	Effluent Treatmen t
Grassy Island/ Wyandotte (1960-1984)	1.9/100	80	Sand and clay dikes	None/None	Overflow weir	Natural settling
Kenosha (1975- )	0.75/66	32	Rubble mound with sheetpile cutoff & graded filter core	None/None	Thru dike & filter cell	Natural settling & flow-thru dike & filter cell
Kewaunee (1982- )	0.50/57	28	Limestone core/rip-rap and filter discharge cell	None/None	Thru dike core & 4 filter cells	Natural settling & flow-thru filters
Kidney Island/Green Bay (1979-1986)	1.2/97	60	Rubble mound with sheetpile cutoff and filterstone core	None/None	Thru core & filter cell	Natural settling & filter cell
Manitowoc Harbor (1975- )	0.80/61	24	Rubble mound with sheetpile cutoff & filterstone core with geofabric	None/None	Thru core & filter cell	Natural settling & filter cell
Milwaukee (1975- )	1.6/44	61	Limestone core & cover with sand filter on granular fill/sheetpile on south side	None/None	Thru dike core & filter cell	Natural settling
Monroe/ Sterling Park (1986- )	4.2/0	89	Limestone core with grouted mattress on fill and rip-rap at lake	2' bentonite & granular fill/ None	Overflow weir & filter cell	Natural settling & filtration
Pointe Mouillee (1979- )	18.6/38	700	Limestone & clay core with coverstone, consists of 5 cells	None/None	Overflow weir	Natural settling

Table D-1 (Continued)

Facility	Capacity (MCY)/ % Filled	Acres Area	Dike Construction	Liner/ Cap Design	Dewaterin g System	Effluent Treatmen t
Riverview (1978- )	0.12/84	11	Clay dike with bentonite slurry wall in lake sands & clay	None/None	overflow weir, in 1982 underdrain added	Natural settling, oil skimmer
Saginaw (1978- )	10/48	283	Limestone dike with coverstone	None/PCB sediments capped with less polluted sediments	Overflow weir	Natural settling, oil skimmer
Renard I. (1979- )	1.2/97	60				

Avg.            3.5 MCY    112 ACRES

**Table D-2**  
**Technical Specifications for Upland CDFs**

<b>Facility</b>	<b>Capacity (MCY)/ % Filled</b>	<b>Area Acres</b>	<b>Dike Construction</b>	<b>Liner/Cap Design</b>	<b>Dewaterin g System</b>	<b>Effluent Treatment</b>
<u><b>BUFFALO DISTRICT</b></u>						
None						
<u><b>CHICAGO DISTRICT</b></u>						
Michigan City (1978-1987)	0.05/100	3.3	Earth dike with stone rip-rap	Natural clay under CDF/clay cap with topsoil	Sand filter & drainpipes	Primary settling & sand filtration
<u><b>DETROIT DISTRICT</b></u>						
Dickinson Island (1976- )	2.0/48	174	Clay dikes	None/None	Overflow weir & oil skimmer	Natural settling
Frankfort Harbor ( ? - ? )	0.07/100	80	No dikes required	None/Site to be seeded	None	None
Harbor Island (1974- ? )	0.31/97	36	Clay berm	None/None	Overflow Weir	Natural settling & oil skimmer
Harsen's Island (1975-1980)	0.10/100	17.2	Clay dike	None/To be leveled & revegetated by State of Michigan	Overflow weir	Natural settling
Crooked River (1982- )	0.02/32	9	Local soil dike	None/None	None	None
Kawkawlin River (1989-90)	NA/100	NA	Clay and sand berm	None/None	Overflow weir	Natural settling
Monroe (Edison) (1979- 1984)	NA/100	43	Preexisting/ earth berm with clay layer inside	None/None	Overflow weir	Natural settling

Table D-2 (Continued)

Facility	Capacity (MCY)/ % Filled	Area Acres	Dike Construction	Liner/Cap Design	Dewatering System	Effluent Treatment
Port Sanilac Village (1979-1983)	0.14/100	13	On-site soil berm with clay cover	None/None	None	None
Keweenaw Waterway (? - ?)	0.24/23	21	Clay Dikes	None/None	Overflow Weir	Natural Settling
Sebewaing (1979- )	0.08/54	9	Rip-rap over filter cloth on clay core, sheetpile cutoff			
Verplank/ Grand Haven (1974-1977)	0.13/100	19	Clay berm	None/None	Overflow weir	Natural settling, oil skimmer
Whirlpool (1978- ?)	0.03/100	14	Clay dike	Plastic membrane/ None	Overflow weir	Natural settling
Windmill Island (1978-1988)	0.16/100	16	clay dike	None/None	Overflow weir	None

Avg.            0.28 MCY    36 ACRES

**Table D-3**  
**Summary of Contaminated Sediment Remedial Actions**  
**in Great Lakes Region**

Facility	Contamination/ Action Date	Site	Sediment Volume (mCY)	Remedial Action
<b>A) CERCLA Remediations (1980)*</b>				
1) Cast Forge Steel Co., Howell, MI	PCB to 4800 ppm, 1977	South Branch Shiawassee River, 8 miles long	Initial 2.3 by 1982	Initial dredge and landfill incomplete--put on NPL (1983; action pending)
2) Crab Orchard National Wildlife Refuge, Cartersville, IL	Cadmium to 780 ppm, chromium to 889 ppm, lead to 20,500 ppm, PCB to 88,000 ppm, plus other metals--NPL 1984	Several scattered industrial sites	About 6.4 total	Excavation and treatment or landfilling (action pending)
3) Dayton Tire and Rubber Co., Dayton, OH	1600 gallons of PCB-contaminated oil released--1987; sediment PCB to 6020 ppm	Wolf Creek	About 0.2 total	August 1987--excavation and landfilling--further remediation needed
4) Fields Brook, Ashtabula, OH	NPL 1983; variety of organics and heavy metals	Fields Brook and 2-mile reach of Ashtabula River	16 mCY sediments with organic contaminants and 25 mCY immobile contaminants	Excavation, dewatering, incineration, solidification, placement in RCRA/TSCA landfill and fluids treated
5) Moss American Co., Milwaukee County, WI	CPAH (creosote) to 500 ppm and PAH to 5900 ppm--NPL 1980	5-mile stretch of Little Menomonee River	5.2 mCY along river corridor	Construct new river channel--excavate, treat with slurry bioreactor, dispose in on-site landfill
6) P. R. Mallory, Crawfordville, IN	PCBs to 165,402 ppm in soil and 9695 ppm in ravine sediments--1985	Ravine that leads to Little Sugar Creek	60 mCY by June 1990--more excavation planned	Remediated to 25 ppm PCB level--placed in hazardous waste landfill
7) Tecumseh Products Co., L. Sheboygan River, WI	PCB to 4500 ppm plus chromium, cadmium, lead, mercury, zinc, nickel--NPL 1985	14 miles of L. Sheboygan River upstream of mouth and Sheboygan harbor	2.7 mCY plus	Excavation, containment and treatment plus in-situ containment--ROD in 1993

mCY = thousand cubic yards

MCY = million cubic yards

Table D-3 (Continued)

Facility	Contamination/ Action Date	Site	Sediment Volume (mCY)	Remedial Action
8) Outboard Marine Corp., Waukegan, IL	PCB to 25,000+ ppm—over 1 million pounds disposed—1976	Waukegan Harbor and on OMC property	8 mCY with greater than 500 ppm PCB and 30 mCY with 50 to 500 ppm	Isolation of Slip 3 hotspot by slurry wall, excavation of upper harbor and parking lot with 750 ppm, treatment and placement as cover on slip 3
9) Westinghouse Electric Co., Bloomington, IN	PCB discharged to sewage treatment facility--August 1985	PCB in local landfill sludge and streams	650 mCY of contaminated materials	Landfills capped by 1987, creek sediments were dewatered, excavated and stored with incineration pending
B) CLEAN WATER ACT (1977) amended 1987, 1990				
1) U.S. Steel Gary Works, Gary, IN	PAHs, heavy metals, oil and grease—October 1988	5- to 12-mile section of Grand Calumet River	500 mCY over 5-mile stretch of river	Recycling of sediment pollutants back into steel-making process
2) U.S. Steel, Lorain, OH	Coke (PAH) from steel plant—PAH over 50 ppm, cadmium over 30 ppm--January 1979	Black River	50 mCY	Dredging and placement in on-site landfill
C) RCRA/TSCA REMEDIATIONS		None		
D) STATE ACTIONS FOR REMEDIATION				
1) ALCOA, Lafayette, IN	Sediment PCB greater than 50 ppm--1982	One mile reach of Elliot Ditch/Wea Creek which flow into Wabash River	5.6 mCY	Damming of stream, treatment of water to .0005 mg/l. Sediment solidified with lime and flue dust--placed in landfill
2) Dana Corp., Churubusco, IN	PCB in sewage treatment sludge and drainage ditch sediments to 7290 ppm--Spring 1986	Ditches feed into Eel River	Upper 12-18 inches of sediment excavated with backhoe	Water treated to 0.1 ppb, sediments stabilized with kiln dust and placed in PCB landfill
3) Deer Lake, MI	Mercury to 15 ppm (v. high) in Deer Creek sediments and fish--1982	Deer Lake is connected to Lake Superior by Carp River	?	Lake level stabilized to allow clean sediment covering of contaminated sediment over 10-year period

Table D-3 (Continued)

Facility	Contamination/ Action Date	Site	Sediment Volume (mCY)	Remedial Action
4) Double Eagle Steel, Dearborn, MI	Zinc from plating operation entered river for 5 months--October 1986	Rouge River for 200 yards	39 mCY	Sediment dredged and placed in USACE Point Mouillee CDF
5) Hitachi Magnetics Corp., Edmore, MI	PCB and mercury plus cadmium, chromium, copper, nickel, lead, zinc, oil and grease	About one mile of Wolf Creek	?	Excavation and placement in licensed landfill or TSCA landfill
6) Dayton Power and Light, Dayton, OH	PCB greater than 50 ppm--November 1985	Oppossum Creek	1.6 mCY	Soils and sediments were excavated to less than 25 ppm of PCBs and placed in a PCB landfill in Ohio
7) Lake Lansing, MI	Dredging of sediments with arsenic	Lake Lansing is about 450 acres	1.6 mCY to restore lake--demonstration project	Dredged sediments placed in three upland CDFs and effluent monitored
8) Little Lake Butte, Des Morts, WI	Demonstration project by WDNR--PCB hotspot contains about 1650 kg of PCBs	Paper mill PCBs along Little Lake Butte, Des Morts and 7-mile stretch of Lower Fox River	56 mCY	Dredging or in-place isolation of hot spot is planned.
9) Starkweather Creek, Madison, WI	WDNR demonstration project for Creek Sediment Restoration--mercury, zinc, lead, oil and grease	Starkweather Creek enters into Lake Monona causing decay of lake	?	Dredging of creek by backhoe and placement in a diked CDF
10) PPG Industries, Inc., Circleville, OH	PCBs leaked into sewer drains discharging into Scioto Creek--PCBs up to 710,000 ppm--Spring 1988	Scioto Creek	Sediments still being removed--1-2 mCY anticipated	Dewatering, stabilization of sediments, excavation and placement in landfill



## APPENDIX E

### RCRA-C HAZARDOUS WASTE LANDFILL PERFORMANCE CRITERIA

#### A.1 Introduction

Current EPA minimum technology requirements for new hazardous waste landfills, surface impoundments, and waste piles require (40 CFR 264.221)

*...two or more liners and a leachate collection system between liners. The liners and leachate collection system must protect human health and the environment... The requirement for the installation of two or more liners... may be satisfied by the installation of a top liner designed, operated and constructed of materials to prevent the migration of any constituent into such liner during the period such facility remains in operation (including any post-closure monitoring period), and a lower liner designed, operated, and constructed to prevent migration of any constituent through such liner during such period.*

The specific minimum properties of this multiple liner system are defined as follows (40 CFR 264.301):

- A top liner designed and constructed of materials (e.g., a geomembrane) to prevent migration of hazardous constituents...
- A composite bottom liner, consisting of at least two components. The upper component must be designed and constructed of materials (e.g., a geomembrane) to prevent... The lower component must be constructed of at least 3 feet (91cm) of compacted soil material with a hydraulic conductivity of no more than  $1 \times 10^{-7}$  cm/sec.
- The maximum head of leachate acting on a liner is 30 cm.

Figure A.1 shows the layers associated with the prescriptive RCRA-C liner system.

#### A.2 De Minimis Leakage

The RCRA-C liner system is designed with the goal to allow no more than the "de minimis" leakage of contaminants. The concept of "de minimus" comes from the legal principal "de minimis non curat lex" (i.e., the law does not concern itself with trifles). Specific levels of acceptable leakage have not been codified but it is possible to estimate the minimum total leakage from a "perfectly" constructed RCRA-C liner system. The downward vertical flow of liquids through the RCRA-C system is slowed as follows:

- The clay liner allows a maximum vertical downward flow velocity of  $1 \times 10^{-7}$

cm/sec based on Darcy's law and a vertical gradient of one. This is approximately 9.2 gallons/acre/day.

- A geomembrane liner will allow liquids to diffuse through the liner based on Fick's first law. The rate of diffusion is controlled by the water vapor transmission (WVT) rate of the polymer. WVT is expressed in units of  $\text{g m}^{-2} \text{d}^{-1}$  where the transmission of  $1 \text{ g m}^{-2} \text{d}^{-1}$  is equal to approximately 1.07 gal per acre per day (EPA/600/2-88/052). WVT values for common geomembranes used in such facilities range in value from 0.006 to approximately 2.0. Thus the geomembrane liner will allow up to 2 gallons/acre/day leakage. Note that this rate is not influenced by the head acting on the geomembrane.

EPA generally believes that the total leakage through composite liner systems (geomembrane overlying a compacted clay liner) should be less than 1 gallon/acre/day based on the above geomembrane flow rates.

### A.3 Liner Equivalence - RCRA-C

The construction of the RCRA-C barrier system in an in-lake environment would be impossible or at the least very expensive. However, an equivalent system can be constructed using clean low permeability dredged material. Three factors are usually considered in evaluating the equivalence of barrier systems:

- the flow rate through the liner system (e.g., how many gallons per acre per day),
- the "break-out time" defined as the time required for liquids to travel through the system and be released to the environment, and
- an equivalent chemical adsorption capacity.

The flow rate through the liner system will be controlled by the least permeable barrier in the system. The RCRA-C liner system is flow limited by the geomembranes used, with flow rates up to 2 gallon/acre/day. This same flow rate can be achieved by a soil layer having a hydraulic conductivity of less than approximately  $3 \times 10^{-8}$  cm/sec assuming 30 cm of head acts on the surface. As previously shown on Figure 6.6, fine grained dredge sediment can achieve such low levels of permeability after consolidation. The head acting within CDFs can be expected to significantly exceed 30 cm. However, the thickness of fine grained dredge materials would probably also exceed the 3 foot thickness of the RCRA-C soil liner. Therefore it may be possible to construct a dredge liner approaching the flow rate criteria of a RCRA composite liner.

The minimum break-out time of a liquid moving through the RCRA-C liner system can be calculated by summing the travel times through the individual barriers under the influence of the allowable 30 cm (1-ft) of leachate head as follows:

- Primary and secondary geomembranes; 60-mil thickness and 1 gallon/acre/day flow rate (k equivalent of  $4.27 \times 10^{-9}$  inch/sec)

$$\text{travel time} = 0.060 \text{ inch} / 4.27 \times 10^{-9} \text{ inch/sec} = 162 \text{ days}$$

- Secondary composite soil liner; 3-feet of  $1 \times 10^{-7}$  cm/sec soil

$$\text{travel time} = 3 \text{ feet} / 1 \times 10^{-7} \text{ cm/sec} = 10580 \text{ days}$$

The total minimum travel time can then be calculated to equal  $162 + 162 + 10580$  or 10904 days. This same travel time is possible with a soil liner having a maximum hydraulic conductivity of  $3 \times 10^{-8}$  cm/sec and a thickness of 27 cm or approximately 1 foot in thickness. The increased head acting within the CDF would obviously reduce the travel time. Note that it is possible to design a liner system such that the break out time exceeds the life of many contaminants.

Chemical adsorption capacity is dependent upon the cation exchange capacity (CEC) of the liner clay and the chemical characteristics of the contaminant of concern. This equivalence must be verified on a site by site basis.

Based on this evaluation, it appears very possible that a barrier system could be constructed using a single layer of fine grained dredged material that would approach, but not fully achieve, the performance standards of the RCRA-C liner system.

#### **A.4 Commentary on Liner Equivalence - RCRA-D**

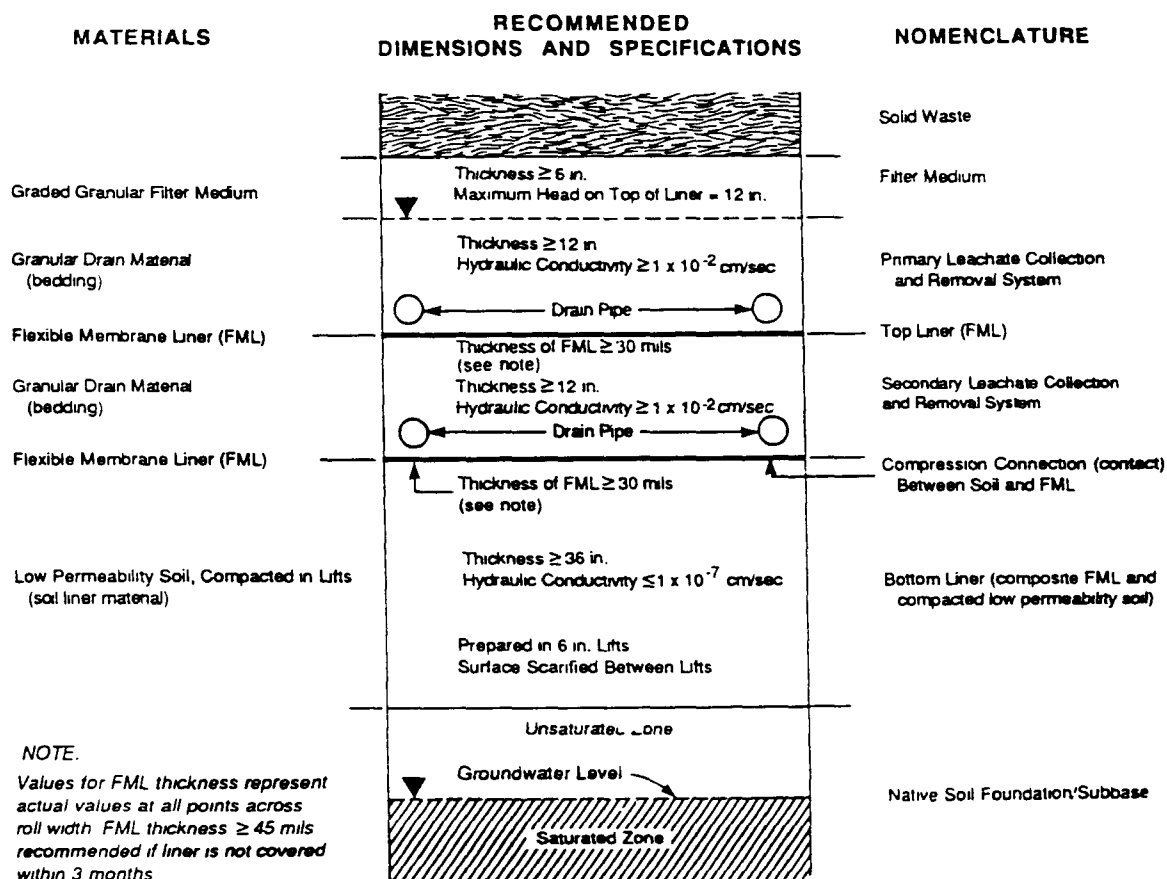
RCRA-C regulations in 40 CFR 258 provide for an alternative method of evaluating liner equivalence. In these regulations, a point of compliance method allows the use of alternative liner system if it can be shown that the liner will limit contaminant migration such that contamination concentrations at the closest down-gradient monitoring well is less than MCLs specified by the CWA. Presently, EPA requires this evaluation to be performed using the EPA generated computer model MULTIMED (Allison, 1992). This model uses a closed-form solution to the contaminant transport problem and incorporates default chemical data.

#### **Reference**

EPA, 1988. Lining of Waste Containment and Other Impound Facilities, EPA/600/2-88/052, Risk reduction Engineering Laboratory, Cincinnati, Oh, 45268.

Allison, T.L., 1992. Using MULTIMED To Evaluate Subtitle D Landfill Designs, Contract 68-WO-0025, Office of Solid Waste, Washington, D.C.

Koerner, R.M. and D.E. Daniel, 1993. "Technical Equivalency Assessment of GCLs to CCLs," *Geosynthetic Liner Systems: Innovations, Concerns and Design*, R.M. Koerner and R.F. Wilson-Fahmy (Eds), Industrial Fabrics Association International, St. Paul, Minn.



(EPA/600/2-88/052)

Figure A-1 Schematic Profile of Double Composite Liner System