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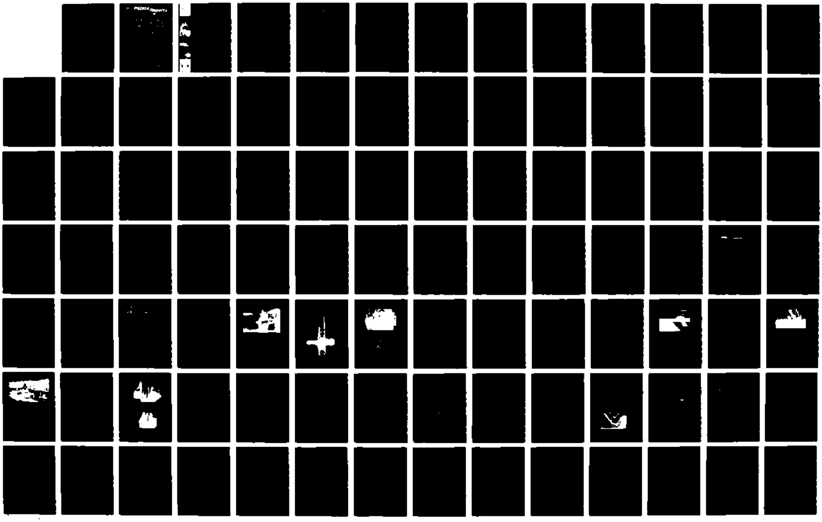

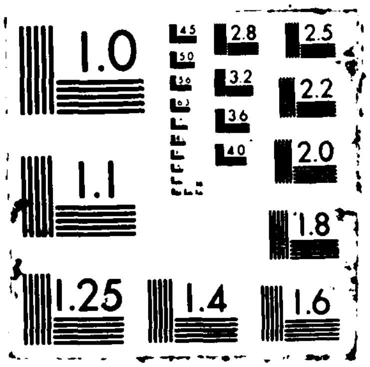
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PSDDA Reports
Puget Sound Dredged Disposal Analysis

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GUIDELINES FOR SELECTING CONTROL AND TREATMENT OPTIONS FOR CONTAMINATED DREDGED MATERIAL

Prepared by: Department of the Army
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Vicksburg, Mississippi

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GUIDELINES FOR SELECTING CONTROL AND TREATMENT OPTIONS FOR CONTAMINATED DREDGED MATERIAL REQUIRING RESTRICTIONS

by

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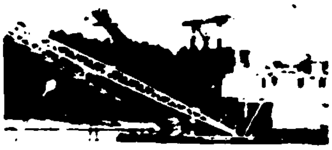

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ENVIRONMENTAL LABORATORY

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Alternative technologies and alternative strategies for dredging, transport, and disposal of contaminated dredged material are reviewed. Contaminant control/treatment during three basic operations are discussed. These include contaminant control/treatment during dredging, contaminant control/treatment during material transport, and contaminant control/treatment during disposal operations.

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The selection of appropriate technologies for contaminated dredged material management depends on the physical and chemical profile of the sediments, the physical state (solid, liquid, gas) of the contaminants of concern, the state changes that may occur at different phases of the dredging and disposal operations, physical characteristics of the proposed disposal site, and contaminant release criteria for the selected disposal site(s). Three disposal site scenarios are discussed: upland, nearshore, and restricted open-water. Appropriate technologies and alternatives are selected on the basis of a comparison between the projected efficiency of an alternative in preventing an off site release and the off site release criteria for a specific site. The objective of the selection process is to minimize the cost of contaminant control/treatment subject to site-specific environmental criteria. Thus, two major categories of information must be compiled: the effectiveness of the proposed control/treatment option and the acceptable criteria concerning concentrations of contaminants in water, sediments and soils, and air at a specific disposal site. Technologies should be used that ensure that criteria will be met during all phases of dredging transport and disposal operations.

Many technologies have been developed for control/treatment of contaminated media. These technologies have the potential for application to a contaminated dredged material handling operation. Such technologies are identified in this report. Technologies are separated into proven, demonstrated, demonstrable, and conceptual categories.

In the case of small projects, it is anticipated that the cost of environmental related testing may exceed the cost of disposal. The concept of disposal area overdesign can be used to offset the high cost of testing. Under this concept, expensive testing is foregone in favor of extensive engineered controls, monitoring, and agreements of implementation of remedial actions.

PREFACE

This study was conducted at the US Army Engineer Waterways Experiment Station (WES) during the period May 1985 through July 1986 by Messrs. M. John Cullinane, Daniel E. Averett, Richard A. Shafer, James W. Male, Clifford L. Truitt, and Mark Bradbury under the direct supervision of Mr. Norman R. Francingues and Dr. Michael R. Palermo. General supervision was provided by Dr. Raymond L. Montgomery, Chief, Environmental Engineering Division and Dr. John Harrison, Chief, Environmental Laboratory.

Technical contributions in the form of test protocol descriptions were received from the following: Dr. Bobby L. Folsom, Jr., for the plant uptake/bioassay tests; Dr. John W. Simmers, Dr. Stratford H. Kay, and Mr. R. G. Rhett for the earthworm bioassay test; Dr. James M. Brannon and Mr. Tommy E. Myers for the leachate test; Dr. Palermo for the effluent test; Dr. Tom M. Dillon, Dr. Henry E. Tatum, and Mr. Victor A. McFarland for the aquatic and benthic bioassay test; and Mr. John G. Skogerboe for the surface runoff tests.

Review and constructive comments were received from the Evaluation Procedures Working Group (EPWG), Puget Sound Dredged Disposal Analysis Committee including: Mr. Jim Krull, Washington Department of Ecology; Mr. David Jamison, Washington Department of Natural Resources; Mr. Brian Ross, U.S. Environmental Protection Agency, Region X; and Mr. Keith Phillips, U.S. Army Engineer District, Seattle. Mr. Phillips is chairman of the EPWG and project coordinator for the Seattle District.

Constructive comments have also been provided by the following: Mr. Doug Hotchkiss, Port of Seattle; Mr. Carl Kassebaum, U.S. Environmental Protection Agency, Region X; Mr. John Malek, U.S. Army Engineer District, Seattle; Mr. Phillip Spadaro, Hart-Crowser, Inc., and Mr. Jim Thornton, Washington Department of Ecology.

The Director of WES during the study and preparation of this report was COL Allen F. Grum, USA. Technical Director was Dr. Robert W. Whalin.

EXECUTIVE SUMMARY

Puget Sound, a major Pacific Coast estuary, is located at the northwest corner of the United States in the State of Washington. The Port of Seattle, located on Puget Sound, is the largest container port on the Pacific Coast of the United States and is the second largest container port in the United States. The waterways, harbors, and port facilities associated with Puget Sound are vital to the economy of the local area, as well as to the nation. Puget Sound is considered to be an ecologically rich and diverse marine water body nestled between two snow-capped mountain ranges. In recent years; however, environmental studies have identified chemical contaminants in sediment and aquatic organisms. Many areas of contamination are near point source outfalls. The trend, which is expected, in view of recent intense pollution abatement programs directed at point source discharges, is for lower concentrations in more recent sediments. Contaminants have also been detected in sediment and biota for areas of Puget Sound previously thought to be clean; however, this probably results from the more intensive investigations now being conducted rather than new contamination. These discoveries have focused agency and public attention on the health of the Sound.

Like most waterways, navigation on Puget Sound is impacted by sedimentation and shoaling, which, if left unattended, can make a waterway impassable to ship traffic. Maintaining authorized channels for navigation and expanding existing facilities on Puget Sound require dredging and disposal of an estimated 1,000,000 cu yd of sediment each year. Of this amount, approximately 500,000 cu yd goes to unconfined open water disposal. These projects are implemented by a variety of public and private sector agencies including the US Army Corps of Engineers, other federal agencies, port authorities, marine industries, municipalities, and private companies.

Sediment deposited on the bottom of streams, lakes, and coastal waters varies in physical and chemical composition. Because many water pollutants are attracted by and become attached to sediment particles, pollutant concentrations in sediment are generally much greater than in water. Drainage basins with concentrated urban, industrial, or agricultural sources contribute significantly to downstream sediment contamination. Such is the case with Puget Sound.

The environmental impact of sediment depends on the amount of contaminant present and the mobility of the contaminant into environmental pathways by biological or hydrodynamic processes. The chemistry of contaminants in sediments is controlled primarily by the physicochemical conditions under which the sediment exists. Fine-grained sediment is typically anoxic, reduced, and near neutral in pH. The manner in which disposal environments affect these chemical characteristics is an important consideration in the selection of disposal options. If sediment is disposed in an aquatic environment, sediment chemistry may not change. However, transfer of the sediment to a dryer environment, such as an upland disposal site, may change the chemistry to an oxic and lower pH condition more favorable to the release of contaminants (Lee et al. 1985).

Biological and physical processes may also affect the release of contaminants at a disposal site. Different contaminants and sediment with different properties do not always respond similarly to an altered biological or physicochemical condition. This requires testing on an individual basis for site-specific sediment contamination problems (Gambrell et al. 1978).

Puget Sound dredging projects may be conducted to maintain navigation channels, to create new harbors and port facilities, or to remove contaminated sediment (remedial actions). Projects whose purpose is remedial action will by definition contain contaminants that require special considerations during disposal. Maintenance or new work dredging may involve sediment with various degrees of contamination. This study considers disposal options for contaminated sediment from all three types of projects.

As the concern over dredging and disposal of contaminated sediments increases, unconfined open-water disposal of dredged material from harbors and navigation channels is being closely scrutinized by state and local governments as well as numerous federal agencies. Due in part to inadequate information regarding the impacts of dredged material disposal on the Sound, new permits and renewals of existing permits for open-water disposal sites include more stringent conditions than permits issued in the past. Delays or restrictions in issuing permits have delayed maintenance dredging and increased the cost of new port facilities.

Because of the environmental significance of Puget Sound, the US Environmental Protection Agency Region X (USEPA), the Washington State Department of Ecology (WDE), and the Washington Department of Natural Resources (DNR) developed a joint program for dealing with Puget Sound pollution problems called the Puget Sound Estuary Program, formerly the Puget Sound Initiative. The purpose of this program is to identify water quality problems and promote cleanup actions. The part of this program aimed at dredged material disposal is the Puget Sound Dredged Disposal Analysis (PSDDA). Lead for PSDDA was assigned to the Seattle District, Corps of Engineers, in 1984.

The goal of PSDDA is to provide the basis for publicly acceptable unconfined disposal of dredged material in Puget Sound. The PSDDA program will prepare an environmental impact statement for each of the two phases of the study. The basis for Phases I and II is geographical division of the Sound into the Central Puget Sound area (Phase I) and balance of the Sound (Phase II). Phase I is to be completed by the end of the second year of study, and Phase II is to be completed during the third year of the study.

The overall purpose of PSDDA is to find acceptable open-water disposal methods and sites for dredged material. The PSDDA plan of study consists of five objectives. This report presents the results of Task 3g (Selection, Design, and Monitoring of Confined Disposal Options) of Objective 3 (Disposal Evaluation Procedures). Task 3g is intended to identify alternative methods of dredging/transportation/disposal and to review alternative evaluation procedures for the handling of sediments that are unsuitable for unrestricted open water disposal.

Dredging operations are conducted in three distinct phases: dredging sediments from their in situ location, transportation of the dredged material to the selected disposal area, and disposal. This report discusses the selection of control/treatment alternatives for limiting contaminant release during all three phases of dredging operations. Furthermore, because of the distinct and significant differences in operation the three disposal scenarios, upland, nearshore, and restricted open water, will be discussed separately. Thus, control/treatment alternatives can be categorized as follows:

a. Control/treatment during dredging.
b. Control/treatment during transport.
c. Control/treatment for upland disposal.
d. Control/treatment for nearshore disposal.
e. Control/treatment for open water disposal.

The selection of appropriate control/treatment alternatives requires that each must be evaluated using a uniform set of criteria. Although important criteria will vary between regions, nine evaluation criteria were selected for use during this study. Each control/treatment alternative presented in this report is evaluated in terms of the nine evaluation criteria. These criteria include: reliability, implementability/availability, technical effectiveness/efficiency, environmental concerns, safety, operation and maintenance, costs, regulatory requirements, and public acceptance. Definitions of these criteria are presented in Part IX.

Characteristics, operational considerations and control, and equipment considerations and modifications for dredging contaminated sediments are described for each dredging alternative. The two basic types of dredges addressed in this report, hydraulic and mechanical dredges, are categorized based on the similarities each has in terms of contaminant loss during dredging. Special-purpose dredges that have been designed for contaminated sediments are also included in the discussion. Different dredging methods appear more appropriate for certain contaminant classes:

a. For volatile contaminants, mechanical dredges are likely to produce less loss than hydraulic dredges.

b. Sediment-bound contaminants can be removed more efficiently by hydraulic dredges than mechanical dredges and appropriate technology exists for control of solids at the disposal end.

c. Soluble contaminants can be removed more efficiently by a hydraulic dredge, but are difficult to control at the disposal end and treatment of the effluent water may be required.

Most projects are likely to contain all three types of contamination, confounding a decision on appropriate dredging technique. In terms of overall contamination, sediment-bound contaminants usually represent the bulk of the contamination, suggesting use of hydraulic equipment for maximum recovery and extraction efficiency. The amount of volatiles that may be lost during dredging are not likely to be a source of major concern in many projects. As the types and amount of soluble, or easily solubilized, contaminants increase in a sediment to be dredged, greater consideration should be given to the cost and environmental impact of mechanical dredging with watertight equipment relative to that of hydraulic dredging and water treatment at the disposal site.

This evaluation is likely to be the key to selecting a dredge for a given contaminated sediment.

In terms of sediment resuspension at the dredge site, special-purpose hydraulic dredges produce less resuspension than conventional hydraulic dredges, and, with the exception of hopper dredge overflow, conventional hydraulic dredges produce less resuspension than mechanical dredges. In terms of slurry water that may require treatment at the disposal site, mechanical dredges produce much less water than special-purpose hydraulic dredges, and special-purpose dredges produce less water than conventional hydraulic dredges. Hydraulic dredges produce less solids resuspension at the dredging site and have a higher removal efficiency for liquid and solid phases than do mechanical dredges. However, use of a hydraulic dredge to obtain high removal efficiency at the dredging site involves a tradeoff requiring consideration of increased slurry water and sediment consolidation time at the disposal site.

A variety of dredging equipment modifications are appropriate for work in highly contaminated sediments. Modifications that appear most promising at this time include:

a. the walking spud (hydraulic dredge).
b. ladder pumps (hydraulic dredge).
c. in-line production meters (hydraulic dredge).
d. large, watertight buckets (mechanical dredge).

Operational modifications to be considered for hydraulic cutterhead dredges include minimizing cutter revolution speed, controlling swing speed, not overdigging the maximum cut depth, and dredging during optimum current conditions. For mechanical dredging, sweeping the bottom with the bucket and digging fine-grained sediments from underneath (heavy buckets penetrating through soft surface materials) are practices to be avoided in contaminated areas. For most operator controls or operational modifications, serious consideration should be given to hourly rental of dredging equipment rather than bidding in order to maintain control of project costs and better define cost factors during first-time use of modifications.

The key considerations involved with disposal method effectiveness are:

a. The class of contaminants of concern.
b. The similarity of disposal site conditions to in situ conditions.

c. The number and magnitude of contaminant transport mechanisms operating at the disposal site.

d. The degree of control or treatment possible to intercept migrating contaminant fractions.

e. The risk of significant adverse effects from contaminants released by the disposal method.

In general, leaving or disposing of contaminated sediment in a chemical environment as close as possible to their in situ state favors contaminant retention (especially metals). Geochemical changes associated with air and oxygen in upland and nearshore sites can change (reduce) sediment pH (mobilizing metals) and alter (dissolve, degrade, or volatilize) sediment organic carbon (mobilizing organics). Based on this, many contaminants would tend to stay bound to sediment better in an open-water capped site than a nearshore or upland site. For organic contaminants, the influence of geochemical changes may be outweighed by the consideration of water exchange.

Metals will often go into solution and become mobile in oxidized, unsaturated sediment (e.g., in an upland site). Organic contaminants tend to constant solubility regardless of how wet or dry the sediment stays. Therefore, they will have greater mobility potential where greater exchange of water occurs within the sediments. These tendencies suggest that heavy metal contaminated sediments should be left under water and organic contaminated sediments should be disposed of above water. Nearshore sites have greater water exchange than upland sites, and upland sites have greater geotechnical changes than open water sites. It should be noted; however, that the net effect of drying, matrix decomposition/solubilization, and water exchange on the mobility of metals and organics is not easy to decipher.

Open-water sites, especially those in deep water, have fewer transport mechanism than upland sites. Nearshore sites have the most transport routes available and are located in a very active environment; therefore, nearshore disposal may be the least preferred method for long-term confinement of contaminants because of significant management considerations.

In terms of controlling contaminant release, open-water disposal allows for very few controls of releases other than cap thickness. However, increasing cap thickness is a relatively simple and effective control method. Upland disposal, on the other hand, allows for the greatest control through design features, monitoring capabilities, backup contaminant intercept systems, and treatment facilities. The nearshore disposal operation does allow for greater control of contaminants than open water disposal, but many fewer than are available in an upland disposal scenario.

For open-water disposal, the levels of contaminant concentration released will be low relative to nearshore or upland sites and will be diluted by the overlying water. The risk of significant damage in this environment is low and would not likely affect human health. For upland disposal, environmental risks incurred may be higher than in open water because of potential human health concerns. Because of its active environment, the risks to the environment and to human health from nearshore disposal may be greater than in open water and in many situations may be greater than at an upland site.

Control/treatment technologies for containment or isolation of contaminants from the environment are discussed in Parts IV (Upland), V (Nearshore), and VI (Restricted Open Water).

Control/treatment technologies for upland disposal are discussed in terms of the potential migration pathways and the media to which the control/treatment technology is applied. Six types of potentially contaminated media are identified: dredged material slurry, dredged material solids, disposal site effluent, disposal site runoff, disposal site leachate (including seepage through and under dikes), and residual solids. Passive site controls such as liners and covers are emphasized. As an alternative, treatment technologies such as chemical extraction, physical separation, and chemical stabilization are discussed.

Disposal of contaminated sediment in the upland environment may produce contaminated liquids including effluent produced during active dredging operations, runoff water produced during initial dewatering and rainfall events, and leachate produced during initial dewatering and subsequent rainfall events. Six levels of treatment for site waters were identified as follows:

a. Level I is the removal by sedimentation of suspended solids and particulate bound contaminants from disposed and site-derived water. This level would remove 99.9 percent of solids, 80-99 percent of toxic metals, and 50-90 percent of organic contaminants.

b. Level II is additional treatment to remove soluble metals. This level would increase metals removal to greater than 99 percent.

c. Level III is treatment to remove soluble organics. This level increases organics removal to 95 percent.

d. Level IV is treatment to remove nutrients such as ammonia and phosphorus.

e. Level V is treatment to remove dissolved solids. This level would increase organics removal to 99 percent, but is primarily designed to remove nonmetallic inorganic contaminants (e.g., nutrients and common anions).

f. Level VI is disinfection for destruction of pathogenic organisms.

In going from upland to nearshore to open-water disposal, the degree of site control and the number of available treatment options decreases. This decreasing control is translated into reduced opportunities to design additional treatment measures that would prevent sudden or accelerated contaminant release into the environment and/or to avoid the extreme expense of sediment removal and relocation.

Potential control/treatment at upland sites includes several methods that cannot be implemented at nearshore sites without site dewatering. Dewatering, greater than natural evaporation, would require extraordinary and extremely expensive construction techniques and is, therefore, not considered here. Foundation material in the nearshore zone may not be adequate to support the necessary diking. Seismic potential, mud foundations, and tidal fluctuations can threaten dike stability. As a result, construction in the nearshore zone has a higher risk of failure. Therefore, equivalent treatment at each site would produce lower containment of contaminants in the nearshore site due to the factors operating on contaminant mobility and the limited site control relative to upland sites.

Restricted open-water disposal is discussed in Part VI. Currently available control/treatment technologies for open-water disposal are generally limited to techniques for isolating the contaminated sediment from the water column during deposition (downpipes and diffusers) and techniques for longterm containment of contaminants (caps and lateral confinement). Concepts for treating the contaminated dredged material followed by unrestricted open water disposal have been proposed; however, are not sufficiently developed for field scale implementation. These concepts employ a variety of treatment technologies including contaminant separation, contaminant immobilization, and contaminant destruction. To date only contaminant separation has been demonstrated at the laboratory and pilot scale. Additional research and development will be required prior to acceptance of this concept as a technically and economically attractive alternative.

Tests required for the selection and design of control/treatment technologies are presented in Part VII. Required tests are divided into four categories: sediment characterization tests, site characterization tests, contaminant release tests, and technology design tests. Many of the protocols, particularly for contaminant release and technology design, have not been standardized and are currently under development. Available protocols specific to testing of contaminated sediments are presented in Appendix A.

Many control/treatment technologies proposed for application to contaminated sediment have not been proven for field scale implementation. Part VIII of this report discusses four categories of control/treatment technologies: proven, field demonstrated, demonstrable, and conceptual. Proven technologies are those that have been applied in either the dredging or other industries for control/treatment of contaminated waste or materials. Field demonstrated technologies are those that have been applied to a dredging operation, either on a pilot or full-scale basis, for control/treatment of contaminated sediment. Demonstrable technologies are those that could be considered for demonstration, either pilot or field scale, without further need for process development. This does not alleviate the need for laboratory and engineering studies to design and implement the technology. Conceptual technologies are those than in theory would treat, control, or destroy dredged material contaminants, but are unlikely choices for current implementation or because of limited knowledge of their reliability and technical effectiveness.

Whereas Parts II through VIII of this report concentrate on the evaluation of control/treatment technologies, Part IX describes a strategy for formulating control/treatment alternatives and selecting between alternatives for restricting contaminant migration from disposal sites. A five-phase Dredged Material Alternative Selection Strategy (DMASS) is discussed in detail. The DMASS is a sequential process which enables a planner or engineer to: (1) select potential sites and screens out poor ones after a detailed site assessment; (2) select potential control/treatment technologies that are appropriate to the remaining potential sites and screen out poor options based on knowledge of how well the technologies address the contaminants and migration pathways of concern; (3) develop and evaluate alternatives based on site/technology combinations; and (4) select an appropriate site/technology alternative. The five phases of the DMASS include:

a. Phase I. Presumption of contamination pathway.

b. Phase II. Confirmation of a site specific contamination pathway.

c. Phase III. Alternative development and initial screening.

d. Phase IV. Detailed alternative evaluation.

e. Phase V. Alternative selection.

The first phase of the alternative selection strategy is the initial determination that the sediment to be dredged is contaminated and that there is some reason to believe that some type of restriction will be required during dredging/transport/disposal operations. The presumption that contaminant migration is a concern can be made using the decisionmaking framework proposed by Lee et al. (1985) and Peddicord et al. (1986).

The end product of Phase I is a listing of potentially restricted contaminant migration pathways. It is assumed that this information indicates the need for some restrictions or at least the need for further detailed analysis of the environmental consequences of a proposed dredging/transport/disposal option. In Phase II, these concerns are evaluated in terms of the characteristics of a specific dredging and disposal site. It is highly possible that one site may require restrictions whereas another site may have characteristics that require different or no restrictions. For example, assume that initial testing of the sediment indicates that generation of contaminated leachate may impact groundwater or surface water resources at a disposal site. This is the presumption of a contamination pathway. As individual disposal sites are assessed, it may be determined that one site requires a liner while at another site, fortuitous geological circumstances may make a liner unnecessary. Thus, the presumption of a contaminant migration problem based on sediment testing must be confirmed by site specific evaluations.

Phase III of the DMASS includes the development of candidate alternatives for accomplishing the required restrictions placed on contaminant migration and performing an initial assessment of proposed alternatives. The primary objective of applying treatment/control alternatives at a site is to reduce risk (a function of contamination, the pathways, and the receptors) by minimizing release and resultant exposure along each of the pathways. The initial site characterization and assessment serves to identify the critical migration pathways for a specific site. Criteria for each of the migration pathways should be developed and compared to the migration potential as determined from the presumptive tests initially applied to the dredged material. In cases where migration potential exceeds allowable criteria for a specific site, design alternatives consisting of one or more technologies can be formulated which, when applied at the site under study, will reduce contaminant migration within acceptable criteria.

Phase IV of the DMASS is a detailed evaluation of control/treatment alternatives. The evaluation of alternatives involves a determination of evaluation criteria and a systematic comparison of alternatives so that alternative selection can be made. Nine evaluation criteria are proposed. Unfortunately, only two of the proposed evaluation criteria can be easily quantified: cost and operation and maintenance which can be valued in terms of dollars. The remaining evaluation criteria are primarily qualitative; however, a relative numerical ranking system is described. Multi-criteria display techniques are proposed to aid in alternative selection.

Phase V of the DMASS is simply alternative selection. The DMASS is not designed to be a substitute for a person or group of people responsible for making decisions. It does not make decisions, but assists in the decision making process by narrowing the number of choices and presenting information in a logical and easily understood format. How the choices are narrowed depends in part on the decisionmaking sequence chosen by the analyst. It is important that decisionmakers understand the process that is followed since selection of the final alternative may be affected by the decision-making sequence chosen. In many cases selection of an alternative is a group decision, often with each member of the group emphasizing different criteria. When a decision is a group effort (and often open to public scrutiny), it is best to have a process that conveys as much information as possible about the relative merits of the alternatives being considered for selection.

Part IX of this report also contains an illustrative example demonstrating application of the DMASS to selection of control/treatment alternatives. The Totem Ocean Trailer Express Terminal Project in the Blair Waterway was selected as the basis for the illustrative example. Each phase of the DMASS is applied to the Commencement Bay project. Practical aspects of alternative selection are identified and discussed in detail.

An alternative to the extensive testing procedures proposed in the Decision Making Framework (DMF) (Lee et al. 1985, Peddicord et al. 1986) is the concept of conservative design without extensive testing based on the results of tests designed to determine the bulk chemistry of sediments. Under this concept, the disposal site is designed to control at least the known characteristics of the dredged material (based on bulk chemistry) and to meet stringent restrictions for assumed but unquantified characteristics. The basis of this strategy is the idea that implementation of a control/treatment alternative designed from bulk sediment chemistry data may be more cost effective or more expedient than conducting the extensive testing protocols identified in the DMF (Lee et al. 1985, Peddicord et al. 1986).

Contaminant mobility testing may not be necessary under at least three scenarios:

a. Bulk chemistry results indicate that the material has acceptably low levels of contaminants and standard disposal site design criteria apply.

b. The intended future use of the disposal site imposes design restrictions more stringent than those that would otherwise be required. For example, if an upland or nearshore disposal site is to be capped and sealed because the site is planned for future industrial use, plant and animal bioaccumulation testing could be avoided.

c. The use of the most environmentally protective design is more cost effective than incurring the cost of testing to demonstrate that a less restrictive design is appropriate.

The planning level design of a contaminated dredged material disposal facility usually incorporates a variety of structural features designed to isolate the contaminated dredged material from the environment and a monitoring program to assess the environmental impacts of the disposal facility. The testing protocols define in the DMF (Lee et al. 1985, Peddicord et al. 1986) are designed to minimize the number of site restrictions while ensuring that measures that are implemented have a high probability of meeting environmental goals. Design in lieu of extensive testing concepts, on the other hand, are generally based on less data and as a result may have more environmental risk. To compensate for the possibility of increased environmental risk, design in lieu of extensive testing concepts usually include more intensive monitoring programs and contingent remedial action plans that are triggered by specific contaminant releases. Thus, the design in lieu of extensive testing proposal includes three major elements: design features (including a management plan), a detailed monitoring plan, and a remedial action plan.

Part X of this report presents a strategy for deciding between the design in lieu of extensive testing strategy and the implementation of the DMF (Lee et al. 1985, Peddicord et al. 1986). The strategy is similar to the DMASS presented in Part IX with the following exceptions.

a. The migration pathway estimate is based on bulk chemistry results rather than detailed contaminant mobility testing.

b. Closer coordination with regulatory and resource management agencies is required, with these agencies actively participating in the alternative development and evaluation process.

c. The alternative package includes a detailed contingent remedial action plan.

d. Monitoring will usually be more intensive because of the environmental uncertainties associated with such projects.

A four-phase strategy for implementing the design in lieu of extensive testing options would be: presumption of contamination, initial design versus extensive testing decision, confirmation of contaminant pathway, and alternative development and selection. The decision to implement the design in lieu of extensive testing alternative should be based on the twin concerns of costs and environmental risks as measured by regulatory acceptances. Costs are generally quantifiable whereas regulatory acceptance will vary from project to project and may be based on a variety of intangible factors. Therefore, the strategy emphasizes the use of costs as an initial screening tool to evaluate the feasibility of implementing the design in lieu of extensive testing options.

The appropriate control/treatment-monitoring-remedial action package will be highly site specific and development of a generic package is not feasible. The total cost of the project is the basis for the final decision. The design in lieu of extensive testing strategy is essentially a tradeoff of testing versus construction costs. Guidelines are developed to assist engineers in the initial cost screening process. For large projects, those greater than 100,000 cu yd, it will almost always be cost effective to conduct extensive testing in an effort to eliminate control/treatment measures. For smaller projects, those less than 100,000 cu yd, the design in lieu of extensive testing option may be cost effective depending on the extent of the required control/treatment options. The decision to implement the design in lieu of testing strategy is very site specific. A detailed preliminary analysis of the technical and cost feasibility must be conducted for each project.

Part XI of this report presents conclusions and recommendations. The broader conclusions and recommendations are presented below.

a. The short- and long-term release of contaminants via various migration pathways from dredged material disposal sites cannot be ignored. Several techniques for predicting releases through specific pathways have been developed; however, the development of additional techniques and more information is needed to assess environmental effects and the need for implementing control/treatment design features.

b. Control/treatment technologies are available and have been proposed for use at dredged material disposal sites. Beyond removal of suspended sediment from disposal area overflow, few technologies have been demonstrated for control/treatment of contaminated dredged material.

c. Design procedures for site water treatment technologies at upland and nearshore disposal sites are available and proven. Nearshore sites that involve saline waters present unusual, but not insurmountable, design problems.

d. A variety of site-control measures such as lining and capping have been developed for control of hazardous waste materials. Such control measures are not easily adaptable to the conditions at a confined disposal site for dredged material. Placement of liners, particularly at nearshore sites, has not been sufficiently demonstrated. Dewatering of confined contaminated dredged material will require special equipment, treatment of site water, and a management plan for controlling contaminant release.

e. Procedures for designing restricted open-water disposal sites are not well developed. In particular, designs for submerged diffusers and downpipes for deep open-water sites have not been thoroughly developed and their implementation has not been documented. To date, the feasibility of implementing lateral confinement and capping in deep water has not been demonstrated. Projects are presently under design that will be used to demonstrate these technologies.

f. The selection of an appropriate control/treatment alternative depends on both site (dredging and disposal) and sediment characteristics. The DMASS presented in this report is a useful tool for developing an array of alternatives, but because of site specificity and lack of experience in applying the available control/treatment alternatives to dredged material, no single alternative will emerge as the best alternative.

g. With the assurance of major cost increases, selection of control/treatment alternatives for very highly contaminated dredged material could rely on technologies developed and being implemented for control of hazardous wastes, i.e., Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) programs. A variety of proven and demonstrated technologies for disposal of low-level contaminated dredged material is also readily available. The most difficult decision is the one addressed by this study: selection of cost-effective environmentally sound control/treatment alternatives for contaminated sediments that require more control than clean dredged material, but do not warrant state-of-the-art controls required for a hazardous material. Until more field experience and data are available on application of control/treatment alternatives to lightly contaminated dredged material, the alternative-selection strategy must remain somewhat open ended.

i. A recurring limitation is the evaluation of alternative technical feasibility-environmental effectiveness-costs interactions. Technical feasibility can only be addressed through the continued development and demonstration of new control/treatment technologies. A number of these new technologies are proposed as demonstration projects. The evaluation of environmental effectiveness will require analysis of the results obtained applying the proposed control/treatment technologies combined with the continued development of criteria against which the effectiveness of a control/treatment alternative can be evaluated. Procedures must be developed that enable planner or engineers to perform site-specific contaminant migration analysis. Finally, the costs of both the control/treatment alternatives and testing protocols are inadequately documented and are highly variable. Additional effort must be expended to refine the costs associated with controlling contaminant migration from contaminated dredged material disposal sites, evaluate the potential for contaminant migration, and assess the environmental impacts associated with contaminant migration.

CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
gallons per minute	3.785412	cubic decimetres per minute
horsepower (550 foot-pounds per second)	745.6999	watts
inches	25.4	millimetres
miles (US statute)	1.609347	kilometres

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PART I: INTRODUCTION

Background

Puget Sound, a major Pacific Coast harbor, is located at the northwest corner of the United States in the state of Washington (Fig. 1.1). The Port of Seattle, located on Puget Sound, is the largest container port on the Pacific Coast of the United States and is the second largest container port in the United States. The waterways, harbors, and port facilities associated with Puget Sound are vital to the economy of the local area, as well as to the nation. Like most waterways, navigation on Puget Sound is affected by sedimentation and shoaling, which, if left unattended, can make a water course impassable to ship traffic. Maintaining appropriate channels for navigation and expanding existing facilities require dredging and disposal of an estimated 1,000,000 cu yd of sediment each year from Puget Sound. Of this amount approximately 500,000 cu yd goes to unconfined open water disposal. In addition to federal navigation projects implemented by the Corps of Engineers, dredging projects are sponsored by Puget Sound ports, marine industries, other federal agencies, municipalities, and private companies.

Puget Sound is considered to be an ecologically rich and diverse marine water body nestled between two snow-capped mountain ranges. In recent years, however, environmental studies have documented elevated levels of chemical contaminants in aquatic organisms and sediment. Many areas of contamination are near point source outfalls. The trend, which is expected in view of pollution abatement programs for point-source discharges, is for lower concentrations in more recent sediments. Contaminants have also been detected in sediment and biota for areas of the sound previously thought to be relatively free of contaminant sources; however, this probably results from the more intensive investigations now being conducted rather than new contamination. These discoveries focused agency and public attention on the health of the Sound.

Open-water disposal of dredged material from harbors and navigation channels is being closely scrutinized by state and local governments. New local shoreline permits and renewals of existing permits for unconfined open-water

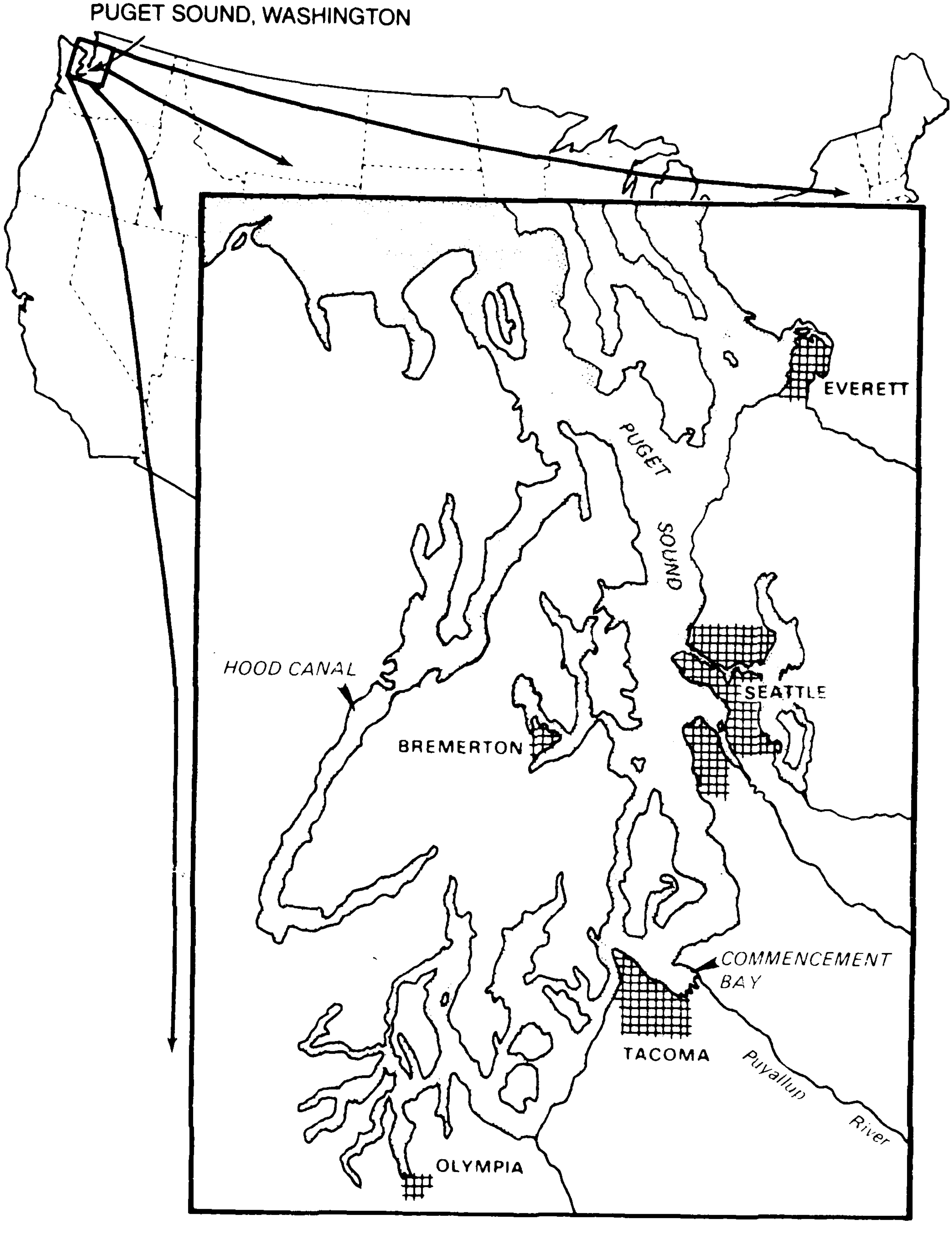

Figure 1.1. Puget Sound, Washington, U.S.

disposal sites include more stringent conditions than permits issued in the past. This is due in part to inadequate information regarding the impacts of dredged material disposal on the Sound. Delays or restrictions in issuing project specific permits may delay maintenance dredging and increase the cost of new port facilities, thereby having an adverse impact on the economy of the Sound.

Because of the environmental significance of Puget Sound, the U. S. Environmental Protection Agency Region X (USEPA), the Washington State Department of Ecology (WDE), and the Washington Department of Natural Resources (DNR) developed a joint program for dealing with Puget Sound pollution problems called the Puget Sound Estuary Program, formerly the Puget Sound Initiative. The purpose of this program is to identify water quality problems and promote cleanup actions. The part of this program aimed at dredged material disposal is the Puget Sound Dredged Disposal Analysis (PSDDA) Committee. The lead agency for PSDDA was assigned to the Seattle District, Corps of Engineers, in 1984.

The goal of PSDDA is to provide the basis for publicly acceptable unconfined disposal of dredged material in Puget Sound. The PSDDA program will prepare an environmental impact statement for each of the two phases of the study. The basis for Phases I and II is geographical division of the Sound into the Central Puget Sound area (Phase I) and balance of the Sound (Phase II). Phase I is to be completed by the end of the second year of study, and Phase II is to be completed during the second and third year of the study.

The PSDDA plan of study consists of five objectives with work tasks defined for each objective. This study represents the results of Objective 3 (Disposal Evaluation Procedures), Task 3g (Selection, Design, and Monitoring of Confined Disposal Options). The overall purpose of PSDDA is to find acceptable open-water disposal methods and sites for dredged material. Task 3g, however, is intended to review evaluation procedures and alternative methods of disposal of sediment that is unsuitable for unrestricted open water disposal. Although included in PSDDA's Phase I, it is a nonsite-specific, (i.e., generic) evaluation.

Related Studies

One area of Puget Sound that has been found to have highly contaminated sediment is Commencement Bay, located in the south end of the Sound near Tacoma, Washington. The sediment is contaminated by heavy metals, primarily arsenic, and organic compounds that were released over past years by numerous and diverse industrial operations. The Commencement Bay Nearshore/ Tideflats area is included on USEPA's National Priority List of hazardous waste (Superfund) sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

The WDE entered into a cooperative agreement with USEPA and took responsibility for implementing Phase I Remedial Investigations for the Commencement Bay Nearshore/Tideflats Superfund Site. As part of these investigations, WDE enlisted the assistance of the Seattle District, Corps of Engineers, to analyze alternative dredging and disposal methods for contaminated sediment with potential application to Commencement Bay. The Seattle District published a final report (Phillips et al. 1985) describing and evaluating alternative dredging methods and equipment, disposal methods and sites, and site-control and treatment practices for contaminated sediment derived from Commencement Bay. The discussion of alternatives included these factors: cost of each alternative; degree of contaminant confinement and release resulting with each alternative; and considerations and limitations specific to each alternative.

The Seattle District made another important contribution to the remedial investigations for Commencement Bay. By agreement with WDE, the Seattle District and the US Army Engineer Waterways Experiment Station developed a decisionmaking framework focusing on how dredged material should be tested and the results interpreted to evaluate potential contaminant impact and the disposal conditions for which dredged material would have minimal adverse impact on the overall environment was developed. The WES report (Lee et al. 1985) discussed these questions for dredged material in general and then used Commencement Bay as an example of application of the decisionmaking framework.

The two Commencement Bay studies performed by the Corps of Engineers provide a starting point for this study. The "Alternative Dredging Methods" report (Phillips et al. 1985) reviewed most of the methods and techniques available for controlling the impacts of dredging and disposing of contaminated sediment. Parts II, III, IV, V, and VI of this report will rely heavily on the process descriptions for the various methods and alternatives discussed in the Commencement Bay report. The "Decisionmaking Framework" (Lee et al. 1985) addresses the question: Are restrictions necessary for disposal of contaminated dredged material? However, it does not identify testing required to address design of a disposal site or selection of necessary control or treatment options. The "Decisionmaking Framework" will be used in Part IX to develop a strategy for selection of control/treatment options.

Nature of Contaminated Sediment

Sediment deposited on the bottom of streams, lakes, and coastal waters varies in physical and chemical composition. Because many water contaminants are attracted by and become attached to sediment particles, contaminant concentrations in sediment are generally much greater than in water. Drainage basins with concentrated urban, industrial, or agricultural sources often contribute significantly to downstream sediment contamination. Such is the case with Puget Sound.

The environmental impact of sediments depends on the amount of contaminant present and the mobility of the contaminant into environmental pathways by biological or hydrodynamic processes. The chemistry of contaminants in sediment is controlled primarily by the physicochemical conditions under which the sediment exists. Fine-grained sediment is typically anoxic, reduced, and near neutral in pH. How disposal environments affect these chemical characteristics is an important consideration in the selection of disposal options. If sediment is disposed in an aquatic environment, sediment chemistry may not change. However, transfer of the sediment to a dryer environment, such as an upland disposal site, may change the chemistry to an oxic and lower pH condition more favorable to the release of contaminants (Lee et al. 1985).

Biological and physical processes may also affect the release of contaminants at a disposal site. Different contaminants and sediments with different properties do not always respond similarly to an altered biological or physicochemical condition. This requires testing on an individual basis for site-specific sediment contamination problems (Gambrell et al. 1978).

Puget Sound dredging projects may be conducted to maintain navigation channels, to create new harbors and port facilities, or to remove contaminated sediment (remedial actions). Projects whose purpose is remedial action will by definition contain contaminants that require special considerations during disposal. Maintenance or new work dredging may involve sediment with various degrees of contamination. This study considers disposal options for contaminated sediment from all three types of projects.

Levels of Control/Treatment

The "Management Strategy" for disposal of dredged material (Francingues et al. 1985) discussed the two initial alternatives available for disposal of contaminated dredged material: open-water disposal and confined disposal. If the testing protocols identified in the management strategy show that conventional open-water, nearshore, or upland disposal will have an adverse impact on the environment, then open-water disposal with restrictions would be considered first followed by confined disposal with restrictions. This study begins where the management strategy ends. It discusses available options and decision points necessary to determine if design of a particular alternative is feasible and to select the best alternative(s) or combination of alternatives.

When dredging contaminated material, two other levels of control should be considered. Control of sediment resuspension and contaminant release during dredging (at the dredge head) and controls to prevent release of contaminated material during transport of dredged material will be discussed. In addition, the confined disposal options for nearshore and for upland sites will be considered as two separate levels although many of the control/treatment measures for the two are the same. This yields five levels of control/treatment to be considered by this study:

- Controls during dredging
- Controls during dredged material transport

- Controls for upland confined disposal with restrictions
- Controls for nearshore confined disposal with restrictions
- Controls for open-water disposal with restrictions

Objectives

The two objectives of this study are (1) to identify control and treatment options for contaminated dredged material unsuitable for unconfined, open water disposal and (2) to describe design tests, design concepts, and guidelines for selection of control and treatment options.

Scope

The study objectives will be accomplished by completion of the following tasks:

a. Identify and describe control and treatment technologies (Parts II through VI).

b. Describe tests necessary for selection of design features (Part VII).

c. Identify proven technology applications (Parts II through VI and Part VIII).

d. Assess the feasibility of pretreatment for open water disposal and use of rehandling facilities (Parts VI and VIII).

e. Develop guidelines for selection of design features (Part IX).

f. Develop scenarios for implementation of controls without predesign testing (Part X).

Assumptions

In order to keep the scope of this study focused on contaminated dredged material in the Puget Sound area and on the objectives of this study, the following assumptions are made:

- The sediment to be dredged may not be acceptable for unconfined, open water disposal due to the presence of contamination exceeding applicable criteria. This determination is based on evaluations and testing protocols proposed in "Management Strategy for Disposing of Dredged Material" (Francingues, et al. 1985) and "Decisionmaking For Management of Dredged Material: Application to Commencement Bay, Washington" (Lee et al. 1985).

- Initial cost analysis of alternatives will be based on an order-of-magnitude precision, using cost incurred elsewhere on similar projects, estimates of costs associated with implementing an average size project, and/or relative cost values. Due to the number of factors that influence cost, ranges of cost will frequently be used.

- Design concepts, guidelines, options, and applications for contaminant control and treatment will be based on existing and emerging technology found in the literature. This study will not involve any new analytical or field work.

Organization of Report

This report consists of eleven parts or chapters. Following this introductory chapter are five chapters dealing with the five levels of treatment or control for contaminated dredged material, i.e., during dredging, during transport, for upland confined disposal sites, for nearshore confined disposal sites, and for restricted open-water disposal sites. These chapters will provide the descriptions of individual treatment technologies. Part VII reviews briefly the testing protocols recommended for evaluating dredged material disposal sites. Part VIII cites documented application of control/treatment technologies to contaminated dredged material or similar applications that have proven or demonstrated capabilities. Part IX is the focal point of the report. It seeks to explain how one would select a control or treatment alternative for a given situation. Part X will discuss the possibilities for design of treatment systems with little or no laboratory or pilot-scale testing. Part XI recommends candidate technologies for pilot or field demonstrations.

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PART II: CONTAMINANT CONTROL DURING DREDGING

Background

During dredging operations all dredge plants, to differing degrees, disturb bottom sediment, creating a plume of suspended solids around the dredging operation. The suspended solids plume can form relatively low concentrations in the upper water column, high concentrations near the bottom, or both depending on the type of soil and the amount of energy introduced into the sediment by the dredge. The material suspended in the water column is often referred to as turbidity; the dense near-bottom suspensions are commonly called fluid mud or fluff. In the most strict sense, turbidity describes a complex relationship of factors that affect the optical properties of the water column. Suspended solids concentrations are best presented in gravimetric units such as milligrams or grams per liter indicating the weight of dry solids in a volume (liter) of sample.

Due to aesthetic and/or biological reasons, it may be generally advantageous to keep resuspension to a minimum. Limitations may be placed on levels of suspended solids when even normal dredging operations occur around public areas or coral reefs or during certain periods in the life cycle of a specific marine species (Lunz, Clark, and Fredette 1984). However, the major problems from suspended solids occur while dredging contaminated sediment. Contaminated sediment may release contaminants into the water column through resuspension of the sediment solids, dispersal of interstitial water, or desorption from the resuspended solids. Once resuspended, fine-grained sediment (clay and silt) tend to remain in the water column longer due to their low settling velocity. These fine-grained sediment fractions also have the highest affinity for several classes of contaminants, such as organics and heavy metals which have made their way into the waterway. Fulk, Gruber, and Wullschleger (1975) showed that, for these classes of contaminants, the amounts that are dissolved or desorbed are negligible and basically all contamination transferred to the water column is due to resuspension of solids. Clearly, the control of sediment resuspension during dredging will reduce the potential for release of contaminants and/or their spread to other previously uncontaminated areas.

As summarized by Raymond (1984), most present dredging equipment and techniques evolved as a result of emphasis on economic return as measured by maximum production. Conventional dredges, therefore, are not specifically designed to operate in contaminated sediment and some modification of equipment or operating techniques may be necessary for such use. Fortunately, these modifications have been shown to be minor and generally within reasonable costs. The reason for this can be seen by looking at one definition of resuspension. Resuspension can be viewed as the difference between the amount of sediment loosened or disturbed from the bottom and the amount actually entrained and removed by the dredge. Therefore, the more efficient the dredging process is the less resuspension is likely to occur. Modifications to equipment or techniques that maximize removal without increasing the energy imparted to the sediment in the loosening process will reduce resuspension (and also increase production).

Minimizing sediment resuspension as described above reduces the potential for impact at the dredging site. However, two additional objectives of the dredging process are a result of disposal considerations. It is likely when dealing with contaminated sediment that disposal will be more costly as a result of controls, treatment, handling procedures, and limited disposal areas. In general, the dredging equipment and techniques should seek to minimize the total volume (and therefore, cost) of dredged material that must be handled in the disposal operation. Maximizing the solids concentration decreases the free water that must be treated as effluent and, by reducing the opportunity for extracting soluble contaminants, lowers the levels of contamination in that effluent. A second problem is simply over-dredging the site so that volumes of clean sediment become mixed with the contaminated material, increasing the overall volume that must be disposed of as contaminated. Certainly some deliberate over-depth or over-area is normally designed into a project to ensure complete removal of the contaminants. But, beyond this design, the dredging equipment and technique must provide sufficient control to remove relatively thin layers (e.g. contour dredging) and small hot spots.

The following sections of this chapter discuss the sediment resuspension characteristics of various conventional and special-purpose dredges followed by suggested techniques or designs that may be used to further control resuspension and address the additional objectives of reducing the volumes handled.

Dredge Equipment

Background

The dredging process itself involves four basic tasks: (1) the loosening or dislodging of sediment by mechanically penetrating, grabbing, raking, cutting, drilling, blasting, or hydraulically scouring; (2) a lifting action accomplished by mechanical devices such as buckets or by hydraulic suction; (3) the transporting of dredged material by pipelines, scows, hopper dredges, or trucks; and (4) disposing of the material by either discharging from a pipeline or by dumping from trucks into a confined disposal area, bottom dumping from barges, or pumping out of scows or hoppers. In some hydraulic operations, all four actions are carried out continuously and concurrently by a single piece of equipment, but in others the various functions are performed separately and intermittently, utilizing two or more pieces of equipment. For instance, where dredging equipment does not have on-board storage capability or where environmental considerations preclude the possibility of disposing of the material into open water adjacent to the dredging site, auxiliary equipment (scows or barges) is required for storage and transport of the dredged material. Dredging equipment and dredging operations resist precise categorization. As a result of specialization and tradition in the industry, numerous descriptive, often overlapping, terms categorizing dredges have developed. For example, dredges can be classified according to: the basic means of moving material (mechanical or hydraulic); the method of storage or disposition of dredged material (pipeline or hopper); the device used for excavating sediments (cutterhead, dustpan, plain suction); the type of pumping device used (centrifugal, pneumatic, or airlift); and others.

Two basic types of dredges, hydraulic and mechanical, are addressed in this report. These descriptive categories were selected based on the differences each have in terms of contaminant loss during dredging and disposal activities.

Mechanical dredges remove bottom sediment through the direct application of mechanical force to dislodge and excavate the material at almost in situ densities. Clamshell, dipper, dragline, and ladder dredges are types of mechanical dredges.

Hydraulic dredges remove and transport sediment in liquid slurry form. They are usually barge mounted and carry diesel or electric powered centrifugal pumps with discharge pipes ranging from 6 to 48 inches in diameter. Cutterhead, suction, dustpan, hopper, and special-purpose dredges are types of hydraulic dredges. Special-purpose dredges, for this report, are dredges designed to pump high solids concentrations and/or produce low turbidity levels.

Selection Criteria

Selection of dredging equipment and method used to perform the dredging will in general depend on the following factors:

a. Physical characteristics of material to be dredged.

b. Quantities of material to be dredged.

c. Dredging depth.

d. Distance to disposal area.

e. Physical environment of and between the dredging and disposal areas.

f. Contamination level of sediment and mobility of contaminants.

g. Method of disposal.

h. Production required.

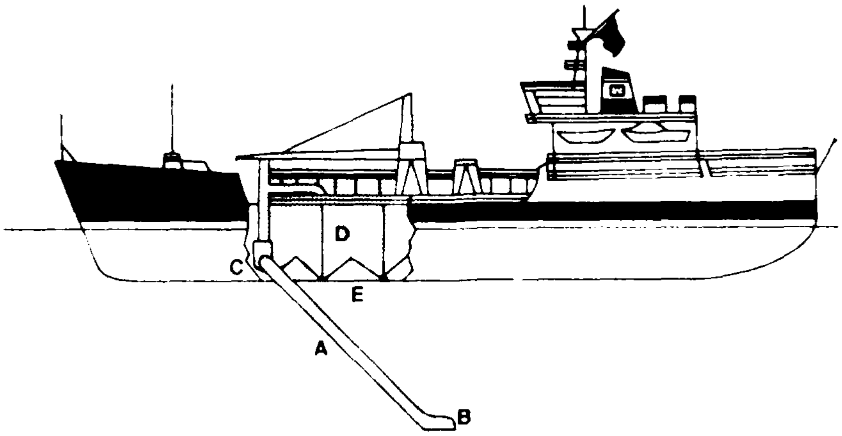
i. Type of dredges available.

Dredging of contaminated sediments require the additional consideration of contaminant loss during the extraction process and meeting of applicable criteria pertaining to removal efficiencies and/or environmental protection. For most jobs, the controlling factors in equipment selection are the degree of contaminant confinement required and the cost necessary to achieve this confinement. For any given dredging method, technologies and practices exist that increase contaminant removal and confinement, though confinement efficiencies will vary greatly among techniques. Therefore, the critical element in the selection of a dredging technique is the definition of criteria that are to be met. These criteria may specify removal efficiencies, allowable losses, emission rates, and/or concentrations for individual contaminants, allowing a variety of dredging techniques to be considered, or the criteria may specify certain equipment or method as requisite for given levels and types of contamination. Other than through exercise of judgment, recommended techniques are difficult to determine prior to consideration of these criteria.

Many operational modifications and controls that can be used for working in contaminated sediment are not standard or accepted practices. Therefore, contractors bidding on a job requiring these modifications may feel the need to protect their job profits by increasing bids. A solution to this cost escalation effect is hourly rental rates until the operators gain experience in use of a specific control practice. Better cost control can result with this approach.

Operational Characteristics of Various Dredges

Hopper Dredges. Hopper dredges are self-propelled seagoing ships of from 180 to 550 ft in length, with the molded hulls and lines of ocean vessels (Fig. 2.1). They are equipped with propulsion machinery, sediment containers (hoppers), dredge pumps, and other special equipment required to perform their essential function of removing material from a channel bottom or ocean bed. Hopper dredges have propulsion power adequate for required free-running speed and dredging against strong currents, and excellent maneuverability for safe and effective work in rough, open seas. Dredged material is raised by dredge pumps through dragarms connected to dragheads (Figs. 2.2 and 2.3) in contact



Dragarms (A) with dragheads (B) extend from each side of the ship s hull The dragheads are lowered to the channel bottom and slowly pulled over the area to be dredged Pumps (C) create suction in the dragarm and the silt or sand is drawn up through the arms and deposited in hopper bins (D) in the vessel s midsection When the bins are full the dredge sails to the designated disposal area and empties the dredged material through large hopper doors (E) in the bottom of the hull

Figure 2.1. Typical hopper dredge components

with the channel bottom, and discharged into hoppers built in the vessel. Hopper dredges are classified according to hopper capacity: large-class hopper dredges have hopper capacities of 6000 cu yd or greater, medium-class hopper dredges have hopper capacities of 2000 to 6000 cu yd, and small-class hopper dredges have hopper capacities of from 500 to 2000 cu yd. During dredging operations, hopper dredges travel at a ground speed of from 2 to 3 mph and can dredge in water depths from about 10 to over 80 ft. Minimum dredging depth is limited by the draft of the dredge. They are equipped with twin propellers and twin rudders to provide the required maneuverability. Track plotting surveying equipment can be placed aboard for exact positioning of the dredge.

Hopper dredging is accomplished by one of three methods: (a) pumping past overflow; (b) agitation dredging; and (c) pumping to overflow. The use of these methods is controlled to various degrees by environmental concerns and the water quality certification permits required in the area in which dredging is being accomplished. The environmental effects of these methods must be assessed on a project-by-project basis. If the material being dredged is clean sand, the percentage of solids in the overflow will be small and

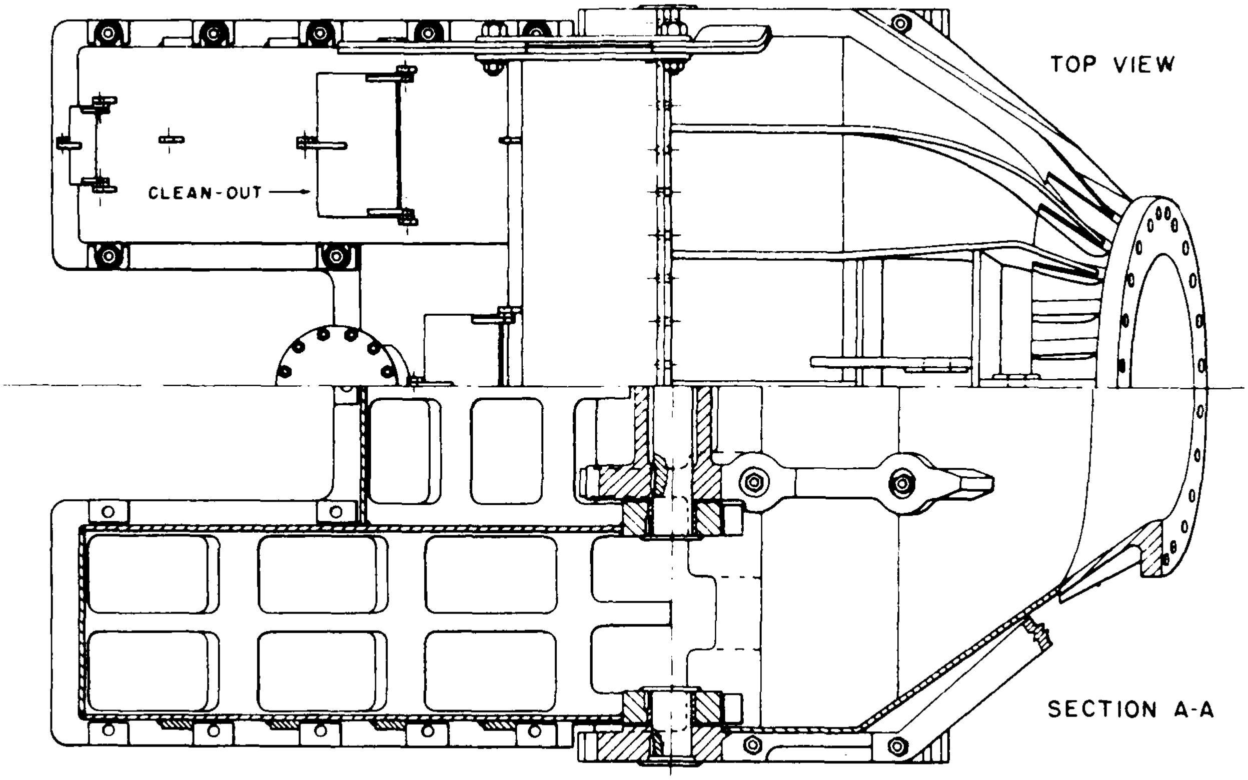


Figure 2.2. Hopper dredge California draghead (top view)

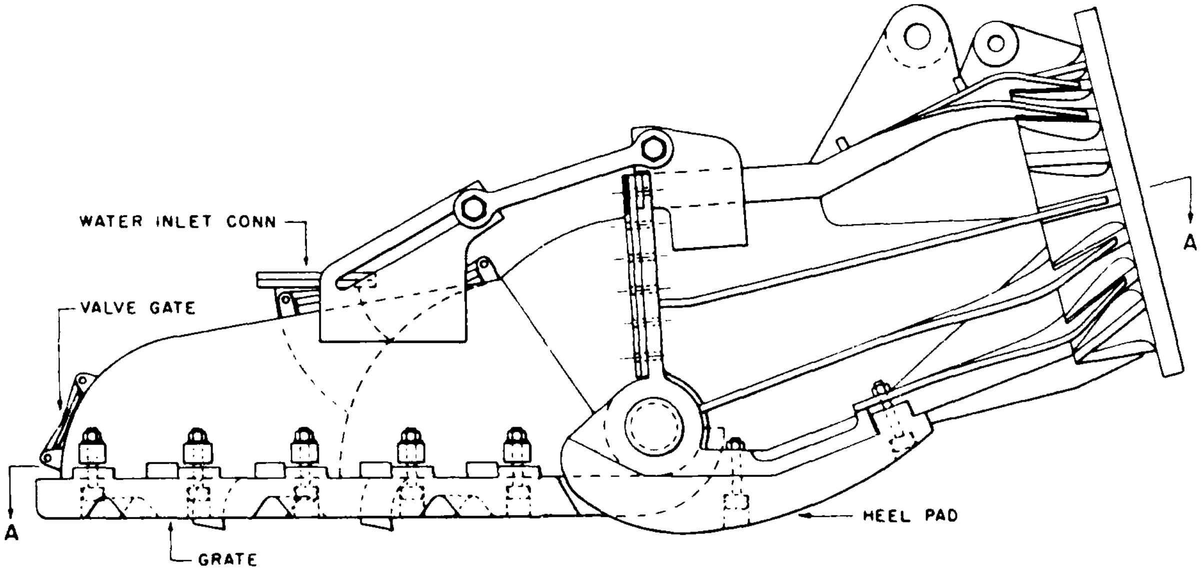


Figure 2.3. Schematic of hopper dredge California draghead (side view)

economic loading may be achieved by pumping past overflow. When contaminated sediment is to be dredged, however, and adverse environmental effects have been identified, pumping past overflow is not recommended. In such cases, other types of dredges may be more suitable for removing the contaminated sediment from the channel prism. If hopper dredges are not allowed to pump past overflow in sediment that has good settling properties, the cost of dredging increases. The settling properties of silt and clay sediment may be such that only a minimal load increase would be achieved by pumping past overflow. Economic loading (i.e., the pumping time required for maximum production of the hopper dredge) should be determined for each project. These determinations, along with environmental considerations, should be used to establish the operation procedures for the hopper dredge.

Agitation dredging is a process which intentionally discharges overboard large quantities of fine-grained dredged material by pumping past overflow, under the assumption that a major portion of the sediment passing through the weir overflow will be transported and permanently deposited outside the channel prism by tidal, river, or littoral currents. Agitation dredging by its very nature creates large amounts of suspended sediment and should not be used when these concentrations could create an environmental problem.

The dredge will usually operate near the edge of the channel using its own power to stay in the dredging area. Dredging is accomplished by repetitive passes over the area to be dredged, each pass removing inches of surface material. The draghead is moved along the channel bottom as the vessel moves forward. The dredged material is sucked up through the drag pipe and deposited in the hoppers of the vessel where it settles. As the hopper is filled, overflow water is usually discharged at the site of dredging. Once loaded, hopper dredges cease dredging and move to the disposal site to unload. The hopper is considered to be full once an economic load has been achieved. The economic load is based on the pumping time required to obtain the least cost per cu yd of solids dredged and discharged. It considers pumping and nonpumping times (travel to disposal site and back) of the entire dredging cycle and considers only solids (suspended and settleable) that make it to the disposal site (not overflow loss). Usually the economic load, which will vary by equipment, disposal site location, and sediment characteristics, is specified as a maximum overflow pumping time that allows the greatest possible amount of dredged material to settle in the hopper. For some exclusively fine-grained materials which may remain in a slurry, the economic load may not require overflow pumping.

Hopper dredges can be used to transport dredged materials greater distances than pipeline dredges. Hopper dredges, though not precise in dredging location (horizontal accuracy often cannot be controlled to less than a 10-feet tolerance), can remove a few inches of contaminated materials from the bottom with each pass. They can dredge shoals that slope or vary in elevation. Few other types of dredges are capable of doing this. However, the hopper dredge cannot dredge effectively along piers or near structures. Hopper dredges are often the most economical type of dredge to use where disposal areas are not available within economical pumping distances of hydraulic pipeline dredges. The hopper dredge provides self-contained storage of dredged material which eliminates the need for separate barge, scow, or pipeline.

Modification of hopper dredges to collect gases from the degasser system and shrouding of the hopper bin to capture gases discharged from the pipe are potential dredge modifications that could be used to reduce loss of volatile contaminants during dredging. These modifications have not been attempted to date.

The hopper dredge can be mobilized and initiate dredging in a relatively short period of time. Hopper dredges have excellent maneuverability and can work effectively in congested harbors.

Cutterhead Dredges. The hydraulic pipeline cutterhead suction dredge is the most commonly used dredging plant and is generally the most efficient and versatile (Fig. 2.4). It performs the major portion of the dredging workload in the United States and Pacific Northwest. Because it is equipped with a rotating cutter apparatus surrounding the intake end of the suction pipe, it can efficiently dig and pump all types of alluvial materials and compacted deposits, such as clay and hardpan. This dredge has the capability of pumping dredged material long distances to upland disposal areas. Although the cutterhead dredge was developed to loosen densely packed deposits and cut through

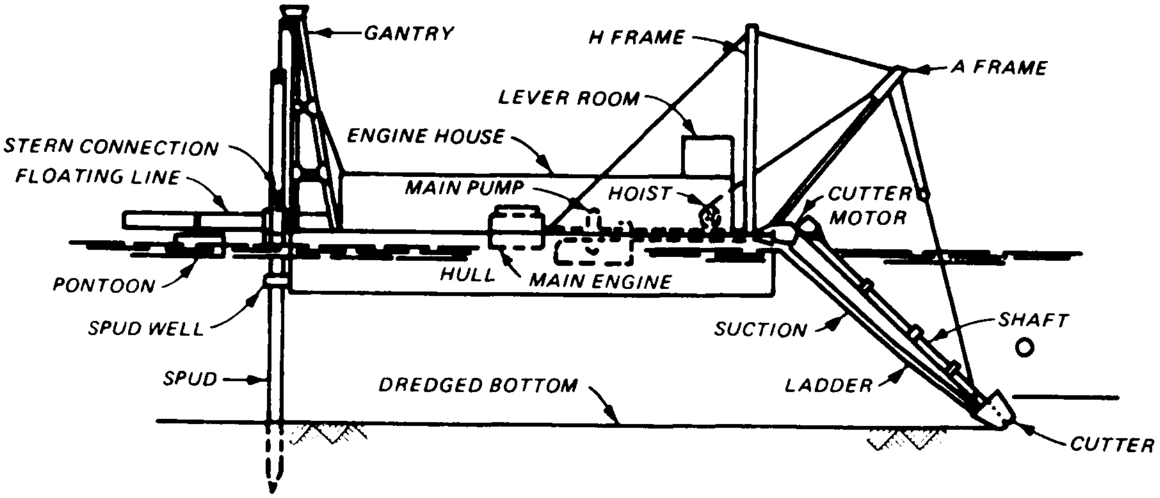


Figure 2.4. Typical components of a pipeline cutterhead dredge

soft rock, it can excavate a wide range of materials including clay, silt, sand, and gravel. The cutterhead dredge is suitable for maintaining harbors, canals, and outlet channels where wave heights are not excessive. A cutterhead dredge designed to operate in calm water cannot operate offshore in waves over 2-3 ft in height: the cutterhead would be forced into the sediment by wave action creating excessive shock loads on the ladder. However, a cutterhead dredge specifically designed to operate offshore can operate in waves up to about 6 ft.

Because it is the basic dredge type to which many of the contaminant related modifications have been applied, a detailed explanation of the hydraulic dredge and its components is given. It has the advantage of being able to excavate materials, move them hydraulically, and dispose of them without rehandling. These dredges are generally classified by size in accordance with the diameter of the discharge pipeline: small-class pipeline dredges have a 4- to 14-in. discharge; medium-class pipeline dredges have a 16- to 22-in. discharge; and large-class pipeline dredges have a 24- to 36-in. discharge. Typical specifications for five sizes of pipeline dredges are shown in Table 2.1, which was adapted from Houston (1970).

Table 2.1

Typical Specifications for Five Sizes of Pipeline Dredges*

Item	Size of Discharge Pipe, In. 12	16	20	24	28
Length, ft	100	120	140	160	175
Beam, ft	35	40	45	50	50
Depth, ft	8	9	10	12	15
Displacement, tons	560	840	1,200	1,850	3,000
Pump power, brake horsepower	570	1,000	1,500	2,700	5,000
Pump speed, revolutions per minute	500	400	350	325	300
Cutter power, brake horsepower	150	200	400	750	1,000
Cutter speed, revolutions per minute	5-30	5-30	5-30	5-30	5-30
Spud length, ft	55	60	70	90	100
Ladder length, ft	50	55	60	70	80
Maximum pipeline, ft	2,500	4,000	5,000	7,000	9,000
Maximum width of cut, ft	160	200	220	270	325
Mamimum width of cut, ft	50	60	70	90	90
Maximum digging depth, ft	35	40	45	50	60
Minimum digging depth, ft	4	5	6	8	12

* Adapted from Huston 1970.

Figure 2.4 shows the major components of a pipeline cutterhead dredge. These components consist of a cutterhead on the end of a suction pipeline, a ladder structure supporting the suction pipeline and cutterhead, support frames (A and H) for the ladder, hoisting equipment, main pump and main engine, the spud and support gantry, and a floating discharge pipeline. Figures 2.5 and 2.6 show the forward components of the cutterhead dredge and the spud gantry, respectively.

The cutterhead is the most forward component of the dredge. It is basket shaped, with spiral blades forming the sides of the baskets as shown in

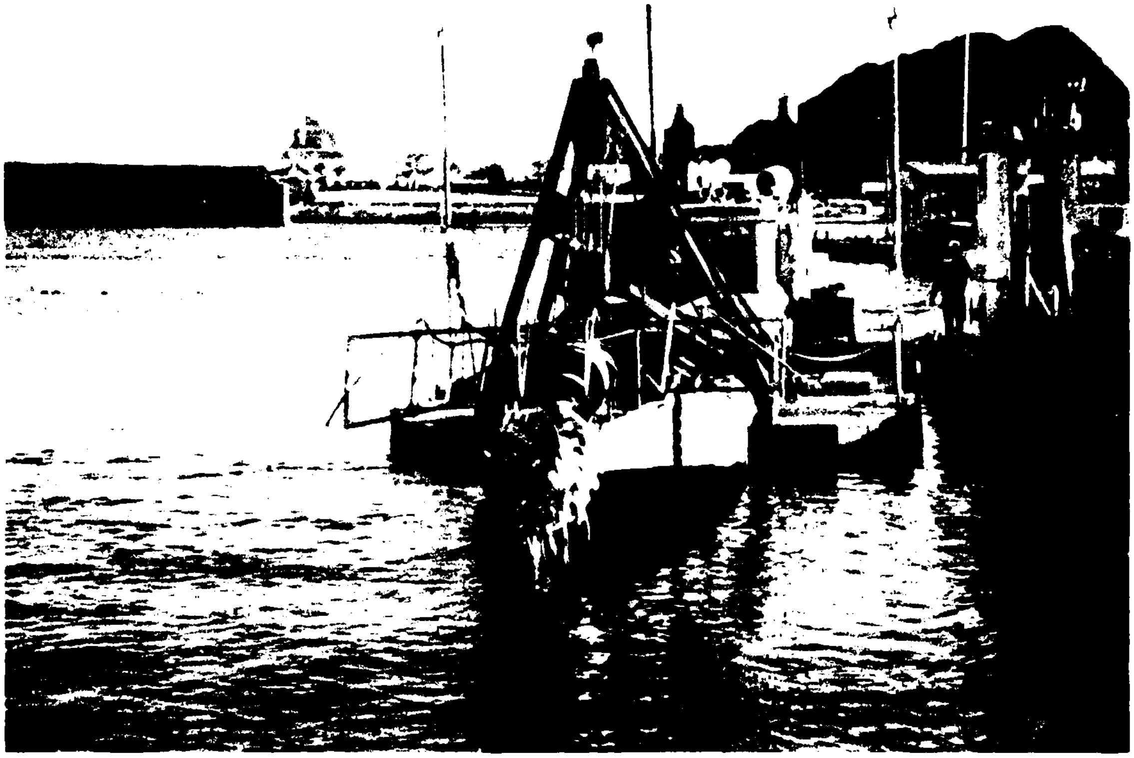


Figure 2.5. Forward components of a pipeline cutterhead dredge

Figures 2.7 and 2.8. It rotates slowly at a speed of 5 to 30 revolutions per minute (rpm) loosening materials to be dredged with the blades.

A secondary purpose of the cutter is to prevent large debris from entering or plugging the intake pipe. Cutter diameters vary from less than 2 ft for a small dredge and up to 10 ft for a large dredge. The many types of cutterheads and modifications to cutters allow efficient dredging of all types of materials. Pick-type teeth can be added to facilitate dredging in hard-packed materials, coral, and soft rock.

The ladder is a heavy triangular steel frame extending forward from the hull. The dredge cutter is attached to the forward end of the ladder. Winch gear attached to the A-frame raises or lowers the cutter end of the ladder. The suction pipe runs from the center of the cutterhead through the ladder to

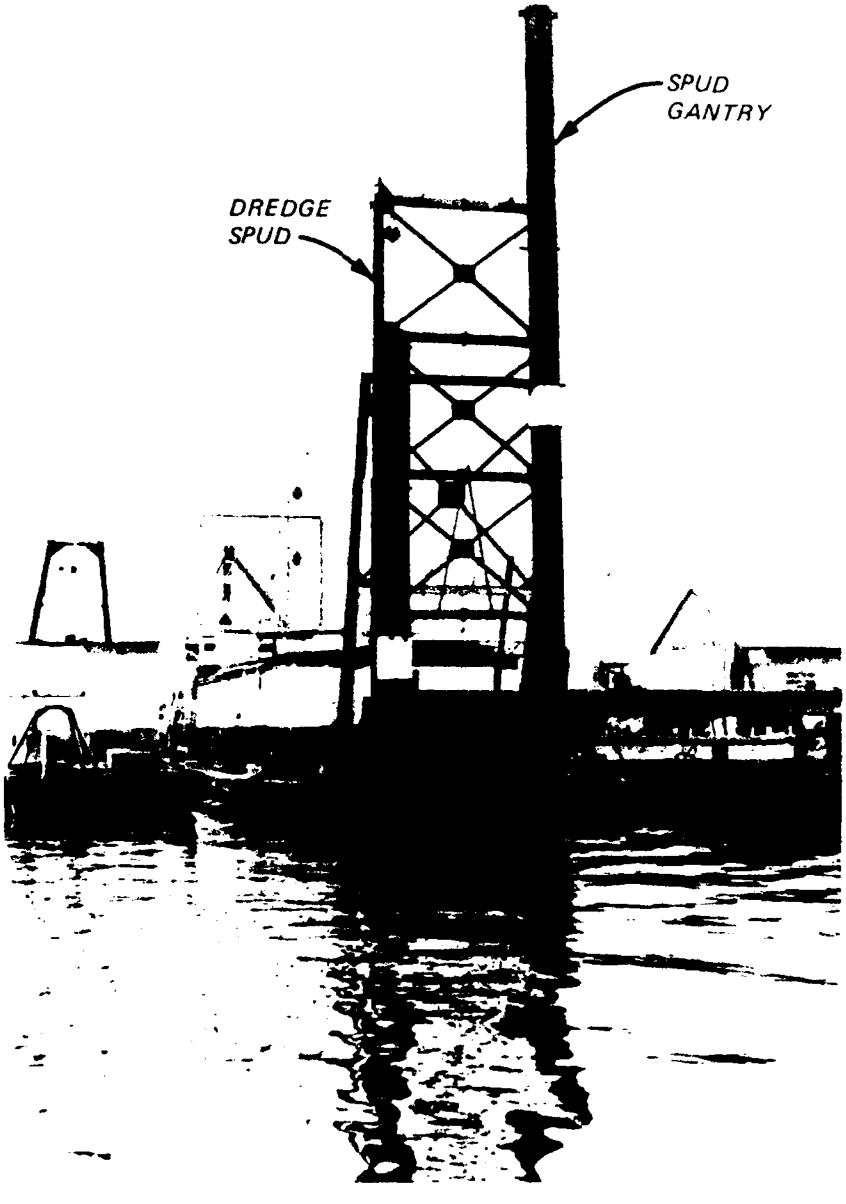


Figure 2.6. Pipeline cutterhead dredge spud gantry

Figure 2.7. Closed-nose basket cutter

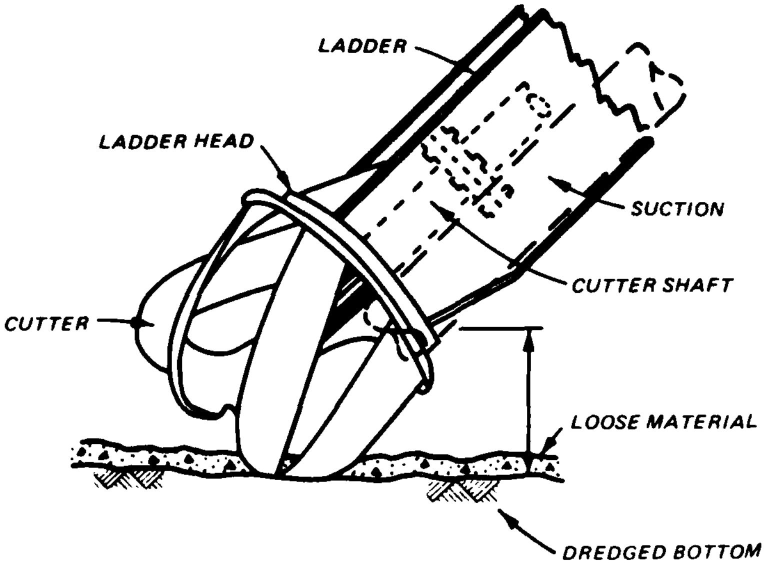


Figure 2.8. Cross-section view of typical cutterhead and suction

the dredge pump. Suction diameters are usually equal to or slightly larger than the dredge discharge pipeline diameter.

The main dredge pump is located forward in the hull of the dredge at the lowest possible elevation. This low elevation reduces the distance the dredge must lift the slurry under vacuum conditions. The dredge pump has a height of approximately four times the discharge pipe diameter and a vaned impeller rotating between 250 rpm (for small dredges) to 900 rpm (for large dredges). The rotating vaned impeller centrifugally forces the dredged slurry to the outer circumference of the dredge pump shell where it enters the discharge line at pressures of 50 to 300 pounds per square inch (psi).

The cutterhead dredge is generally equipped with two stern spuds used to hold the dredge in working position and to advance the dredge into the cut or excavating area. During operation, the cutterhead dredge swings from side to side alternately using the port and starboard spuds as a pivot, as shown in Figure 2.9. Cables attached to anchors on each side of the dredge control lateral movement. Forward movement is achieved by lowering the starboard spud after the port swing is made and then raising the port spud. The dredge is then swung back to the starboard side of the cut centerline. The port spud is lowered and the starboard spud lifted to advance the dredge.

Excavated material is pumped through the discharge pipe to the disposal site. Open-water disposal requires only a floating discharge pipeline made up of sections of pipe mounted on pontoons and held in place by anchors. Additional sections of shore pipeline are required when upland disposal is used. The excavated material may be placed in hopper barges for disposal in open water or in confined areas that are remote from the dredging site. Depending on the size of the dredge and the physical character of the material, pipeline transport distances can range up to about 2 miles. Transportation beyond that point usually requires another pump to boost the slurry along. Distances less than 2 miles may require booster pumps for coarse sediments, with small dredges, and to dispose in sites that are elevated in relation to the dredge (1 ft of vertical discharge pumping is approximately equal to 200 ft of horizontal pumping distance).

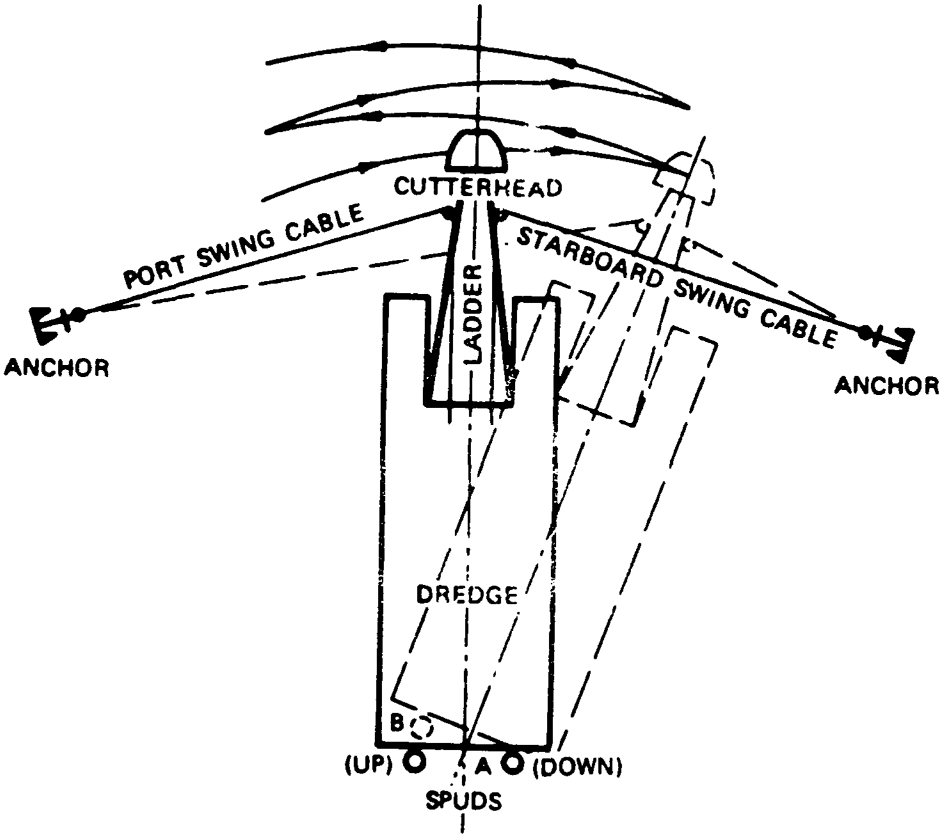


Figure 2.9. Cutterhead dredge - plan view

Cutterhead dredges in pipeline diameters from 8 through 27 in. are readily available in the Pacific Northwest. Table 2.2 shows specifications for typical cutterhead dredges working in the Commencement Bay area. The minimum depth of single pass excavation would be approximately the same as onehalf the pipeline diameter. Production (Prod.) for minimum depth pass excavation can be calculated from the table as follows:

$$\text{Prod. (Min. Pass)} = \frac{(1/2 \times \text{Discharge Diameter})}{(\text{Maximum Depth Pass Excavation})} \times \text{Prod. (Max. Pass)}$$

Actual vertical precision of the cut is often limited by the mechanical control of the ladder and suction head to approximately 1 ft.

Cutterhead dredges can excavate a range of material normally found in harbor dredging projects (except where old piers and piling may be

Table 2.2

Specifications for Typical Cutterhead Dredges Working in Commencement Bay Area

Pipeline Diameter in.	Dredge Pumps H.P.	Dredge Pumps Size, in.	Dredge Pumps Drive	Production Rate cu yd/hr	Maximum Dredging Depth ft	Maximum Single Pass Excavation in.
6	175	8	Diesel	71	12	18
8	175	8	Diesel	79	12	18
10	335	12	Diesel	225	25	18
12	520	14	Diesel	405	25	18
14	520	16	Diesel	525	25	21
16	1,125	18	Diesel	656	40	21
20	1,700	24	Diesel	1,024	50	24
24	2,250	24	Diesel	1,211	50	30
30	3,600	30	Diesel	1,875	50	36

encountered) and pump the dredged material through pipelines to an upland, nearshore, or open-water disposal site without rehandling. This minimizes handling of, and exposure to, contaminated dredged material.

Most available cutterhead dredges have limited capacity for dredging deeper than 50 ft below water level. Dredge ladder modifications would be required to dredge in deeper water. Conventional cutterhead dredges are not self propelled but require towboats to move them between dredging locations. Thus, mobilization and set up are major and costly undertakings.

Concentrations of suspended sediments from a cutterhead dredging operation range from 200 to 300 mg/ℓ near the cutterhead to a few mg/ℓ one to two thousand feet from the dredge. The suspended solids plume is usually contained in the lower portion of the water column. The plume is generated by the rotational speed of the cutter, the swing speed of the cutter, and the depth of burial of the cutter below the sediment surface.

Suction Dredges. The suction dredge is a pipeline cutterhead dredge with the cutterhead removed (Figure 2.10). Many times skid plates under the ladder and a vertical elbow on the suction are added to improve operations. The

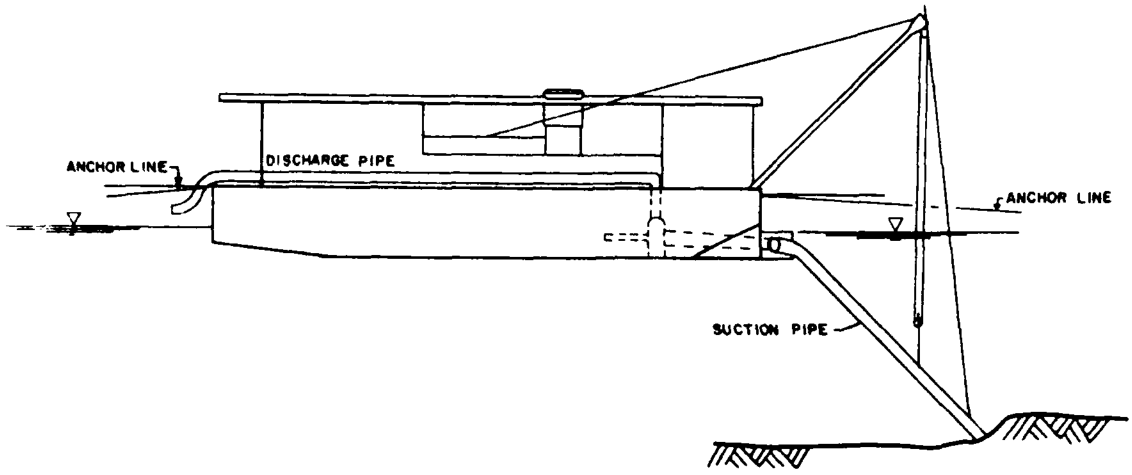


Figure 2.10. Plain suction dredge

operations, production rates, and dredging depths for the suction dredge are comparable to those for the cutterhead pipeline dredge.

Suction dredges generate low levels of turbidity. However, they are limited to dredging soft, free-flowing, and unconsolidated material. Trash, logs, and other debris in the dredge material will clog the suction and greatly reduce the effectiveness of the dredge.

Dustpan Dredges. The dustpan dredge is a hydraulic suction dredge that uses a widely flared dredging head along which are mounted pressure water jets (Fig. 2.11). The jets loosen and agitate the sediment, which is then captured in the dustpan head as the dredge itself is winched forward into the excavation. This type of dredge was developed by the Corps of Engineers to maintain navigation channels in uncontrolled rivers with bedloads consisting primarily of sand and gravel. The first dustpan dredge was developed to maintain navigation on the Mississippi River during low river stages. A dredge was needed that could operate in shallow water and be large enough to excavate the navigation channel in a reasonably short time. The dustpan dredge operates with a low-head high-capacity centrifugal pump since the material has to be raised only a few feet above the water surface and pumped a short distance. The

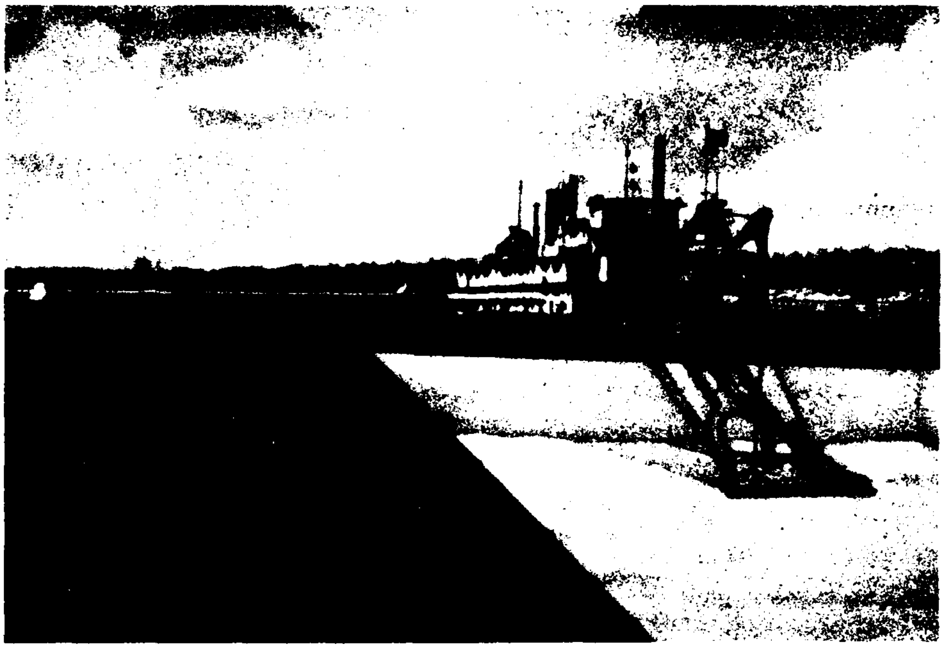


Figure 2.11a. Illustration of dustpan dredge

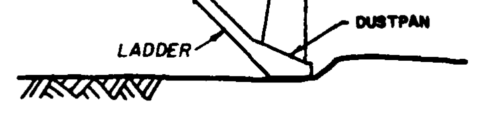


Figure 2.11b. Schematic of dustpan dredge

dredged material is normally discharged into open water adjacent to the navigation channel through a pipeline usually only 800 to 1000 ft long.

Dustpan dredges generate suspended solids plumes similar to, or in greater concentration, than those generated by cutterhead dredges. Because of this, their relatively short pumping distance and their lack of efficiency in fine-grained material, dustpan dredges are not recommended for sites where turbidity must be controlled.

Dipper Dredges. The dipper dredge is basically a barge-mounted power shovel. It is equipped with a power-driven ladder structure and operated from a barge-type hull. A schematic drawing of the dipper dredge is shown in Fig. 2.12. A bucket is firmly attached to the ladder structure and is forcibly thrust into the material to be removed.

Dipper dredges are best used for excavating hard compacted materials, rock, or other solid materials after blasting. Although it can be used to remove most bottom sediment, the violent action of this type of equipment may cause considerable sediment disturbance and resuspension during maintenance digging of fine-grained material. In addition, a significant loss of the fine-grained material will occur from the bucket during the hoisting process. The dipper dredge is not recommended for use in dredging contaminated sediment or where resuspension of sediment must be controlled.

Bucket Dredges. The bucket type of dredge is so named because it utilizes a bucket to excavate the material to be dredged (Fig. 2.13). Different types of buckets can fulfill various types of dredging requirements. The buckets used include the clamshell, orange-peel, and dragline types and can be quickly changed to suit the operational requirements. The vessel can be positioned and moved within a limited area using only anchors; however, in most cases anchors and spuds are used to position and move bucket dredges. The material excavated is placed in scows or hopper barges that are towed to the disposal area. Bucket dredges normally range in capacity from 1 to 25 cu yd. The crane is mounted on a flat-bottomed barge, on fixed-shore installations, or on a crawler mount. Twenty to thirty cycles per hour is typical, but large variations exist in production rates because of the variability in depths and

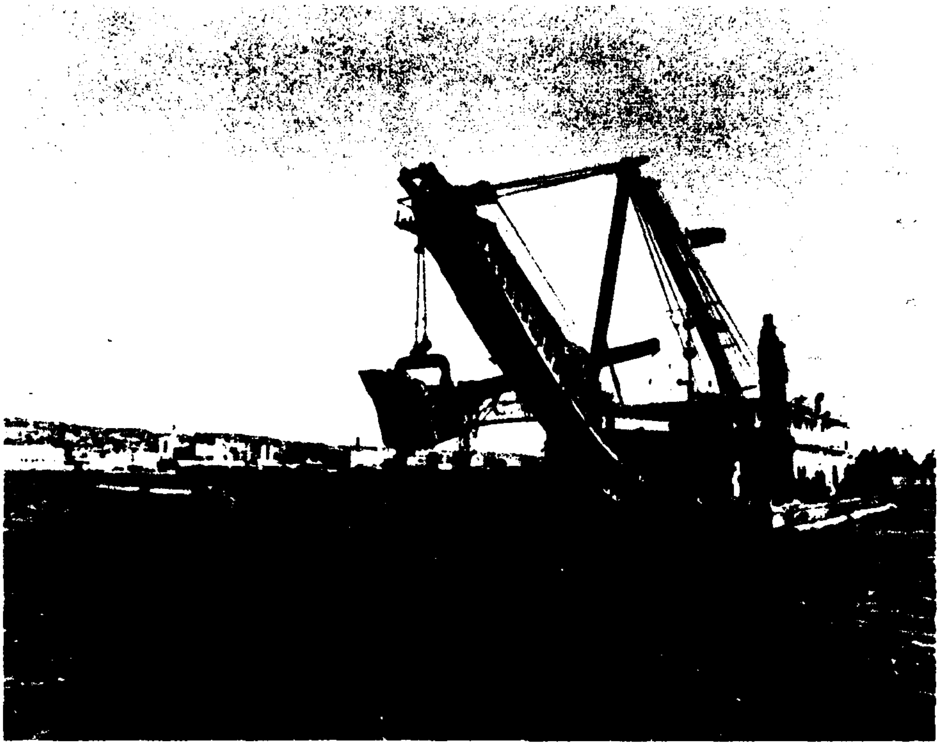


Figure 2.12a. Illustration of a dipper dredge

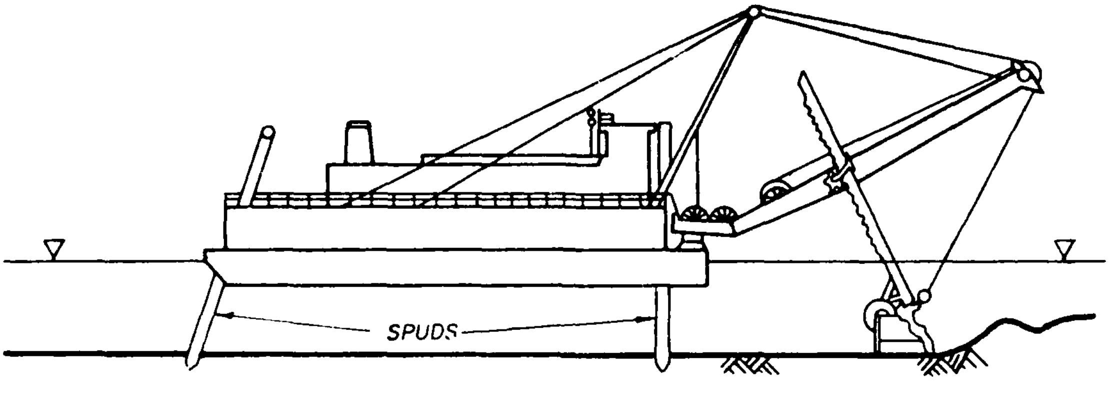


Figure 2.12b. Schematic of a dipper dredge

Figure 2.13a. Illustration of a bucket dredge

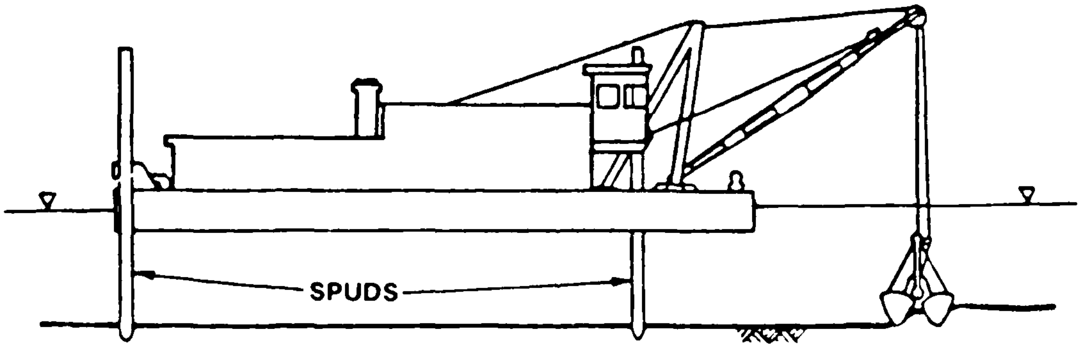


Figure 2.13b. Schematic of a bucket dredge

materials being excavated. The effective working depth is limited to about 100 ft.

Bucket dredges may be used to excavate most types of material except for the most cohesive consolidated sediment and solid rock. Bucket dredges usually excavate a heaped bucket of material, but, during hoisting, turbulence washes away part of the load. Once the bucket clears the water surface, additional losses may occur through rapid drainage of entrapped water and slumping of the material heaped above the rim. Loss of material is also influenced by the fit and condition of the bucket, the hoisting speed, and the properties of the sediment. Even under ideal conditions, substantial losses of loose and fine sediment will usually occur. Because of this, special buckets must be used if the bucket dredge is considered for use in dredging contaminated sediment. To minimize the turbidity generated by a clamshell operation, watertight buckets have been developed (Fig. 2.14). The edges seal when the bucket is closed and the top is covered to minimize loss of dredged material. Available sizes of enclosed buckets range from 1 to 25 cu yd. These buckets are best adapted for maintenance dredging of fine-grained material. A direct comparison of 1.3 cu-yd typical clamshell and watertight clamshell operations indicated that watertight buckets generate 30 to 70 percent less turbidity in the water column than typical buckets. This reduction is probably due primarily to the fact that leakage of dredged material from watertight buckets is reduced by approximately 35 percent. The bucket dredge is effective while working near bridges, docks, wharves, pipelines, piers, or breakwater structures because it does not require much area to maneuver; there is little danger of damaging the structures because the dredging process can be controlled accurately.

Special-Purpose Dredges. Special-purpose dredging systems have been developing during the last few years in the United States and overseas to pump dredged material slurry with a high solids content and/or to minimize the resuspension of sediment. Most of these systems are not intended for use on typical maintenance operations; however, they may provide alternative methods for unusual dredging projects such as in contaminated sediments. The special-purpose dredges that appear to have the most potential in limiting resuspension are presented in Table 2.3 and reviewed in the following paragraphs.

Figure 2.14a. Open position of the watertight bucket

Figure 2.14b. Closed position of the watertight bucket

Table 2.3

Suspended Sediment Levels Produced by Various Special-Purpose Dredges

Name of Dredge	Suspended Sediment Level
Mud Cat Dredge	5 ft from auger, 1000 mg/ℓ near bottom (background level 500 mg/ℓ)
	5 to 12 ft in front of auger, 200 mg/ℓ surface and middepth (background level 40 to 65 mg/ℓ)
Pneuma Pump	48 mg/ℓ 3 ft above bottom
	4 mg/ℓ 23 ft above bottom (16 feet in front of pump)
Cleanup System	1.1 to 7.0 mg/ℓ above suction
	1.7 to 3.5 mg/ℓ at surface
Oozer Pump	6 mg/ℓ (background level) 10 ft from head
Refresher System	4 to 23 mg/ℓ at 10 ft from head

Pneuma pump. The Pneuma system was the first dredging system to use compressed air instead of centrifugal motion to pump slurry through a pipeline. It has been used extensively in Europe and Japan. The operation principle is illustrated in Fig. 2.15. During the dredging process, the pump is submerged and sediment and water are forced into one of the empty cylinders through an inlet valve. After the cylinder is filled, compressed air is supplied to the cylinder, forcing the water out through an outlet valve. When the cylinder is almost empty, air is released to the atmosphere, thus producing atmospheric pressure in the cylinder. A pressure difference occurs between the inside and outside of the cylinders, creating a suction that forces the sediment into the cylinder. When the cylinder is filled with sediment, compressed air is again pumped into the cylinder to expel the sediment

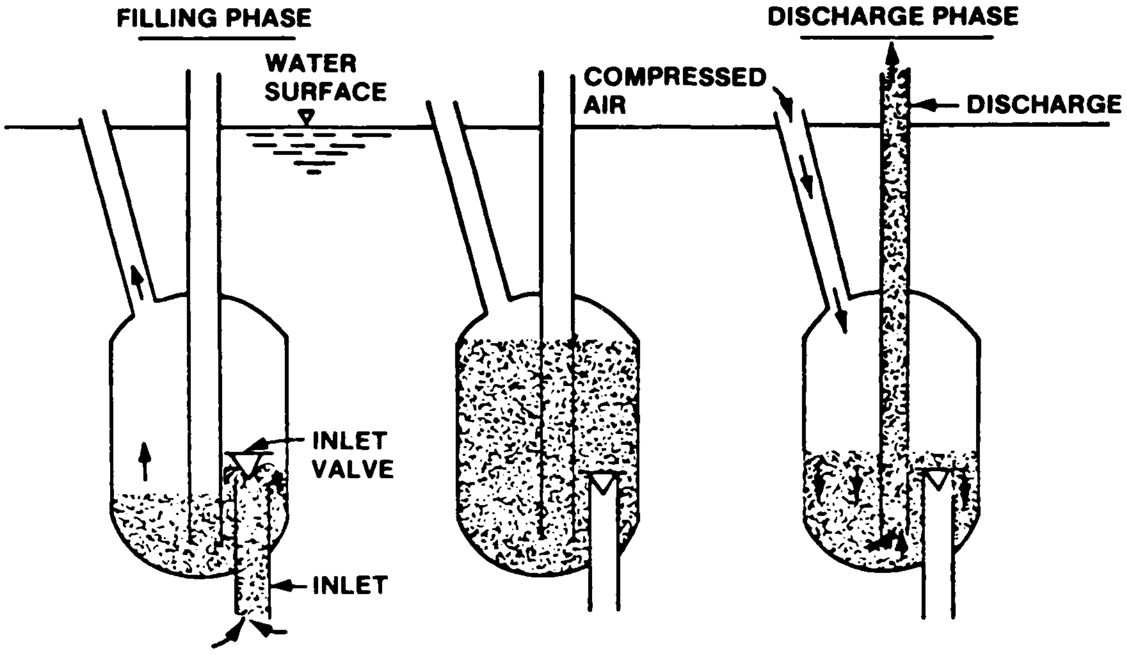


Figure 2.15. Operating cycle of Pneuma Pump

from the cylinder. The capacity of a large plant is 2600 cu yd/hr. The system has been used in water depths of 150 ft; however, 500-ft depths are theoretically possible.

Field tests on a Pneuma model 600/100 were conducted by Waterways Experiment Station (WES) (Richardson et al. 1982). The results of turbidity monitoring, although not definitive, seemed to support the manufacturer's claim that the Pneuma pump generates a low level of turbidity when operated in loosely consolidated fine-grained sediment. It was also found that the Pneuma pump was able to dredge at almost in-situ density in loosely compacted silty clay typical of many estuarine sediment. The Pneuma pump, however, was not able to dredge sand at in-situ density and the efficiency of the dredge was consistently below 20 percent.

The only Pneuma-type dredge available in the United States at this time is operated by Namtex Corporation of Chicago, Illinois. The Pneuma system is crane supported and thus can be operated in confined areas using various structural mounts. It dismantles easily for truck or air transport and can be operated in most water depths. Cables and pipelines used for the system will create temporary obstructions to navigation.

Clean-Up system. To avoid resuspension of sediment, Toa Harbor Works of Japan developed a unique Clean-Up System for dredging highly contaminated sediment (Sato 1976). The Clean-Up head consists of an auger that collects sediment as the dredge swings back and forth, and a shield that guides the sediment towards the suction of a submerged centrifugal pump (Fig. 2.16). To minimize sediment resuspension, the auger is covered and a movable wing covers the sediment as it is being collected by the auger. Sonar devices indicate the elevation of the bottom. An underwater television camera is used to show the material being resuspended during a dredging operation. Suspended sediment concentrations around the Clean-Up System ranged from 1.7 to 3.5 mg/ℓ at the surface to 1.1 to 7.0 mg/ℓ at 10 ft above the suction equipment, relative to the background near-surface levels of less than 4.0 mg/ℓ (Herbich and Brahme in press).

Oozer pump. The Oozer pump was developed by Toyo Construction Company, Japan. The pump operates in a manner similar to the Pneuma pump system; however, there are two cylinders (instead of three) and a vacuum is applied during the cylinder-filling stage to achieve more rapid filling of the cylinders. The pump is usually mounted on a dredge ladder and is equipped with special suction and cutter heads depending on the type of material being dredged. Dredging depth is only limited by ladder depth. The conditions around the dredging system, such as the thickness of the sediment being dredged, the bottom elevation after dredging, and the amount of resuspension, are monitored by high-frequency acoustic sensors and an underwater television camera. A large Oozer pump has a dredging capacity ranging from 400 to 650 cu yd/hr. Producing a slurry of up to 80 percent of in situ density. During one dredging operation, suspended solids levels within 10 ft of the dredging head were all within background concentrations of less than 6 mg/ℓ (Herbich and Brahme in press).

Refresher system. Another system recently developed in Japan is the Refresher system. This system is an effort to modify the cutterhead hydraulic dredge. The Refresher uses a helical shaped gather head to feed the sediments

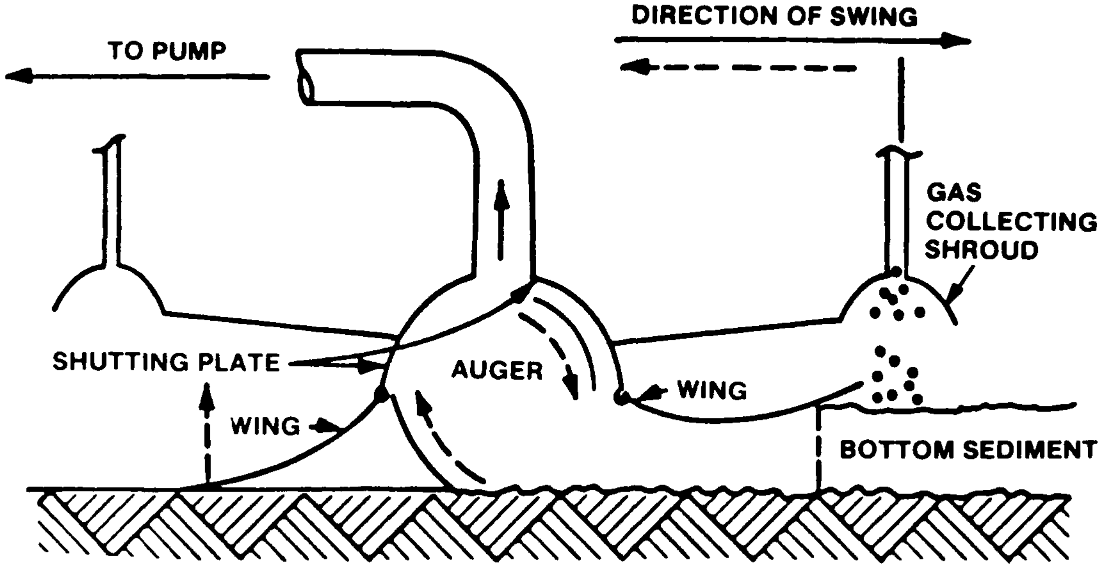
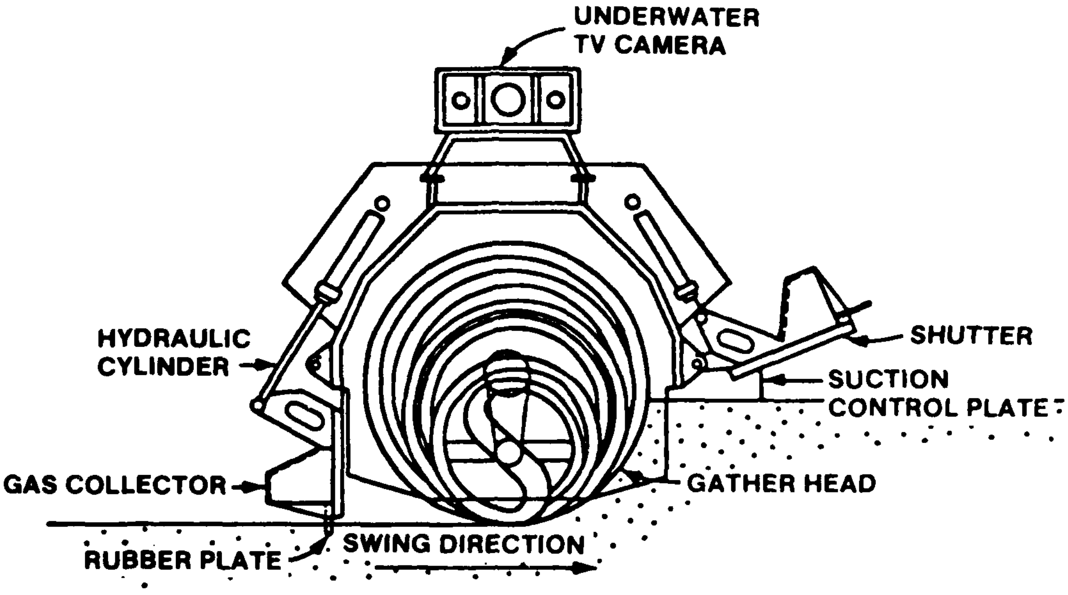


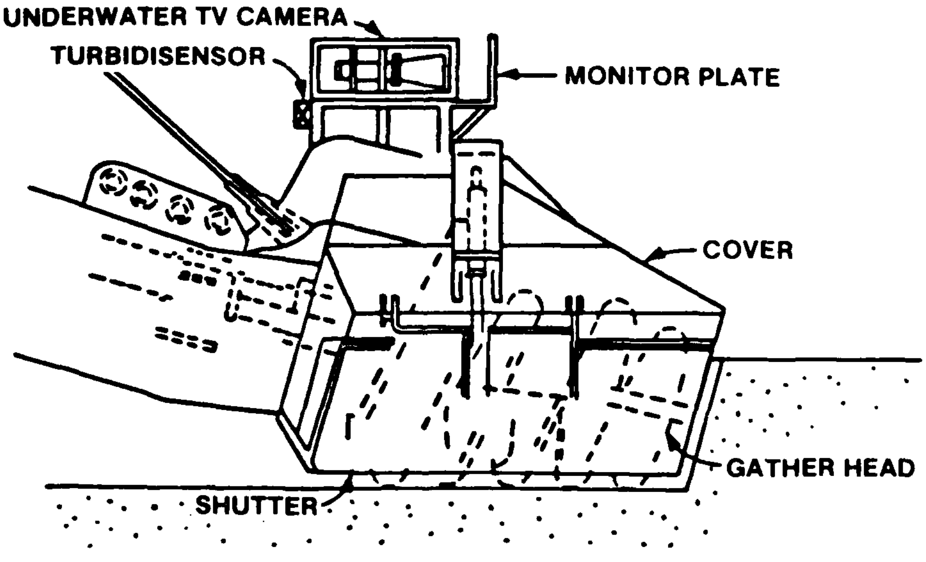
Figure 2.16. Schematic of Japanese Clean-Up dredge system

into the suction, with a cover over the head to reduce resuspension (Fig. 2.17). The Refresher also uses an articulated dredge ladder to keep the head level to the bottom over a wide range of dredging depths. During several tests in similar material, the Refresher system produced suspended sediment levels of from 4 to 23 mg/ℓ within 10 ft of the dredge head as compared to 200 mg/ℓ with a conventional cutterhead dredge. Production for the cutterhead (26-in. discharge) was 800 cu yd/hr while production with the Refresher system (17-in. discharge) was 350 cu yd/hr. The researchers felt that the Refresher system produced one-fiftieth of the total resuspension produced by the operation of a cutterhead dredge (Kaneko et al. 1984).

Mud Cat. The Mud Cat is a relatively small portable hydraulic dredge designed for projects where a 50- to 120-cu yd/hr discharge rate is sufficient. Instead of the conventional cutter, the Mud Cat has a horizontal cutterhead equipped with cutter knives and a spiral auger that cuts the material and moves it laterally toward the center of the auger where it is picked up by the suction (Fig. 2.18). This cutter can remove a layer of material 9 ft wide and 1.5 ft thick from water depths of 2.0 to 15 ft leaving the



A. FRONT VIEW



B. SIDE VIEW

Figure 2.17. Front and side view of Japanese Refresher dredge system (Kaneki, Watari, and Aritoni 1984)

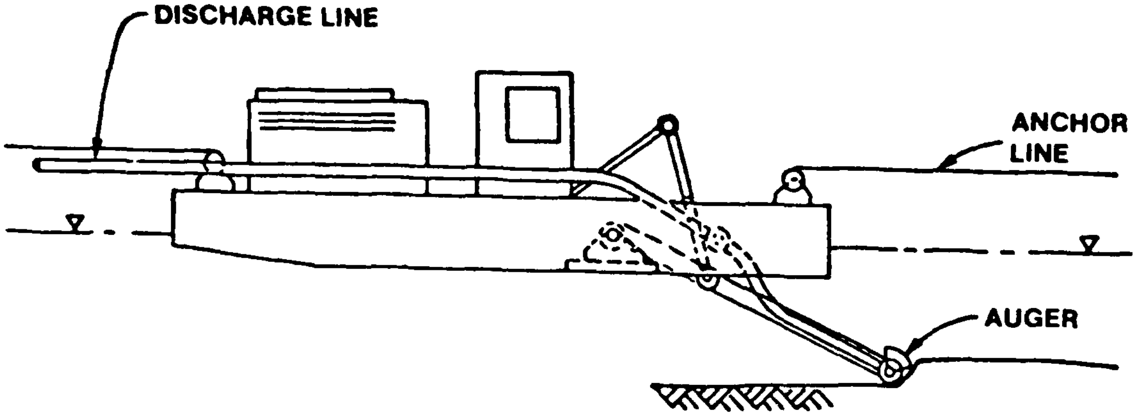


Figure 2.18. Mud Cat dredge

dredged bottom flat and free of the windrows that are characteristic of the typical cutterhead dredging operation.

By covering the cutter/auger combination with a retractable mud shield, the amount of turbidity generated by the Mud Cat's operation can be minimized. During a monitored operation, near-bottom suspended solids concentrations 5.0 ft from the auger were usually slightly greater than 1000 mg/ℓ, relative to near-bottom background concentrations of 500 mg/ℓ. Surface and middepth concentrations measured 5.0 to 12 ft in front of the auger were typically less than 200 mg/ℓ above background values of 40 to 65 mg/ℓ. In general, the turbidity plume was confined to within 20 ft of the dredge (Nawrocki 1974).

Waterless dredge. The waterless dredge is a recently developed dredging system where the cutter and a submerged centrifugal pump are enclosed within a half-cylindrical shroud. By forcing the cutterhead into the material, the cutting blades remove the material near the front of the cutterhead with little entrainment of carrier water. According to the manufacturer, this system apparently is capable of pumping slurry with a solids content of 30 to 50 percent by weight with little generation of turbidity. Dredge (pipeline) sizes range from 6 to 12 in.

Delta dredge. The delta dredge was developed as a small portable dredge that apparently removes material at a high solids concentration using a submerged 12-in. pump coupled with two counter-rotating low-speed reversible cutters (Fig. 2.19). According to the manufacturer, this equipment is capable of making a relatively shallow 7.5-ft wide cut without disturbing the surrounding material. For this reason, turbidity levels in the vicinity of the cutterhead are apparently low (Delta Dredge 1977).

Bucket wheel dredge. The bucket wheel dredge is a unique bucket wheel excavator (Fig. 2.20) developed to improve the efficiency of the cutting operation. Because the cutting force is concentrated on a much shorter cutting edge, the bucket wheel has the capability of efficiently digging highly consolidated material. In addition, the material is force fed to the suction as the wheel turns, making it possible to control the solids content of the dredged material slurry by varying the rotation speed of the wheel. Theoretically, this bucket wheel not only accurately digs to prescribed level, but also maximizes the pickup of the excavated material (Turner 1979). By maximizing the disturbed sediment pickup, the bucket wheel dredge may produce less turbidity than the clamshell or cutter suction dredges.

Ooze Dredge. In recent years, in an effort to clean up the water environment, the Japanese have developed a new dredge called Ooze Dredge, which is capable of removing ooze deposited at the bottom of the rivers, lakes, harbors, bays, etc. (Noguchi et al. 1980). An ooze-dredging apparatus called "Drex" consisting of a suction mouth and a device moving the mouth back and forth was later developed (Fig. 2.21). The Ooze dredge maintains high

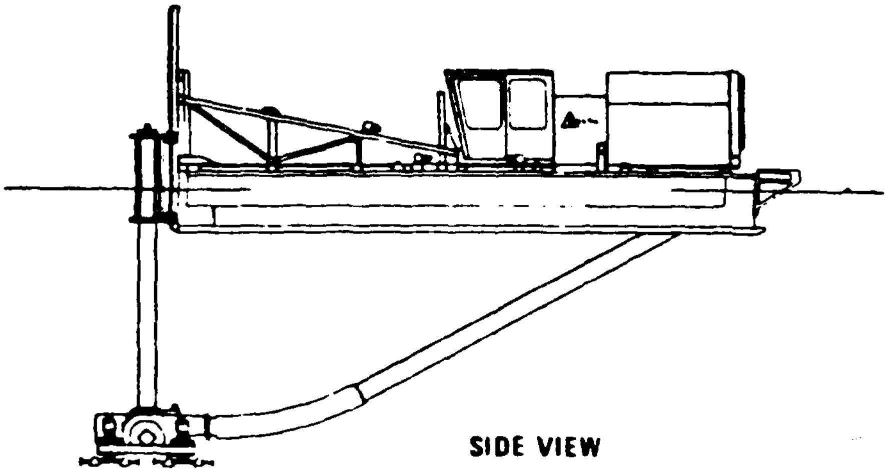


Figure 2.19. Schematic of Delta Dredge

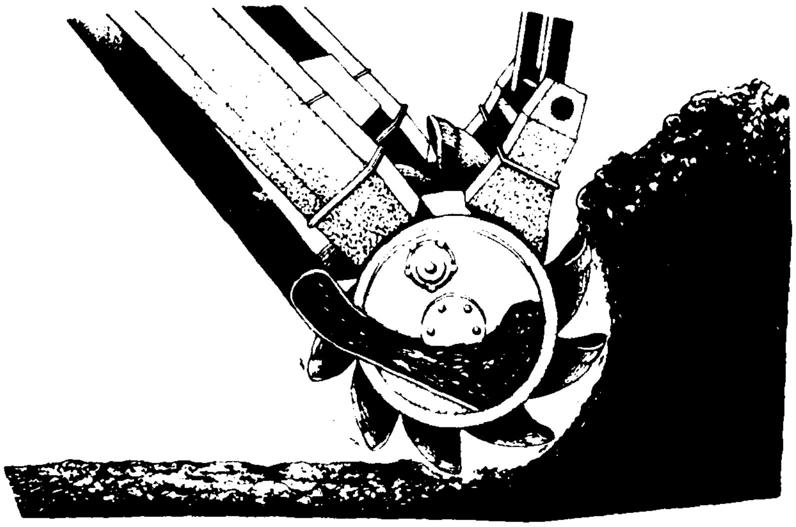


Figure 2.20. Bucket wheel dredge

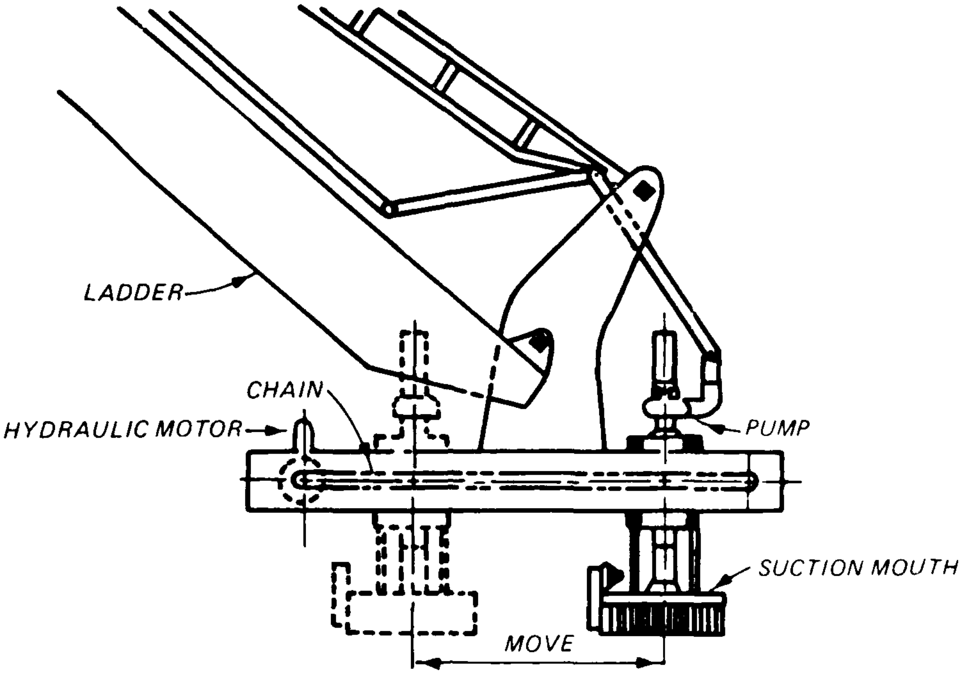


Figure 2.21. Schematic sketch of ooze dredging apparatus

solids concentrations in the exit pipe while generating little turbidity in the dredging vicinity.

Match box suction head dredge. To dredge highly contaminated sediments in the Rotterdam harbor, Volker Stevin Dredging developed the match box suction head dredge (Fig. 2.22) (d'Angemond et al. 1984). The suction head was designed to dredge silt as close to in situ density as possible, keep resuspension to a minimum while dredging layers of various thickness, and operate with restricted maneuverability. To keep resuspension to a minimum all cutter and waterjet devices commonly found on dredgeheads were avoided.

Several innovative design features were incorporated into the match box dredgehead construction. These design features include:

a. A plate that covers the top of the draghead to contain escaping gas bubbles and avoid the influx of water.

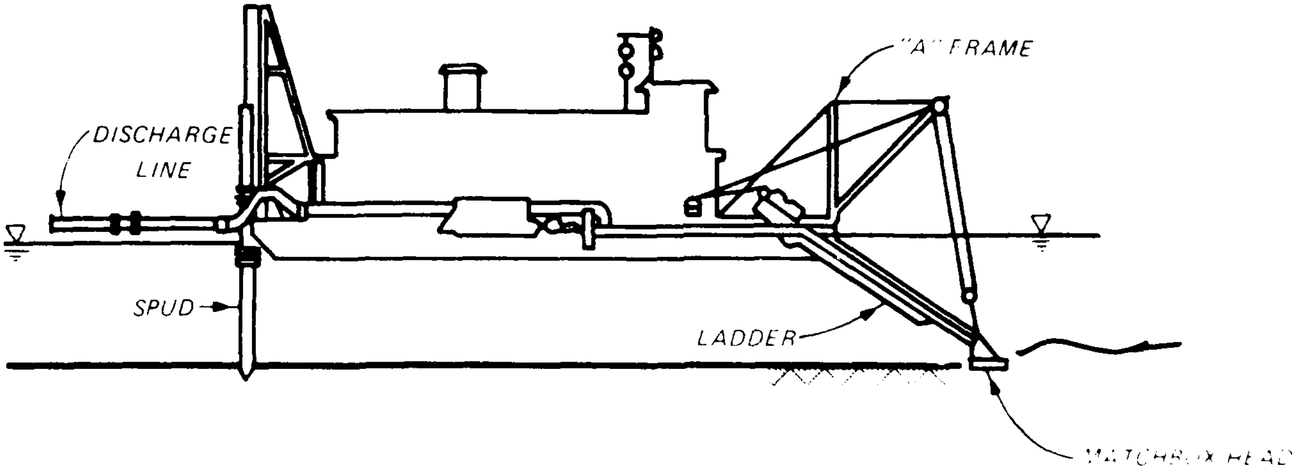


Figure 2.22. Match Box suction head dredge

b. An adjustable angle was constructed between the dredgehead and ladder to maintain the optimum dredging position regardless of dredging depth.

c. Openings on both sides of the dredge were installed so that the leeward opening could be closed by a valve to avoid water influx.

d. Dimensions of the dredging plant were carefully designed to account for the average flow rate and swing speed of the dredge.

Equipment and Operational Controls to Reduce Resuspension

Hopper Dredge Operation

Overflow. Hopper dredge sources of sediment resuspensions mentioned earlier were draghead and pumping past overflow. The overflow of material from the hopper produces by far the most sediment resuspension. This source of near-surface resuspension can be addressed in several ways. The first is to assess the type material being dredged and its environmental impact. If the material being dredged is clean sand, the percentage of solids in the overflow will be small and economic loading may be achieved by pumping past overflow. In the case of fine-grained material, the settling properties of silt and clay sediment may be such that only a minimal load increase would be achieved by pumping past overflow. When contaminated sediment is to be dredged and adverse environmental effects have been identified, pumping past overflow is not recommended.

The hopper dredging of contaminated material may be restricted by pumping or loading the hopper bins with dredge slurry and not allowing overflow. This would result in a load that would be approximately 80 percent water and 20 percent sediment for the silty sand found in Commencement Bay. This compares to an average of 70 percent sediment using an economic load. The rate of solids loss in the overflow (which may determine if overflow is acceptable) will vary with amount of water in the hopper, hopper capacity and drainage characteristics, material characteristics (settleability), pumping rate, and elapsed time overflow.

Flow rate. Reduction of sediment resuspension can be accomplished by reducing the flow rate of the slurry being pumped into the hopper during the latter phases of the hopper-filling operation. This operational procedure reduces the solids concentration in the plume by reducing the sediment concentration in the overflow. By using this technique, the solids content of the overflow can be reduced by as much as 50 percent while the loading efficiency of the dredge is simultaneously increased.

Submerged discharge. Another approach that has been developed is a submerged discharge system for hopper dredge overflow, called an anti-turbidity overflow system (ATOS) (Ofuji and Naoshi 1976). The overflow collection system in the dredge was streamlined to minimize incorporation of air bubbles, and the overflow discharge ports were moved from the sides to the bottom of the dredge's hull (Fig. 2.23). With this arrangement, the discharge descends rapidly to the bottom with a minimum amount of dispersion within the water column. The system can be incorporated in existing dredges through modifications of their overflow systems. It should be pointed out, however, that the ATOS system is intended only to reduce near-surface resuspension, not overall resuspension. The ATOS device has the effect of forcing the solids plume down to a lower level. This in itself can have the effect of inducing more rapid settlement of the resuspended solids.

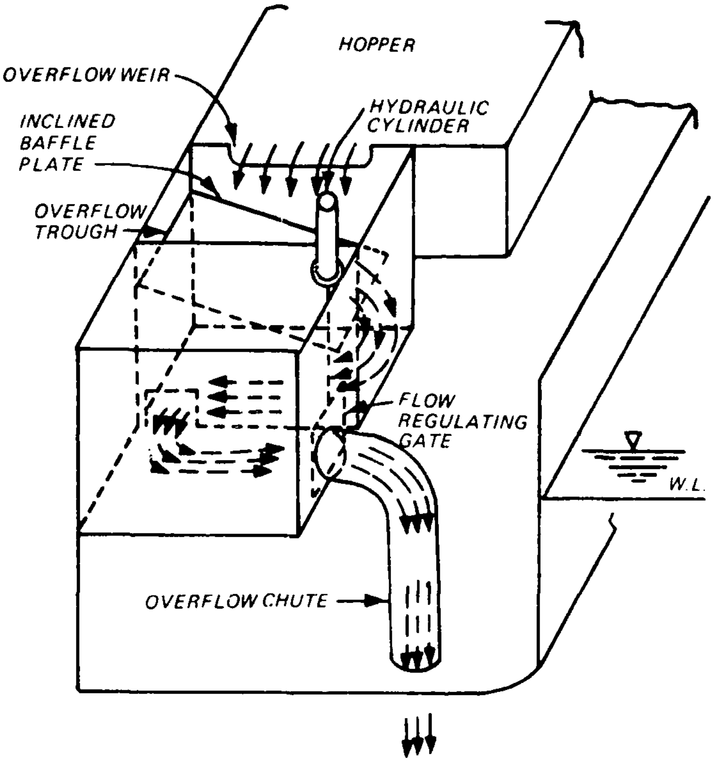


Figure 2.23. Schematic drawing of a hopper dredge bin equipped with the Japanese-designed Anti-Turbidity Overflow System (ATOS)

Cutterhead Operation

General. Resuspension of sediment during cutterhead excavation is dependent on the operating techniques used. Indeed the cutterhead may be the most sensitive of any dredge type to changes in operating techniques. The sediment resuspended by a cutterhead dredge depends on thickness of cut, rate of swing, and cutter rotation rate (Barnard 1978). Proper balance of these operational parameters can decrease sediment resuspension while having little or no effect on production (Hayes et al. 1984).

Operational controls. Based on the impact of the factors described above, the following operational controls to reduce levels of sediment resuspension are recommended. These controls will reduce the amount of material disturbed by the cutterhead but not entrained by the suction (Huston and Huston 1976):

a. Large sets, very thick cuts, and very shallow cuts should be avoided. Thick cuts tend to bury the cutterhead and may cause high levels of resuspension if the suction cannot pick up all of the dislodged material while in shallow cuts the cutter tends to throw the sediments beyond the intake of the dredge (Hayes et al. 1984).

b. The leverman should swing the dredge so that the cutterhead will cover as much of the bottom as possible. This minimizes the formation of windrows or ridges of partially disturbed material between the cuts; these windrows tend to slough into the cuts and the material in the windrows may be susceptible to resuspension by ambient currents and turbulence caused by the cutterhead. Windrow formation can be eliminated by swinging the dredge in close concentric arcs over the dredging area. This may involve either modifying the basic stepping methods used to advance the dredge or using a Wagger or spud carriage system.

c. Side slopes of channels are usually dredged by making a vertical box cut; the material on the upper half of the cut then sloughs to the specified slope. The specified slope should be cut by making a series of smaller boxes.

This method, called "stepping the slope", will not eliminate all sloughing, but will help to reduce it.

d. On some dredging projects, it may be more economical to roughly cut and remove most of the material, leaving a relatively thin layer for final cleanup after the project has been roughed out. However, this remaining material may be subject to resuspension by ambient currents or prop wash from passing ship traffic. Requiring complete removal on each pass will reduce [illegible] resuspension.

e. When layer cutting is used, the dredge will remove a single layer of material over a large portion of the channel; the dredge is then set back to dredge another layer. This continues down to the required depth of the project. [illegible] material is often left on the bottom after each layer is dredged, this technique should only be used where resuspension of the remaining material will not create sediment resuspension problems.

f. Because the cutterhead dredge was developed to loosen densely packed deposits and cut through soft rock, it can excavate a wide range of material. The cutterhead, however, may not be needed to remove soft free-flowing sediments. Rotation of the cutterhead produces a turbidity cloud that may escape from the dredge. Common practice is to use the cutterhead whether it is needed or not, for debris control and because of the effort needed to remove the cutterhead. With the cutterhead removed, the cutterhead dredge becomes, in effect, a plain suction dredge with reduced turbidity during dredging. It could remove softer shoaled material and leave the hard-packed native material below. This would be especially useful when the softer surface materials contain the majority of the contaminants. If the cutterhead is required for effective operation, turbidity caused by conventional cutterhead dredging can be reduced by controlling the cutter rpm's and swing speed. Since optimum rpm and swing speed will vary with each dredge and type of material, experimentation will be required.

Equipment design considerations. Recent modifications to pipeline dredges have improved their production capabilities and reduced dredged sediment resuspension. Greater production rates are achieved by pumping a higher solids concentration, which reduces the quantity of return water that may be contaminated and require treatment. Recent modifications considered here include walking spuds, ladder pumps, flow and density instrumentation, underwater video and sensor equipment, shape of the cutterhead, and rake angle.

A recent improvement in cutterhead pipeline dredges is the addition of the walking spud. This is a hydraulic ram connected on a horizontal platform to the spud gantry which can advance the dredge up to 40 ft without taking a step (Fig. 2.24). Using the walking spud, the dredge does not have to stop pumping sediment to move forward. Lost pumping time or increased pumping of water during dredge stepping is eliminated. Walking spuds are common on European dredges; few dredges have them in the United States, and none are located in the Pacific Northwest.

Figure 2.25 shows an additional pump located on the ladder of the dredge. Called a ladder pump, this pump is underwater during normal dredging operations and supplies the dredge slurry to the main pump under slight pressure. This allows the main pump to use all of its available power to transport dredged material. It increases the percentage of solids pumped and dredge production.

The addition of flow gages and nuclear density gages provides the dredge operator with instant production data. This information can be used to make adjustments to optimize production, such as adjusting cut depth, cutter rotation, ladder swing, etc.

Closed circuit underwater video cameras and water sensors can be mounted on the dredge ladder and used to monitor turbidity in vicinity of the cutterhead. Adjustments can be made in cutter rotation speed (rpm's) and swing speed to minimize resuspension of dredged material. Video cameras are only effective when dredging in relatively clear waters. Sensors are best used in turbid waters.

The shape of the cutterhead also affects the sediment resuspended, particularly if no over-depth is allowed. The cutterheads shown in Figure 2.26 have the same length and base width. They are also depressed to the same

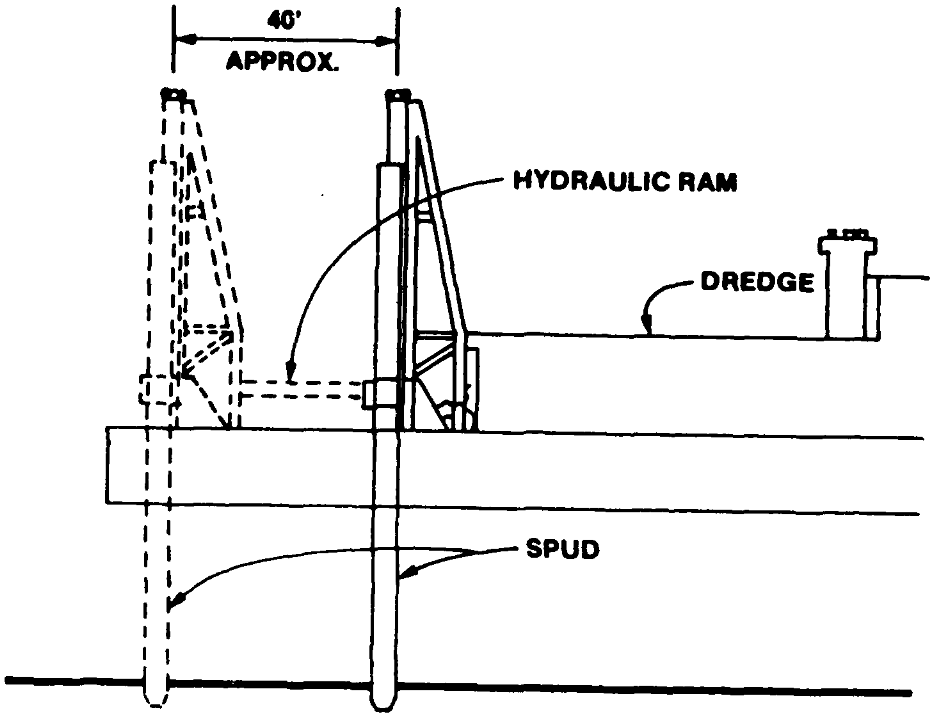


Figure 2.24. Schematic of a walking spud

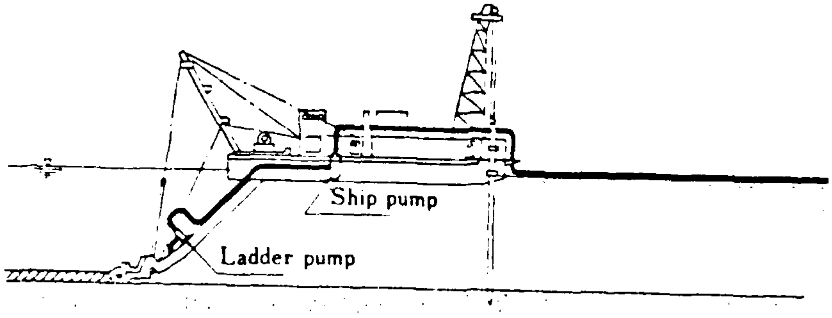


Figure 2.25. Ladder pump arrangement

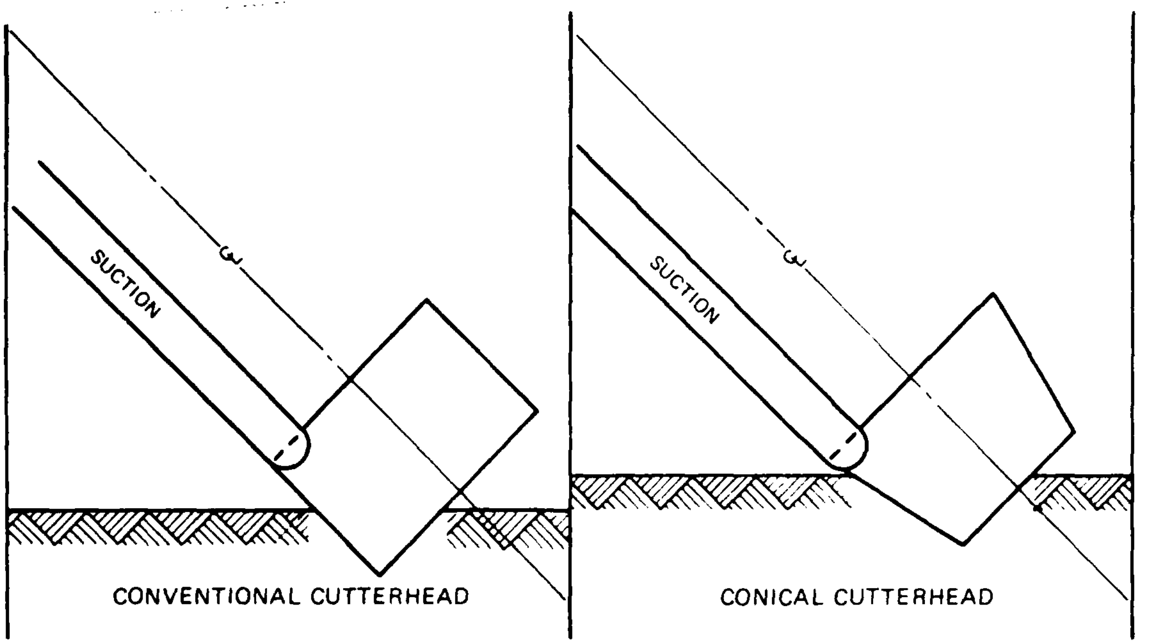


Figure 2.26. Effect of cutterhead shape on suction height above the bottom (Turner)

angle and are buried to the same depth. However, with the conical shaped head (right hand drawing), the suction is brought closer to the material and the chance of entrainment is improved. This shape difference would be particularly important if the head were not completely buried (Turner 1983).

The angle α (Fig. 2.27) is called the rake angle. If the rake angle is too large, it will cause a gouging action that will sling soft, fine-grained material outward. If the rake angle is too small, heeling (the striking of the bottom with the heel of the tooth) will occur and increase resuspension. For fine-grained maintenance-type material, a small rake angle of from 20 to 25 deg would be best. This would allow a shallow entry that would lift the bottom sediment and guide it toward the suction (Turner 1983).

Suction Dredges

With the exception of cutterhead controls, applicable operational controls for a suction dredge are similar to those for a cutterhead dredge.

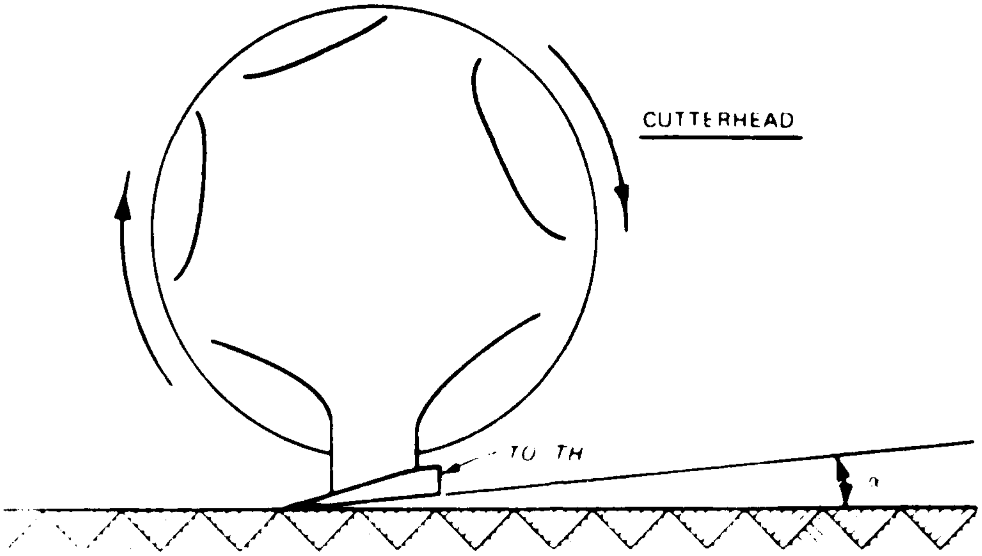


Figure 2.27. Schematic front view of a cutterhead showing the cutter tooth rake angle

Dustpan Dredges

Dustpan dredges are not well suited for dredging contaminated materials. However, when used in this application, the angle of the water jets on the dustpan and the water pressure from these jets should be adjusted to achieve the minimum amount of sediment resuspension.

Clamshell Bucket Dredge Operations

General. Resuspension of sediments during clamshell dredging operations can be reduced by implementing operational controls and/or altering the bucket design. Operational controls can be applied to hoist speed, placement of the dredged material in the hopper barge, loading the hopper past overflow and dragging the bucket along the bottom. Equipment design includes the fit of the bucket and the use of enclosed clamshell buckets. The sediment resuspension associated with a clamshell bucket dredging operation is largely dependent on the type of bucket and condition of the dredging equipment; however, a substantial amount of resuspension reduction can be accomplished through operational controls.

Operational Controls. During clamshell dredging projects, operational controls can be implemented to help reduce sediment resuspension. Controlling the speed of the bucket through the water column is one method of control. The hoist speed of the bucket should be kept below 2.0 ft/sec to keep from washing sediment out the bucket. The hoisting process should also be as smooth as possible so as not to jerk the bucket. When the bucket has been brought about to empty the load into the hopper dredge, care should be taken in the placement of the material. The dredged material should be deliberately placed in the hopper, as opposed to dropping or free-fall from several feet above. It should also be placed in such a manner so that it is evenly distributed throughout the hopper minimizing the risk of spillage. The hopper barge should not be allowed to overflow when dredging contaminated sediment. Often when a clamshell dredge has finished dredging a certain reach, it will drag the bucket along the bottom to create a smoother bottom. This practice should not be used when dredging in contaminated reaches or in similar cases when resuspension must be limited.

Equipment Design. A watertight bucket has been developed in which the top is enclosed so that the dredged material is contained within the bucket (Barnard 1978). Comparisons between standard open clamshell bucket and a watertight clamshell bucket indicates that watertight buckets generate [illegible] to 70 percent less resuspension in the water column than the open buckets. The enclosed bucket did, however, produce increased resuspension near the bottom, which is most likely due to a shock wave of water that precedes the watertight bucket due to the enclosed top. Earlier buckets also had rubber gaskets along the cutting edge of the bucket to seal it. This limited the use of the bucket to soft material and trash-free areas. Current design concepts include the use of interlocking tongue-and-groove edge to overcome the sealing problems. The operational controls mentioned above can also be used for enclosed buckets to help further reduce suspended sediments.

Additional Techniques for Suspended-Sediment Control During Dredging

Several additional techniques and/or considerations have been suggested to assist in controlling resuspension and contaminant release during dredging. Success with these has been varied and their application is very site specific. The following sections discuss the most commonly suggested and the most promising dredging site controls.

Silt Curtains

One method for physically controlling the dispersion of near-surface turbid water in the vicinity of dredging (and some disposal) operations in quiescent environments involves placing a silt curtain or turbidity barrier either downcurrent from or around the operation. Silt curtains are not recommended for operations in the open ocean, in currents exceeding 1 knot, in areas frequently exposed to high winds and large breaking waves, or around hopper dredges or some cutterhead dredges where frequent curtain movement would be necessary.

Silt curtains are impervious floating barriers that extend vertically from the water surface to a specified water depth. The flexible nylon-reinforced polyvinyl chloride (PVC) fabric (or similar material) forming the barrier is maintained in a vertical position by flotation segments at the top and a ballast chain along the bottom. A tension cable is often built into the curtain immediately above or below the flotation segments (top tension) or some distance below the flotation (center tension) to absorb stress imposed by currents and other hydrodynamic forces. The curtains are manufactured in sections that can be joined together at a particular site to provide a curtain of specified length. Anchored lines hold the curtain in a deployed configuration that is usually U-shaped or circular.

In many cases, especially disposal applications, the concentration of fine-grained suspended solids inside the silt curtain enclosure may be relatively high (i.e., in excess of 1 g/ℓ), or the suspended material may be composed of relatively large rapidly settling flocs. In studying a typical pipeline disposal operation surrounded by a silt curtain, results showed that the vast majority (95 to 99 percent) of the fine-grained material descended rapidly to the bottom where it formed a low-gradient fluid mud mound. While the curtain provides an enclosure where some of the remaining fine-grained suspended material may flocculate and/or settle, most of the turbid water and fluid mud flow under the curtain. The silt curtain does not indefinitely contain turbid water, but instead diverts its flow under the curtain, thereby minimizing the turbidity in the upper water column outside the silt curtain.

Silt curtain effectiveness, defined as the degree of turbidity reduction outside the curtain relative to the turbidity levels inside, depends on several factors: the nature of the operation; the quantity and type of material in suspension within or upstream of the curtain; the characteristics, construction, and condition of the silt curtain as well as the area and configuration of the curtain enclosure; the method of mooring; and the hydrodynamic conditions (i.e., currents, tides, waves, etc.) present at the site. Because of the high degree of variability in these factors, the effectiveness of different silt curtain operations is highly variable. Considerable additional detail on silt curtains is provided by JBF Scientific (1978).

Other Barriers

At those sites where the geometry of the harbor/waterway permits and where contaminant levels are unusually high, more extensive structural barriers may be warranted. Dikes, wiers, and sheet pile enclosures have all been suggested and could be effectively used depending on site specific characteristics. Obviously the design must provide for necessary ingress/egress for dredging and support equipment. Provisions must also be made for removal of the barrier. As with silt curtains, contaminated sediments trapped inside the barrier will accumulate against it and must be carefully controlled before the barrier is removed. A predredged sedimentation basin down-current from a removal operation can also be an effective sink or barrier.

Other Operational Controls

In certain situations it may be possible to reduce the spread of resuspended sediments by taking advantage of strong cyclic stratifications in the water column and/or tidal currents. Again, the site specific nature of such considerations must be emphasized. However, with advanced planning specific dredging sites within a harbor or bay could be rotated during tidal cycles to productively use confining current patterns. Sequencing of an entire project might also consider moving progressively from up-current to down-current, from more hydrodynamically active areas to naturally quiescent areas, or using a two-layer/sweep pattern or similar techniques to pick-up sediments disturbed earlier in a project and subsequently redeposited at other areas of the site.

Part III: CONTAMINANT CONTROL DURING DREDGED MATERIAL TRANSPORT

Background

Part II described techniques for maximizing control of contaminated dredged material during the dredging operation. This part addresses management techniques to control contaminated materials while in transit to a disposal site. The primary emphasis during this phase of the overall dredging process is towards spill/leak prevention. Accidental release of contaminated materials into a previously uncontaminated environment has extremely costly consequences in monetary and public relations aspects. Thus each step in the transport system must be carefully evaluated.

Primary transportation methods used to move dredged material includes pipelines, barges, scows, trucks, and rail. Hopper dredge transport with direct pumpout is also commonly used in the Great Lakes region. These means are the expected modes of transport for contaminated dredged material. Each has specific requirements planners must be aware of when determining transport options.

Controls for Pipeline Transport

Controlling contaminated dredged material during pipeline operations requires review of two aspects of the pipeline system, a pump and pipeline. The pump is critical as it is the prime mover for the dredged material and as such, must withstand the stress of handling materials of varying consistencies. The pipeline acts as the conduit for dredged material to flow into a designated containment area. Pipelines must be able to accommodate the dredged material under pressure as well as resist external environmental stresses. Factors having an impact on transport of contaminated dredged material via pipeline will be addressed in the following paragraphs.

Pipeline Transport

Pipelines are commonly used to transport bulk materials over relatively short distances. For navigation dredging, pipelines are up to 3 miles in length whereas commercial land reclamation/fill operations may have pipelines as long as 15 miles. Pipelines may be longer depending on distance from excavation point to the disposal site. Regardless of length, there are common aspects that must be considered when designing, constructing and operating a pipeline to prevent spread of contaminated materials.

During the design stage, planners should carefully consider pipeline routes, climatic conditions expected, material's corrosion resistance, redundancy of safety devices (i.e., additional shutoff valves, loop/by-passes, pressure relief valves), coupling methods and systems to detect leaks. Souder et al. (1978) outlines specific pump and pipeline design procedures.

Pipeline routing, as well as geologic setting of the pipeline, will influence the degree of contaminant control required. Pipelines should not be routed across terrain that would be adversely affected should leakage occur during operation. Routing the pipeline to take advantage of natural slope or channelization away from public use areas (i.e. drinking water wells and reservoirs, streams, rivers, or lakes). Designers reviewing routing plans should also consider access to the pipeline during periods of adverse weather or in the event of a ruptured line. Access to a ruptured pipeline after dredged material has been pumped out over the ground for several hours might be impossible until the material consolidates and dries.

Climatic conditions can have an impact on the smooth operation of a pipeline. Normally pipelines using a water-slurry mixture of dredged material must be buried or covered with earth in areas where freezing may occur. Freeze-thaw action on a pipe connection can lead to rupture, thus consideration as to weather-resistant connections is very important. In more temperate areas, above-ground installation is commonly used. However, heat, humidity (or lack of humidity), and surface winds can damage pipelines. In both temperate and cold regions, salt spray may corrode critical components of pipelines leading to rupture and leaks. Temperature is a strong influence on the corrosion rate. For example, under a low-moisture/high-temperature environment, corrosion rates would rise rapidly.

Planners or engineers should also consider placement of leak-detection instrumentation at critical locations along the pipeline route. Early detection of leaks may prevent major contamination from occurring. Detection devices should be located where frequent inspection, maintenance, and calibration may be accomplished. Devices such as flow or pressure indicators should [illegible] situated between pump stations so the loss of pressure or flow would activate a leak alarm.

Pump Control

Proper design and selection of pumps for dredged material transport are critical for smooth operation of a pipeline system. Correct sizing, installation, and construction of protective shelters will significantly reduce maintenance and likelihood of pump failure. Pumps should be selected on the basis of flows and material content expected during the dredging operation.

Basically there are three pump types used in pipeline transport: positive displacement, centrifugal, and compressed air pumps. Positive displacement pumps are used in long-distance pipelines as fewer pumps are required due to their higher pumping pressure. However, positive displacement pumps are sensitive to variation of material particle size due to minimal valve clearances. Dredged material, due to its origin and nature of waterway use, [illegible] highly variable in terms of particle gradations and presence of foreign objects (i.e., nut, bolts, chain links, cables, etc.). Thus positive [illegible] placement pumps should not normally be used unless a screen is [illegible].

Centrifugal and compressed air pumps are better able to [illegible] material owing to their ability to accept variable size [illegible] Technical Report D-78-28 (Souder et al. 1978) provides [illegible] procedures for determining pump size and estimates [illegible] of contaminant control during pumping operations, [illegible] be given for mitigating corrosion and cavitation [illegible] water content as well as other contaminants will [illegible] quickly corrode internal mechanisms of pumps [illegible] on impellers and interior housing will [illegible] well as cause (or contribute to leakage

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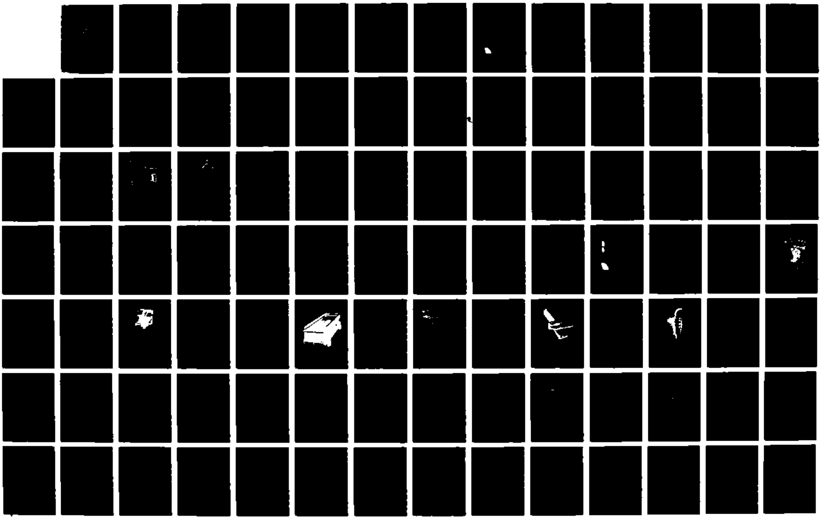

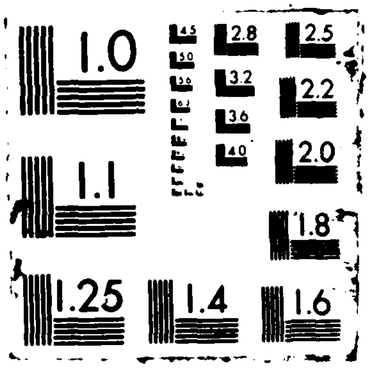
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Controls for Scow/Barge Transport

Barge/scow transport of dredged material has historically been one of the most used methods to move large quantities over long distance. Barge movement of material is reasonably cost effective and lends itself to adapting to most dredging operations. Controls to prevent spread of contaminated materials when utilizing barge transport are primarily concerned with loading/unloading procedures, fugitive emissions, route and navigation hazards, and decontamination of equipment.

Material condition prior to placement into a barge has a great impact on what controls planners must consider. Dredged material that has a high moisture content will require less concern about possible windblown dust but will create much more difficult loading and unloading conditions and will require a greater number of barges. In general, lower material moisture content is better for handling and control. For purposes of discussing control mechanisms in barge transport, the dredged material will be assumed to be in one of two states: freshly dredged material, having a very high water content and being transported a short distance to an unloading site, or consolidated (dewatered) dredged material to be barge transported over long distances.

Route/Navigation Controls

Route selection for barge transport of dredged material (regardless of material conditions) is very important to control/prevent potential spill situations. Routes should avoid, as much as possible, public use areas and areas where there is a high degree of public visibility. The route selected should be carefully surveyed for possible underwater navigation hazards, as well as above-waterline obstructions. A study of river conditions to determine optimum operational conditions and those situations when barge towing would be most susceptible to accidents must be conducted. Also a worst-case study should be performed to determine effects of a significant spill/leak of the dredged material. Results of these reviews should then be incorporated into spill-response plans.

Loading/Unloading Controls

Loading and unloading operations present the greatest potential for uncontrolled release of contaminated materials. Use of clamshell and dragline attachments at the dredging site will release substantially more dredged material into the water column than vacuum/suction systems. However, when planning for pumping dredged material into barges, planners should consider how the material will be transferred from the dredge onto a barge. Overflow during such operations can cause a significant return of contaminants to the water column. It is at these interface points in which particularly stringent control measures must be followed to prevent spread of contaminated material. Flexible connections from dredge to barge will reduce the possibility of pipe damage due to wave action. If the dredged material is tremied into the barge, then movement of the boom between barges or dredge and barges must be carefully controlled to prevent material from falling directly into the waterway.

At barge unloading points, removal of material is commonly done with clamshell cranes and the material loaded into a truck or rail car. This situation presents the greatest possibility of contaminating work areas and adjacent land/water use areas. Points where spillage will undoubtedly occur are during the crane's boom swing from the barge to an awaiting transporter and when the material is placed in the transporter. During the swings, materials will flow out the clamshell. Careful release must be made to avoid part of the material missing the transporter. Control measures that planners should consider include site drainage, spill collection sumps, and decontamination systems.

Controls for Truck Transport

Trucks are used for dredged material when the distance from the dredging site is beyond the range normally used for overland pipelines and less than the distance for rail car transport. Controls associated with transporting dredged material by truck parallels those for barge/scow transport.

Federal, state, and local regulations will govern the maximum size and weight a truck can attain. During loading operations care must be exercised to ensure the truck is not overloaded for the route over which it must traverse. A primary factor affecting weight is the moisture content of the dredged material. A material high in moisture content will significantly add to the shipping weight as well as necessitating additional round trips to move the same amount of solids.

In line with shipping weight, planners may wish to consider pre-transport material conditioning to eliminate excess liquids, increase solids, and enhance handling characteristics. For efficient removal of materials from truck beds, the moisture content of the material should be reduced by dewatering, either by allowing the material to drain freely in stock piles or by using mechanical dewatering equipment.

Selecting a truck route for transporting contaminated dredged material has similar factors as barge/scow transport. Planners should carefully analyze local traffic patterns and volumes so as to avoid congested routes or routes which may offer increased risk of accidents. In addition, routes should avoid public use areas, environmentally sensitive areas and major residential areas. Planners should review:

a. Bridge/tunnel/underpass restrictions.
b. Roadway capacity (size and weight).
c. Drainage patterns into nearby lakes and streams.
d. Existence of sanitary/storm water sewers.
e. Groundwater levels and direction of flow.
f. Grades and curves of proposed route.

Transporting contaminated materials over long distances will require controlling potential emissions from the truck such as dust or water leaking from the bed. Covering the dredged material will substantially reduce windblown dust. This is particularly necessary when using roadways with heavy traffic, where reducing public exposure to contaminated dust is desired. To prevent water leaking from the truck bed, use of heavy polyethylene liners are recommended. Lining the truck bed will also aid in decontamination after the truck has dumped its load.

Without proper controls, the loading and unloading operations present the greatest potential risk of contaminating nearby clean areas. Trucks may be loaded by belt conveyor, cranes, or buckloaders. Regardless of loading method, there will be some spillage of contaminated materials. Controls suggested for consideration are:

a. Drainage of water from loading and unloading area into central sump for periodic removal.

b. Daily removal of spilled material.

c. Specially designed loading ramps to collect spilled material.

d. Use of watertight clamshells for transferring materials from barges into truck.

Decontamination of truck under carriages may be necessary to control contaminated materials from falling onto public roadways when leaving loading/unloading areas. High-pressure water sprays to remove contaminated material will suffice in most cases. Planners will have to consider water residue collection. If the dredging operation is to be of long duration, a semi-permanent wash stand may be constructed to more efficiently remove material and control runoff. Whenever trucks are to be utilized for other purposes, beds should be decontaminated prior to reuse.

Controls for Rail Transport

Rail transport is normally used only when the distance to disposal sites is very large (> 50 to 100 miles). Often rail cars are used to move consolidated dredged material from local disposal sites to locations where the material may be reused. Many of the control measures applicable for rail transport have been discussed in the preceding paragraphs. Control of dust by using covers is important as the material may remain in the rail car for lengthy time periods in rail yards, dry out, and begin to present a dust problem. Also, covers will prevent the material from becoming resaturated with water from rainfall making removal difficult. Decontamination of rail cars after shipment is complete is particularly important since the rail car may be used in different operations. Also the decontamination operation will have to be carefully planned to prevent runoff from entering clean areas. Moisture content of material must be very low to aid in removal. A material with high moisture content will stick to the car sides and bottom or in cold weather become a frozen block.

PART IV: CONTAMINANT CONTROL/TREATMENT ALTERNATIVES FOR UPLAND DISPOSAL SITES

Background

Prior to discussing available control/treatment alternatives for upland disposal sites, it is necessary to understand the various media to which control or treatment alternatives may be applied and the environmental protection goals associated with a specific disposal site. The media to be controlled or treated can be directly defined whereas the environmental protection goals are usually defined in terms of the contaminant migration pathways that may be available at a specific site.

Contaminated Media

Six categories of contaminated media may be associated with the disposal of contaminated sediment. These include:

a. Dredged material slurry.
b. Dredged material solids.
c. Site effluent.
d. Site runoff.
e. Site leachate (including flow through dikes).
f. Residual solids.

Migration Pathways

Upland disposal involves the placement of dredged material in environments not inundated by tidal waters (Fig. 4.1). Upland disposal sites are normally diked confined areas that retain the dredged solids while allowing the carrier water to be released and, as such, are most often associated with hydraulic dredges (pipeline or hopper with pump-out capability). Upland sites can also accept dredged material that has been dewatered elsewhere and transported in by truck or rail (if hydraulically dredged) or has simply been loaded directly into trucks or railcars by mechanical dredges. Upland disposal sites may be located immediately adjacent to, or removed great distances from, the dredging site.

As nearly all upland disposal sites are diked areas, the major components of a diked containment area are shown schematically in Fig. 4.2. The two objectives inherent in design and operation of containment areas are to

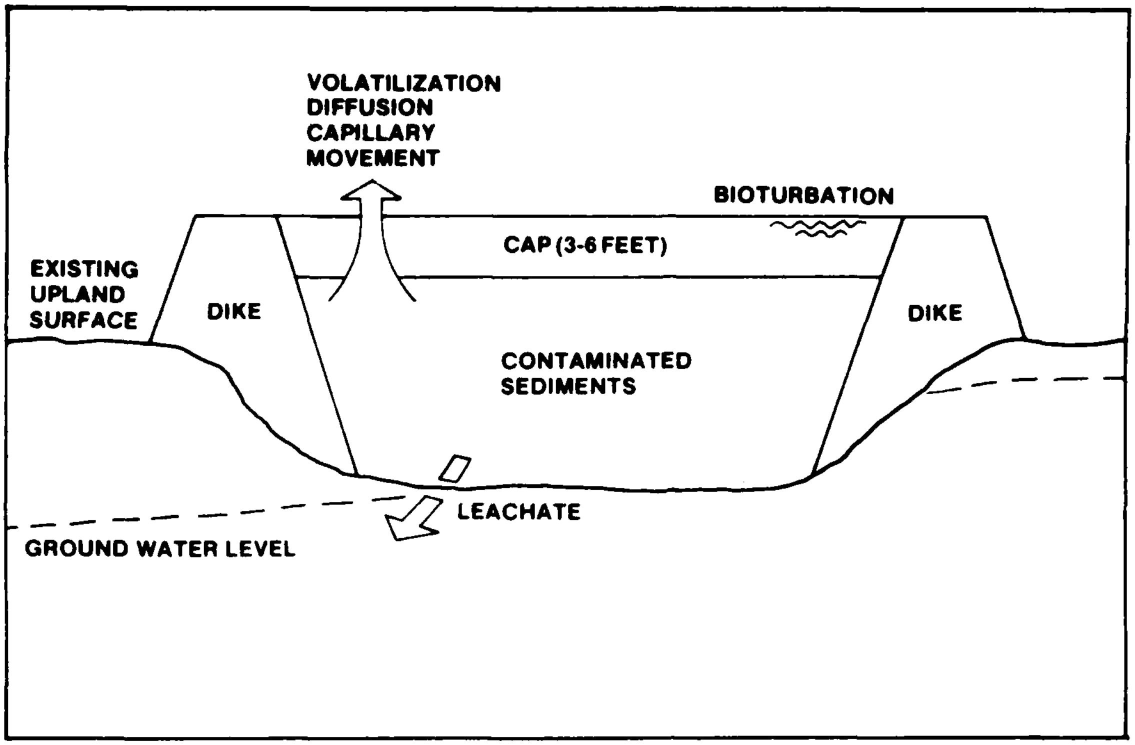


Figure 4.1. Migration pathways from a diked upland disposal site

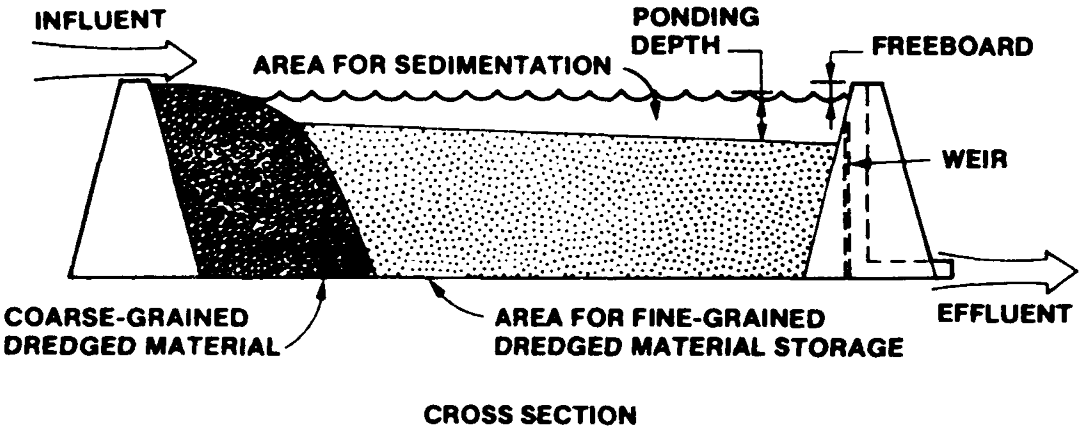


Figure 4.2. Components of a typical diked upland disposal site

provide adequate storage capacity to meet the dredging requirements and to attain the highest possible efficiency in retaining solids during the dredging operation. Basic guidelines for design, operations, and management of containment areas are presented by Palermo et al. (1978) and Montgomery et al. (1983).

When dredged material is placed in an upland environment, drastic physicochemical changes occur. As soon as the dredged material is placed in a confinement and allowed to be exposed to the atmosphere, oxidation processes begin. The influent slurry water initially is dark in color and reduced with little oxygen as it is discharged into the confinement area from a hydraulic dredge. Mechanically dredged sediment such as with a clamshell will have sediment pore water that will initially be dark in color and reduced. As the slurry water passes across the confined disposal site and approaches the discharge weir, the water becomes oxygenated and will usually become light grey or light yellowish brown. The color change indicates further oxidation of iron complexes in the suspended particulates as they move across the confinement. Once disposal operations are completed, dredged material consolidation will continue to force pore water up and out of the dredged material, and it will drain toward the discharge weir. This drainage water will continue to become oxidized and lighter in color. Once the surfaced pore water has been removed from the confinement, the surface of the dredged material will become oxidized and lighter in color, such as changing from black to light gray. The dredged material will begin to crack as it dries out. Accumulation of salts will develop on the surface of the dredged material and especially on the edge of the cracks. Rainfall events will tend to dissolve and remove these salt accumulations in surface runoff. Recent research on contaminant mobility from dredged material placed in an upland disposal site indicates that certain metal contaminants can become dissolved in surface runoff as dredged material dries out. During the drying process, organic complexes become oxidized and decomposed. Sulfide compounds also become oxidized to sulfate salts. These chemical transformations could release complexed contaminants to surface runoff, soil pore water, and leachate through the material. In addition, plants and animals that colonize the upland site could take up and bioaccumulate these released contaminants. Contaminant mobility will be significantly controlled by the physicochemical changes that occur during drying and oxidation of the dredged material.

Upland disposal of contaminated dredged material must be planned to contain the dredged material within the site and restrict contaminant mobility out of the site in order to control or minimize potential environmental impacts. Lee et al. (1985) identified and described five possible mechanisms for transport of contaminants from upland disposal sites.

a. Release of contaminants in the effluent during dredging operations.

b. Surface runoff of contaminants in either dissolved or suspended particulate form following disposal.

c. Leaching into ground water and surface waters.

d. Plant uptake directly from sediments, followed by indirect animal uptake from feeding on vegetation.

e. Animal uptake directly from the sediments.

Treatment/Control

The general strategy for eliminating potential environmental problems associated with the disposal of contaminated dredged material is to apply treatment or control technologies to selected contaminated media for the purpose of eliminating or minimizing contaminant release through the affected migration pathway. Once the technology has been applied, its efficiency in contaminant removal or control must be evaluated. This section of the report presents the various treatment/control technologies available for each media. Part IX of the report presents a framework for selecting appropriate technologies.

Site Selection

Site location is an important, if not the most important, consideration in minimizing the cost of required restrictions. Selection of a technically sound site can reduce or eliminate the need for applying contaminant control/treatment technologies. Significant site variables are ones that affect the pathways of migration of contaminants, and/or design and implementation of control/treatment alternatives. Site characteristics that are particularly important in the evaluation of the need for contaminant control/treatment alternatives are discussed below.

a. Location. While the significant characteristics of a given site are usually unique, useful hypotheses about pathways of migration and estimates of parameters needed to calculate migration rate can often be developed from available regional data and keyed to location, topography, surface drainage patterns, flood potential, subsurface stratigraphy, groundwater flow patterns, and climate.

b. Topography. Topographic variables are important in evaluating surface drainage, runon and runoff potential to and from contaminated areas of the site, and logistics of moving and/or placing equipment for in-place treatment.

c. Stratigraphy. The nature of subsurface soils, determined by examination of soil core borings to bedrock, is an important input to the evaluation of pathways of migration in both the unsaturated and saturated zones.

d. Groundwater levels (equipotential surfaces). Seasonal maps of water table contours and piezometric surfaces, developed by analysis of groundwater monitoring well data, are important in predicting groundwater flow directions and hydraulic gradients.

e. Groundwater flow. Information on permeability and porosity of subsurface strata, combined with data on hydraulic gradients, is important in predicting groundwater flow velocities and in estimating contaminant transport times.

f. Meteorology and climate. Wind velocity and direction is important in determining the potential for migration of airborne particulate matter and volatile waste constituents. Temperature, including seasonal or monthly means and duration of the frost-free period, is important in estimating rates of biological and chemical reactions in place and in evaluating the technical feasibility of in-place treatment methods. If possible, data on soil temperatures as well as ambient temperatures should be obtained, since they often differ. Precipitation, including annual, seasonal, or monthly rain and snowfall, is an important parameter in determining a water balance for the site and in evaluating leachate potential. Evapotranspiration is also important in developing a water balance for the site. It is often estimated from temperature and the nature of vegetative growth at the site.

g. Soil properties. pH is an important variable in evaluating mobility of many metal contaminants, as well as organic acids and bases and in designing several of the alternatives discussed in this report. Cation exchange capacity (CEC) is an important determinant of the mobility of metallic species in soils; if the CEC is sufficiently high to adequately immobilize the heavy metals present in the soil, no further action may be necessary. Redox potential (Eh) is important in determining the stability of various metallic and organic species in the subsurface environment of the site. Organic carbon content is a major variable affecting adsorption, and hence mobility, of organic species in the subsurface environment. Microbial content as a function of depth is an important variable, if potentially biodegradable constituents are present in the waste. Soil type (e.g., clay, till, sand, fractured bedrock) is a major variable affecting rates and routes of groundwater migration and contaminant transport. Hydraulic conductivity is important in determining feasibility and spacing of drains and wells.

h. Trafficability. Factors that affect the mobility and/or placement of equipment on the site and the ability to perform tillage and other in-place treatment operations need to be considered in a remedial action design. Significant variables include bearing capacity, traction capacity, soil strength, slipperiness, stickiness, moisture content, clay content, presence of debris, structures and/or vegetation, and slope of the terrain (topography), as mentioned earlier.

i. Potentially exposed human populations and sensitive ecological environments. Groundwater and surface water usage, especially downgradient of the site, are important in evaluating risks and environmental benefits of remedial alternatives. Size of population and nature of ecological resources downgradient and downwind of the site are also important variables for risk assessment.

Examples where site location can be used to reduce or eliminate the need for applying treatment/control problems include:

a. Selection of sites where surface runon and resulting runoff and contaminant release are minimized.

b. Selection of sites that have underlying natural clay formations can minimize potential ground-water contamination concerns.

c. Selection of sites to avoid aquifer recharge areas can minimize potential ground-water contamination concerns.

d. Selection of sites where surface water discharges are to large water bodies may reduce the need for treating liquid wastes.

Normally, the selection of appropriate upland disposal sites are related to the method of dredging employed and the volume of material dredged. Typical criteria include site size (which affects its capacity), distances from the site of dredging, site elevation, and amount and cost of site preparation.

When contaminated materials are dredged, the site selection process is more involved and includes a detailed evaluation of the potential for contaminant migration through any one of the migration pathways. Site characteristics that may affect the need for, or type of, treatment/control are listed in Table 4.1.

Site Controls

Covers

Description. Covers are control measures designed to seal or isolate the surface of contaminated dredged material from physical, chemical, or biological processes that could release contaminants from a confined upland or nearshore disposal site. Surface covers can be as simple as a 1- to 3-ft-thick layer of clean dredged material or as complex as a multilayer cap that includes impermeable membranes, filters, gas channels, biobarriers, and top soil. Functions of a cover could include one or more of the following:

- Prevent or minimize surface water infiltration.
- Promote aesthetics.
- Reduce water erosion and dissolution of contaminants in surface water runoff.
- Reduce wind erosion and fugitive dust emissions.
- Contain and control gases and odors.
- Provide a surface for vegetation and/or site reclamation.
- Prevent direct bioturbation (human and animal).

Since these functions address all of the migration pathways (i.e., surface water, groundwater, air, and direct contact), some type of surface cover will likely be a component of any upland or nearshore disposal system. Functional requirements that must be met will depend on the chemical nature (toxicity) of the sediment and the site characteristics.

Design. Reducing surface-water infiltration through contaminated dredged material and preventing contact between precipitation and contaminated dredged material are cover functions that are generally foremost in determining the type of cover to use. Therefore, most covers include a layer of impermeable material. Impermeable materials employed alone often cannot withstand environmental conditions at a site. A multilayer cover system may be used to provide a reliable barrier to infiltration and to address various combinations

Table 4.1

Site Characteristics Affecting the Need for Control/Treatment Technologies

Site volume
Site area
Site configuration
Dredging method
Climate (precipitation, temperature, wind, evaporation)
Soil texture and permeability
Soil moisture
Topography
Drainage
Vegetation
Depth to bedrock
Depth to aquicludes
Direction and rate of groundwater flow
Existing land use
Depth of groundwater
Ecological areas
Drinking water wells
Receiving streams (lakes, rivers, etc.)
Level of existing contamination
Nearest receptors

of the functions listed. McAneny and Hatheway (1985) presented an eight-layer cover that would address all functions. The layers and their functions are listed below in order of top to bottom:

a. Surface layer - top soil for vegetative support.

b. Filter(s) - separate fine from coarse materials and prevent clogging of coarse interstices by fine particles.

c. Biotic barrier - hinders plant roots and burrowing animals from disrupting the layers below, particularly the hydraulic barrier.

d. Drainage - intercepts downward percolating water and conveys it laterally out of the system.

e. Hydraulic barrier - prevents percolation into the contaminated material.

f. Foundation (buffer) - isolates the hydraulic barrier from the wastes and serves as a strong base to support the rest of the system.

g. Filter(s) - same as b.

h. Gas control - intercepts gases evolved from the contaminated material and leads them to the atmosphere via vents. , It is unlikely that a cover for contaminated dredged material would include all of these layers. Lutton, Regan, and Jones (1979) presented the two examples of cover shown in Fig. 4.3. Phillips et al. (1985) discussed potential application of this type of cover to Commencement Bay sediment. The gravel layer in Fig. 4.3 (top) serves as a biobarrier and as a gas channel. The gravel breaks capillary pumping of moisture from the dredged material, reduces upward migration of contaminants through the cap, prevents root penetration into the dredged material, and discourages animals from burrowing into the dredged material. USEPA (1985) presented the RCRA-recommended 3-layer cover consisting of an upper vegetative layer underlain by a drainage layer over a low-permeability layer formed by a combination of synthetic membrane and soil liner with a permeability of less than 10^{-7} cm/sec. Of the different types of layers that could be used, the two that would most always be provided as a final cover for contaminated dredged material are a surface layer and a hydraulic barrier.

The different layers of a cover can be composed of a number of different types of material. Most commonly used in cover systems are soils, but not all soils are suitable for the different cover layers. Soil properties that are important to cover selection and design are gradation, Atterberg limits, density, and permeability. Standard laboratory procedures are available for determining all of these properties, and field correlations to the laboratory data are available for these properties, except that permeability variations with respect to field applications are not well established particularly in the low range considered for covers. More extensive laboratory or bench-scale tests may be required to predict field permeabilities and, hence, the quantity of water passing through a cover or a mass of dredged material.

The Hydrologic Evaluation of Landfill Performance (HELP) model uses climatological, soil, and design data to estimate water movement access, into, through, and out of landfills (Schroeder et al. 1984). For planning purposes, HELP could be useful in determining the water balance for various cover alternatives. Table 4.2 illustrates the capabilities for various Unified Soil Classification System (USCS) soil groups to meet cover requirements. No single soil group will meet all requirements, thus dictating a need for a multilayer cover. Blending of different soils is a technique used to meet specific design requirements for a particular layer. The most desirable soil

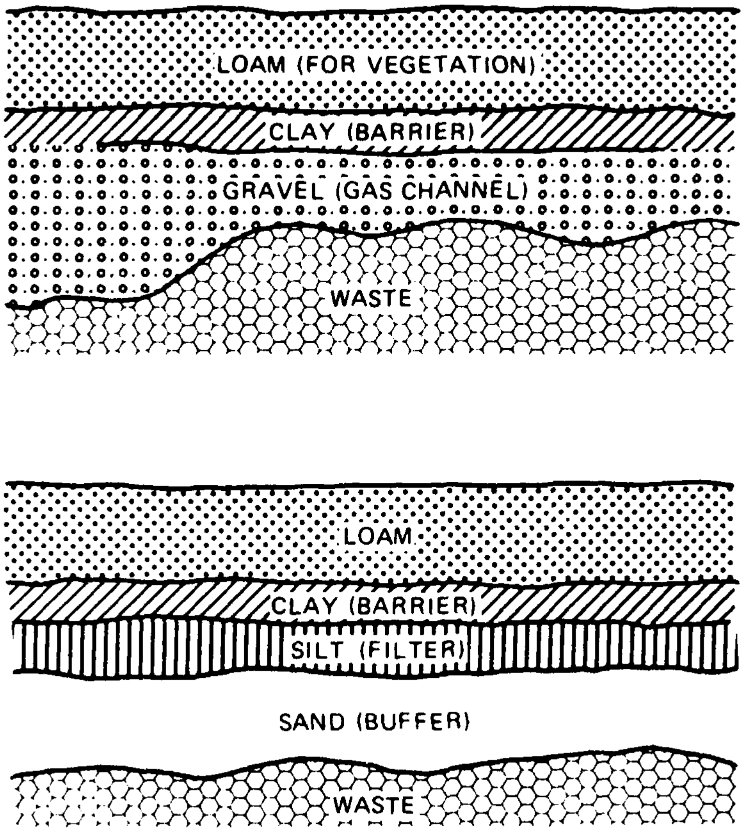


Figure 4.3. Typical cover system design (Lutton et al. 1979)

types may not be available locally. Tradeoffs must be made based on environmental impacts, reliability, costs, availability of soils, and other factors.

A number of soil additives or treatments are available to improve on the capabilities of soil to meet the function required of a cover. These additives include chemical stabilizers, asphalt, cement, lime, fly ash, chemical dispersants, swell reducers, and bentonite. These materials are mixed with a layer of soil and usually with water to create a stronger and less permeable cover layer. Ehrenfeld and Bass (1983) presented a long list of soil additives that can be considered. Applicability of these materials and design of a system using these materials depend on the type of soil available and the desired effectiveness.

Flexible synthetic membranes are available to serve as hydraulic barriers in combination with layers of soil. Membranes made from polyvinyl chloride (PVC), chlorinated polyethylene (CPE), ethylene propylene rubber, butyl rubber, Hypalon, neoprene, and elasticized plyolefin are available. These membranes are delivered (in rolls of various width) to the field where

Table 4.2

Ranking of USCS Soil Types According to Performance of Cover Functions*

USCS Symbol	Typical Soils	Trafficability			Water Percolation		Gas Migration	
		Go-No Go (RCI Value)	Stickiness (Clay, %)	Slipperiness (Sand-Gravel, %)	Impede (k, cm/s)**	Assist (k, cm/s)**	Impede (H_c, cm)**	Assist (H_c, cm)**
GW	Well-graded gravels, gravel-sand mixtures, little or no fines	I (>200)	I (0-5)	I (95-100)	X (10^{-2})	III	X (6)	I
GP	Poorly graded gravels, gravel-sand mixtures, little or not fines	I (>200)	I (0-5)	I (95-100)	XII (10^{-1})	I	IX ---	II
GM	Silty gravels, gravel-sand-silt mixtures	III (177)	III (0-20)	III (60-95)	VII (5×10^{-4})	VI	VII (68)	IV
GC	Clayey gravels, gravel-sand-clay mixtures	V (150)	VI (10-50)	V (50-90)	V (10^{-4})	VIII	IV ---	VII
SW	Well-graded sands, gravelly sands sands, little or no fines	I (>200)	II (0-10)	II (95-100)	IX (10^{-3})	IV	VIII (60)	III
SP	Poorly graded sands, gravelly sands, little or no fines	I (>200)	II (0-10)	II (95-100)	XI (5×10^{-2})	II	VII ---	IV
SM	Silty sands, sand-silty mixtures	II (179)	IV (0-20)	IV (60-95)	VIII (10^{-3})	V	VI (112)	V
SC	Clayey sands, sand-clay mixtures	IV (157)	VII (10-50)	VI (50-90)	VI (2×10^{-4})	VII	V ---	VI
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	IX (104)	V (0-20)	VII (0-60)	IV (10^{-5})	IX	III (180)	VIII
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clay	VII (111)	VIII (10-50)	VIII (0-55)	II (3×10^{-8})	XI	II (180)	IX
OL	Organic silts and organic silty clays of low plasticity	X (64)	V (0-20)	VII (0-60)	---	---	---	---
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	VIII (107)	IX (50-100)	IX (0-50)	III (10^{-7})	X	---	---
CH	Inorganic clays of high plasticity, fat clays	VI (145)	X (50-100)	X (0-50)	I (10^{-9})	XII	I (200-400+)	X
OH	Organic clays of medium to high plasticity, organic silts	XI (62)	---	---	---	---	---	---
Pt	Peat and other highly organic soils	XII (46)	--	---	---	---	---	---

Same k values as for Impede Water Percolation

Same H_c values as for Impede Gas Migration

(Continued)

(Sheet 1 of 3)

Table 4.2 (Continued)

USCS	Fire	Erosion Control		Dust	Reduce Freeze Action		Crack
		Water	Wind		Fast Freeze	Saturation	Resistance
Symbol	Resistance	(K-Factor)*	Sand-Gravel, %	Control	(H_c, cm)*	(Heave, mm/day)	(Expansion, %)
GW	Same as Impede Gas Migration	I (<.05)	I (95-100)	Same ranking and values as for Wind Erosion Control	X	I (0.1-3)	I (0)
GP		I ---	I (95-100)		IX	I (0.1-3)	I (0)
GM		IV ---	III (60-95)		VII	IV (0.4-4)	III ---
GC		III ---	V (50-90)		IV	VII (1-8)	V ---
SW		II (.05)	II (95-100)		VIII	II (0.2-2)	I (0)
SP		II ---	II (95-100)		VII	II (0.2-2)	I (0)
SM		VI (.12-.27)	IV (60-95)		VI	V (0.2-7)	II ---
SC		VII (.14-.27)	VI (50-90)		V	VI (1-7)	IV ---
ML		XIII (.60)	VII (0-60)		III	X (2-27)	VI ---
CL		XII (.28-.48)	VIII (0-55)		II	VIII (1-6)	VIII (1-10)
OL		XI (.21-.29)	VII (0-60)		---	VIII ---	VII ---
MH		X (.25)	IX (0-50)		---	IX ---	IX ---
CH		IX (.13-.29)	X (0-50)		I	III (0.8)	X (>10)
OH		VIII ---	---		---	---	IX ---
PT		V (1.13)	---		---	---	---

(Continued)

(Sheet 2 of 3)

Table 4.2 (Concluded)

USCS Symbol	Side Slope			Discourage Burrowing	Impede Vector Emergence	Discourage Birds	Support Vegetation	Future Use	
	Stability	Seepage	Drainage					Natural	Foundation
GW	Determine on basis of laboratory testing	Same ranking and values as for Impede Water Percolation	Same ranking and values as for Assist Water Percolation	Same ranking and values as for Slipperiness Trafficability	X	All soils are suitable	X	Same ranking as for Support Vegetation	Same ranking and values as for Go-No Go Trafficability
GP					X		X		
GM					VIII		VI		
GC					V		V		
SW					IX		IX		
SP					IX		IX		
SM					VII		II		
SC					IV		I		
ML					VI		III		
CL					III		VII		
OL					VI		IV		
MH					II		IV		
CH					I		VIII		
OH					---		VIII		
Pt					---		III		

* Source: USEPA (1979).

** RCI is rating cone index, K is coefficient of permeability, H_c is capillary head, and K-Factor is the soil erodibility factor. The ratings I to XIII are the best through poorest in performing the specified cover function.

(Sheet 3 of 3)

adjoining sheets are spliced together. The integrity of the seam is often a question mark for reliability of the seal. However, higher quality seams commonly are achieved by modern seaming methods and quality-control practices (McAneny and Hatheway 1985). Care is necessary during liner installation and subsequent soil covering to avoid penetrating the membrane with construction equipment. Manufacturers generally guarantee a liner to remain impermeable for 20 years or longer. However, marine environments are often not addressed by manufacturer's claims. There is some concern about compatibility of liners with waste materials, particularly where organic or corrosive vapors are possible. Laboratory tests (liner challenges) are available for assessing this possibility. However, for the concentrations experienced in contaminated dredged material, liner compatibility is not expected to be a problem.

Synthetic membranes depend on the soil layers placed above and below them for reliability and protection. The layer below the membrane is usually a fine- to medium-grade fill that will support the weight of the entire cap and not abrade the liner. A drainage layer is usually employed above the synthetic membrane or other hydraulic barrier. Permeability of the drainage layer should be on the order of 10^{-3}cm/sec (USEPA 1985).

Vegetative layers of a multilayer cap usually exceed 2 ft in thickness, but may be greater depending on the depth of frost penetration, the maximum depth of root penetration, and the rate of soil erosion at the surface. The type of vegetation selected should be suited to local conditions. Generally, grass or nonwoody vegetation with limited maintenance requirements is recommended (USEPA 1985).

Tests for Design. Design of a cap for contaminated dredged material depends on selection of the proper capping materials, usually soils, and quality control during construction. The tests for accomplishing these requirements are standard laboratory and field procedures. A listing of the principal soil tests with each procedure referenced to several standard manuals is presented in Part VII. In addition, liner compatibility tests may be in order for sites where extremely high contaminant concentrations are anticipated. Shafer et al. (1984) discussed chemical compatibility of synthetic liners and referenced the pouch test for liner compatibility presented by Haxo (1980). For this test waste fluid is placed in a small pouch made from the membrane material. The pouch is immersed in deionized water and changes in pouch weight, water ph, and water electrical conductivity are monitored to provide an estimate of the relative permeability of a liner material.

Evaluation Factors. Reliability of a cover is dependent on the design and complexity of the cover. A cover system with a number of layers will be more reliable than one with fewer layers. However, compared to an uncovered site, a single well-selected and well-constructed cover will improve reliability of the site.

Covers are susceptible to failure due to root penetration, consolidation of underlying material, adverse weather conditions, and disturbance at the surface by man or animals. Whether soil covers are more or less reliable than synthetic covers is a subject of debate. Membranes are less susceptible to moisture changes and are more impermeable, but the chance for failure is greater due to improper installation. Improper seaming techniques or puncture by equipment are significant concerns. The most reliable cover system would be one that has multiple layers to meet the functional needs of the site and, to limit percolation, include an impermeable soil layer or a synthetic membrane.

Covers have proven implementability and have been widely applied at sanitary landfills and hazardous waste disposal sites. They are familiar to the construction industry and design engineers. Soil covers require suitable soils, which, if not available at the site, can increase cost. A wide variety of synthetic materials are available. Implementation may be delayed or troubled by dewatering and consolidation of the dredged material to a trafficability condition and moisture content suitable for installation of the cover.

Technical effectiveness of a cover could be related to the particular functional design of a cover. Covers can be designed to be technically effective in blocking most of the migration pathways. Elimination of percolation through a cover would be difficult to guarantee, but it could be minimized to a degree, in combination with other control measures, to meet most environmental protection goals.

Environmental concerns associated with covers will be site specific and depend on the land use of the site prior to dredged material disposal. A covered site generally would not provide the habitat and diversity of vegetation and species and the visual qualities of a previously idle land area. However, covers would generally enhance the environment compared to an uncovered dredged material disposal site.

Covers are an integral part of any system designed to protect the safety of the public. Safety of workers installing the cover must comply with OSHA requirements. Covers minimize airborne releases of contaminants.

Once installed, covers do not have any operational requirements, but maintenance is required over both the short term and long term, primarily for the vegetative component. For effective vegetation of the most desirable type to survive and to prevent unwanted vegetation, mowing and fertilization are recommended. Reclamation of the site for other uses (e.g., paving with concrete or asphalt) could eliminate maintenance of the cover, as such.

There are currently no state or Federal regulatory requirements that relate specifically to the need or design for covers of contaminated dredged material. One could expect that the to-be-published sections of the State of Washington regulations for dredged material disposal will address this issue.

A cover will be very important to public acceptability of any disposal alternative for contaminated dredged materials. Well-maintained vegetative covers should have little problem gaining public acceptance.

Surface-Water Controls

Control of surface water in and around a disposal site should be included in the plans for management of all sites. The overall objective of surface water controls is to minimize the volume of water that becomes contaminated via contact with the contaminated sediment. Surface-water controls are selected and designed to accomplish this objective by preventing surface water runon from areas adjacent to the disposal site, by draining the disposal site efficiently to reduce infiltration and leachate generation, and by preventing erosion and sediment loss from the cover of the site. Surface-water controls also aid in collecting and transferring water that may be contaminated to treatment or disposal systems.

Control Measures. Surface-water control methods are well established and are familiar to the engineering and construction industry. The period immediately following placement of the site's cover is particularly critical for having adequate surface-water control measures because vegetation is not well established and the bare soil is unprotected from erosion forces. Some surface-water controls are designed for this initial period of site operation and may be considered temporary. Lee et al. (1985b) provided a detailed discussion of management practices of Corps of Engineers construction sites.

Table 4.3 lists surface-water control measures and their duration of use at disposal sites.

Dikes and berms. Runoff-control dikes are earthen ridges designed to direct or retain surface runoff to reduce slope length or to protect a site from floodwater. Generally, a dredged material confined disposal facility is diked on all sides in order to contain the dredged material during settling, consolidation, and drying. Such facilities do not require additional diking for preventing surface water from running onto the site. Dikes for containment areas have been evaluated by the DMRP and will be discussed in Appendix D of this report.

Additional diversion dikes or berms are applicable where a containment area is constructed at the base of a slope and is not diked on all sides. Containment areas for contaminated sediment constructed in a floodplain may require additional dike construction to prevent overtopping during floods or above average tides. Flood-control dike design depends on the level of protection required. Ehrenfeld and Bass (1983) presented three classes of flood-control dikes as shown in Table 4.4. Procedures for design of flood-control sites are available from a number of agencies including the Corps of Engineers and the Soil Conservation Service. Runoff-control dikes are smaller

Table 4.3

Normal Duration of Surface Water Diversion and Collection Measures*

Technology	Duration of Normal Use
Dikes and berms	Temporary
Channels (earthen and CMP)	Temporary
Waterways	Permanent
Terraces and benches	Temporary and Permanent
Chutes	Permanent
Downpipes	Temporary
Seepage ditches and basins	Temporary
Sedimentation basins	Temporary
Levees	Temporary
Floodwalls	Permanent

* USEPA (1985).

Table 4.4

Classes of Flood-Control Dikes*

Class	Site Conditions	Design Requirements
Class I	Maximum protection against flooding is required Water levels ≥4 m (13 ft) above normal ground level are expected	Design height equals depth of record, 100 year, or 50 year flood, plus wave allowance in excess of 60 cm (2 ft) Cross-section design based on wave action, site exposure, and soil stability analysis Stable mineral soil required in foundation and embankment
Class II	Moderate protection required Water levels ≤4 m (13 ft) above normal ground level are expected	Design height equals depth of 25-year flood or greater. A less stringent design may be used if fuse plug sections or other relief measures are included in the design Cross-section design based on design water height
Class III	Minimum protection required Water levels <2 m (7 ft) for mineral soils and <1.3 m (4 ft) for organic soils are expected	Design based on SCS state standards for specific site condition

* Based on Engineering Standard for Dikes - Code 356, SCS, National Engineering Handbook. Source: SCS (1973) as reported in Ehrenfeld and Bass (1983).

structures requiring much less reliability in performance. Typical runoff-dike requirements are provided in Table 4.5.

Grading. Grading is reshaping the surface of a site in order to manage surface water infiltration while controlling erosion. An undulating surface will pond precipitation and increase infiltration into the contaminated material. Grading smooths the surface and covers the low spots to improve drainage at the surface. Slope lengths and gradients are chosen to provide adequate drainage while avoiding water velocities that would erode the

Table 4.5

Runoff-Dike Requirements

Parameter	Typical Requirement	Comments
Height	0.45 m (1.5 ft) minimum	9 cm (4 in.) freeboard required if used as a diversion
Top width	0.6 m (2 ft) minimum	1.2 m (4 ft) if used as a diversion
Side slope	2:1 (50%) or flatter	
Drainage area	$2\text{x}10^4\text{m}^2$ (5 acre) maximum	
Design life	1 year	Can be extended if stabilized and well maintained
Grade	Should be positive	
Stabilization	Required is slope is over 5%	

Source: USEPA (1976).

surface. It is important that vegetation be established as soon as possible after grading to protect the surface soil from erosion by raindrop impact.

Requirements for grading a dredged material containment area will depend on the method of filling and dewatering the containment area. Where the dredged material is hydraulically dredged fine-grained material, the sediment surface will be relatively uniform and slope to the outlet weir. Mechanically dredged fine-grained material may also slump to a uniform slope. Sandy material and very cohesive fine material may be deposited in mounds or irregular shapes near the inlet. Once filling of a confined disposal facility is completed, the site is usually ditched to provide for dewatering the surface and allow runoff of precipitation. Grading at this point would not be necessary. If the site is to be covered with an impermeable material, then grading would likely be required to reshape the surface. However, as will be facility can be dewatered only near its surface. The drier layer of material in the site will crust over, but will not support conventional earthmoving equipment. Grading is applicable only where subsurface drainage, site management techniques to minimize lift thickness, or other means have been provided to more completely dewater the site. Where a site is dry enough for conventional grading equipment, the techniques shown in Table 4.6 may be used.

Channels and waterways. Surface water collected at a site must be conveyed away from the site into a drainage system or stream. This may be accomplished by a system of channels or by waterways. Channels are excavated ditches that are generally wide and shallow with trapezoidal, triangular, or parabolic cross sections. Channels or ditches in a confined disposal facility are key to draining and drying out the surface and may also collect and transfer rainfall runoff to storage or treatment facilities or to a discharge point. Channels and ditches outside the confined disposal facility can be used to reduce slope length and prevent erosion. Earthen channels must be protected from the erosive action of flowing water. Where velocities are low, vegetation will stabilize the channel surfaces. For greater velocities, rock riprap or concrete lining may be necessary. Waterways used in combination with a dike or berm are called diversions and may be used to divert rainfall runoff away from a contaminated area. Figure 4.4 shows a typical drainage ditch at the base of a confined disposal facility (CDF). Typical design criteria for channels and waterways are given in Table 4.7.

Chutes and downpipes. Chutes and downpipes are control structures used to convey rainfall runoff down a steep earthen embankment without eroding the embankment. Chutes (or flumes) are open channels lined with a nonerodible material such as concrete or grouted rock riprap. Downpipes are used for small drainage areas (less than 5 acres) and may be corrugated metal, plastic, or other types of piping. Flexible tubing of heavy-duty fabric is sometimes used (USEPA 1985). Examples of a chute and downpipe are shown in Fig 4.5 and 4.6, respectively.

Terraces and benches. Terraces and benches direct water flow and reduce slope length in order to reduce erosion of sloping land. They are similar to diversions but are employed as a system of two or more small berms. Two types of terraces are gradient terraces and parallel terraces. Gradient terraces follow the cross-slope contour elevation and usually outlet to vegetated waterways. Parallel or level terraces are equally spaced regardless of the slope contour and outlet through underground pipes.

Table 4.6

Grading Techniques

Technique	Description	Use	Equipment
Excavation	Soil removal	Slope grade construction	Dozer, loader, scraper
Spreading	Soil application, smoothing	Slope grade construction	Dozer, loader, grader
Compaction	Compacts soil, increases density	Slope grade construction	Dozer, loader, compactor
Scarification	Roughening technique, loosens soil	Preparation for revegetation, increase infiltration	Dozer, tractor, harrow
Tracking	Roughening technique, grooves soil along contour	Preparation for revegetation, increase infiltration	Cleated crawler tractor
Contour Furrowing	Roughening technique creates small depressions in soil along contour	Preparation for revegetation, increase infiltration	Dozer

Source: Ehrenfeld and Bass (1983)

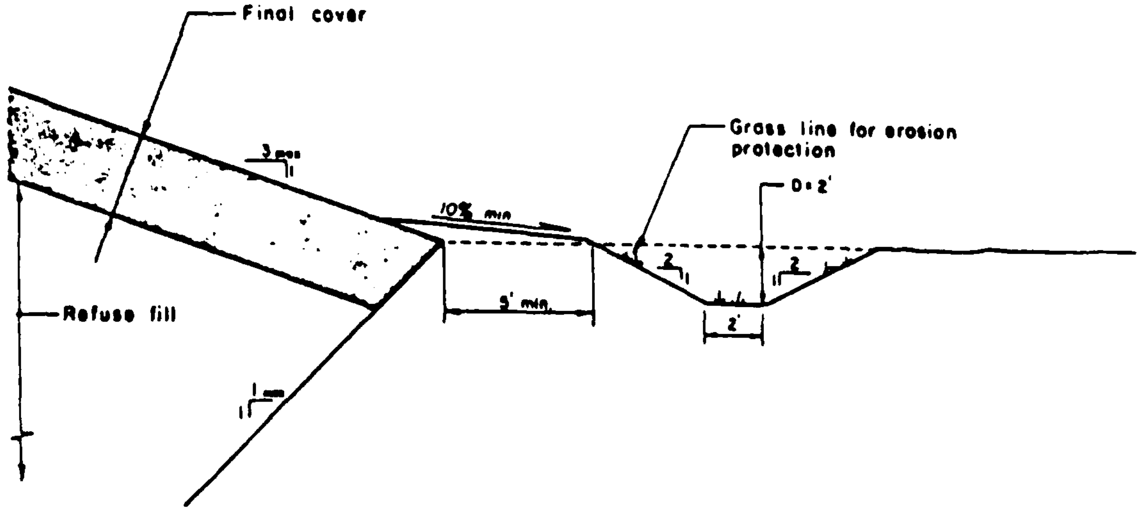


Figure 4.4. Typical drainage ditch at base of disposal site (USEPA 1985)

Most confined disposal facilities would not have slopes inside the dikes that were steep enough to justify a terrace system. Terrace or benches would be more applicable to an area outside the diked area that had been disturbed during construction and required erosion control.

Sedimentation ponds. Sedimentation ponds used as site control measures remove suspended sediment produced by rainfall runoff. Sedimentation as a treatment process will be discussed in the section on liquid waste treatment. Sedimentation ponds may be needed for reducing the discharge of uncontaminated suspended sediment from areas disturbed by construction of the confined disposal facility. The design of these facilities depends on the flowrate, influent sediment concentration, required effluent sediment concentration, and the particle-size distribution of the sediment. For coarse materials discrete settling occurs and the pond can be designed using Stoke's Law. For fine-grained materials, laboratory settling tests as will be described for dredged material should be performed. Removal of clay and colloidal material may require chemical addition to achieve a high quality effluent.

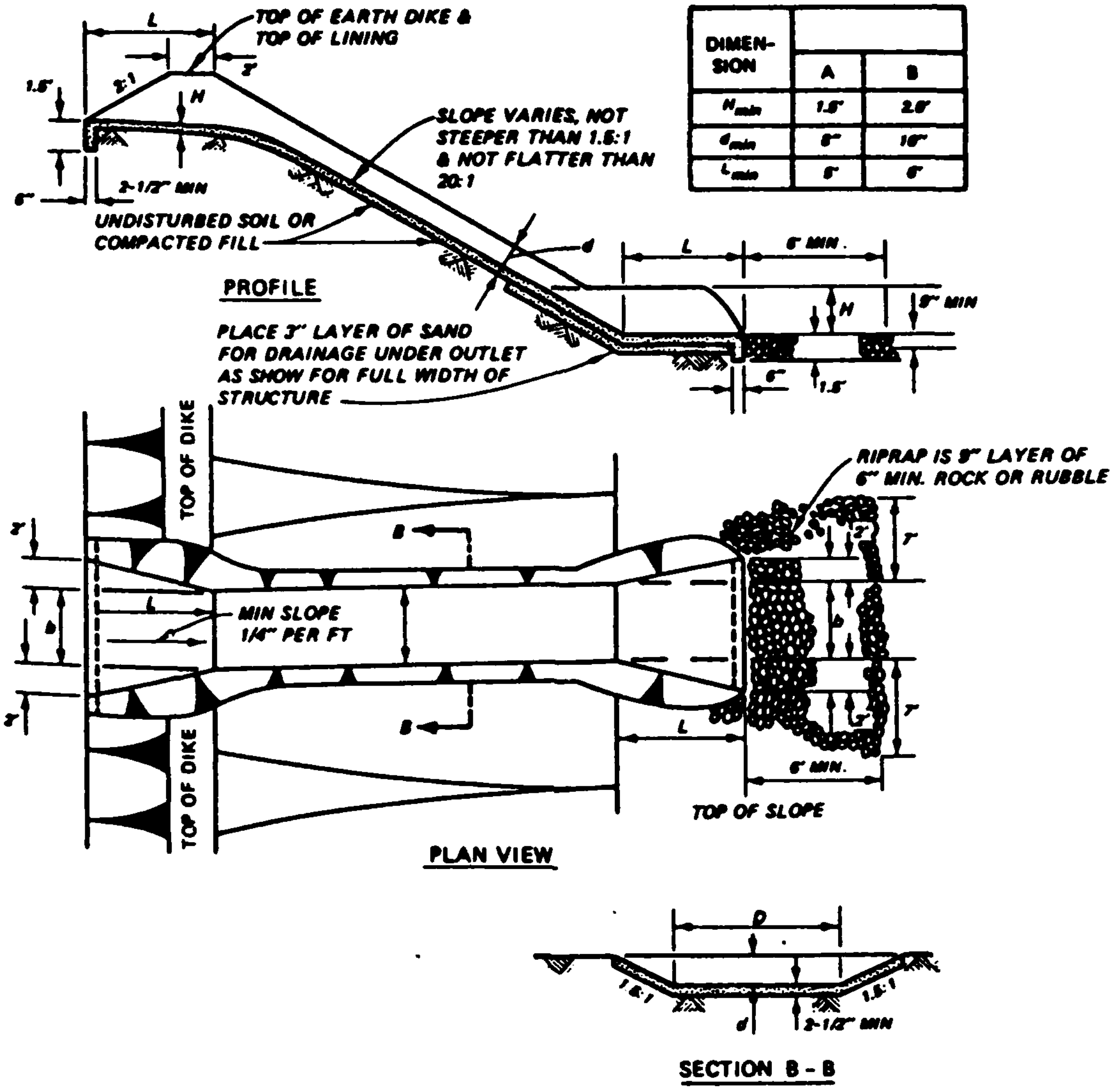
Summary. A variety of surface-water control measures are available for collecting and controlling rainfall runoff and for preventing erosion at a site. These commonly used measures are familiar to the construction industry, and procedures for their design are well documented in publications of the

Table 4.7

Typical Design Criteria for Channels and Waterways

Technology	Drainage Area	Maximum Permissible Velocity ft/sec	Depth	Duration of Normal Use	Maximum Side Slopes	Stabilization
Earthen channels	Less than 5 acres	2	1 ft minimum	Temporary	2:1	Grass or soil additives desirable if used for considerable time
Corrugated metal pipe channels	No size limitation	10	Radius of pipe	Temporary	--	--
Sodded waterways	No size limitation	5	0.4 to 3 ft (parabolic) 0.5 to 6 ft (trapezoidal)	Permanent	2:1	Sod, stone bottom for base flow
Stone waterways	No size limitation	6	1 ft minimum	Permanent	2:1	--

Source: SCS Engineers (1980) as reported in USEPA (1985)

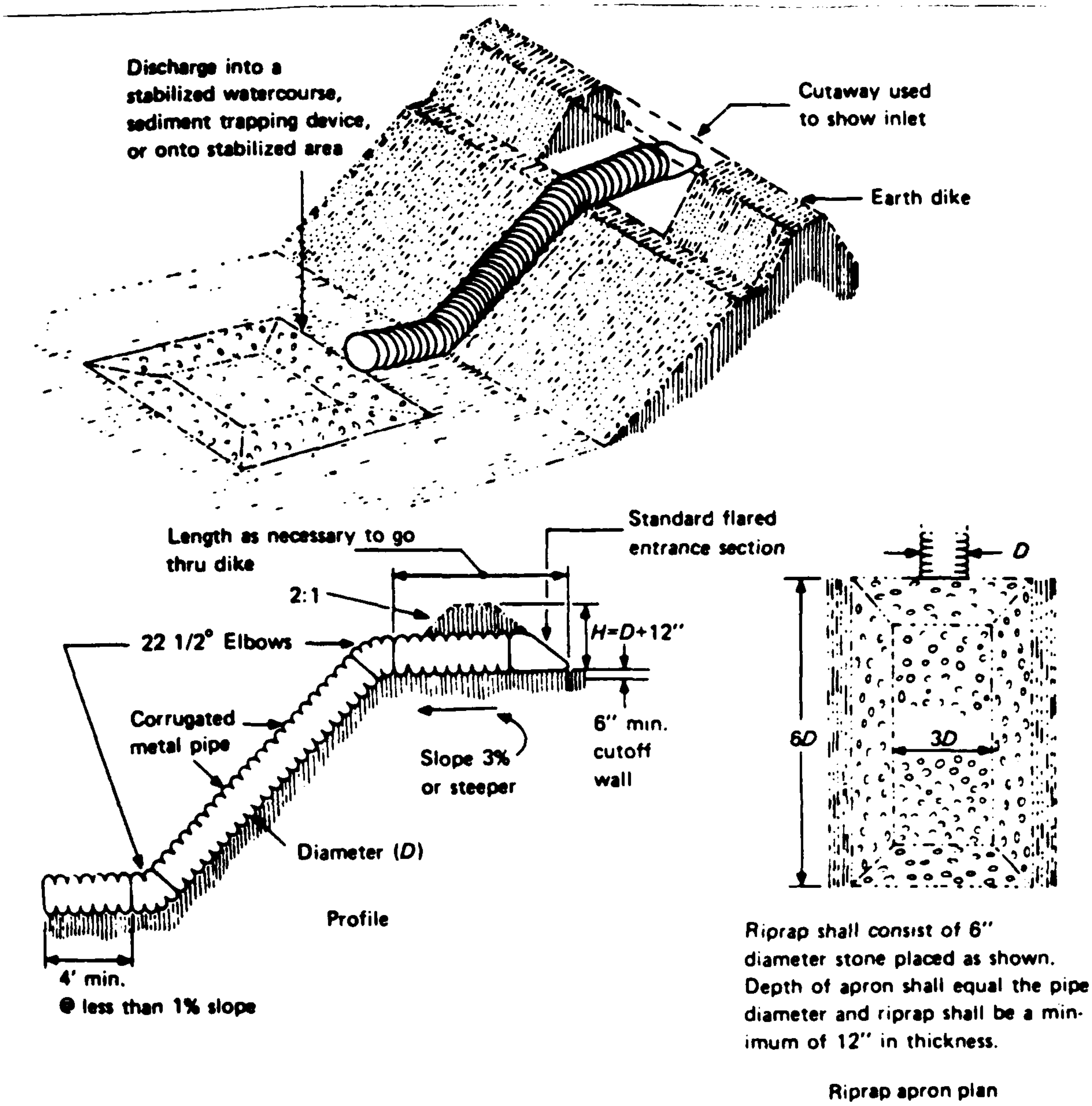


DIMENSION	A	B
H_{min}	1.5"	2.0"
d_{min}	6"	16"
L_{min}	5"	6"

Figure 4.5. Paved chute (or flume) (USEPA 1985)

USEPA, USDA Soil Conservation Service, and the Corps of Engineers. Any of these control measures could be applied at a site where contaminated sediment is handled and disposed as a solid or for areas surrounding a confined disposal facility. However, use of these measures inside the dikes of a confined disposal facility may not be critical because the dredged material surface is relatively flat. Construction problems could arise when the crust on fine-grained dredged material would not support operation of conventional earth-moving equipment.

Design Considerations. Designs of surface-water control measures are well-established techniques that are published by the Corps of Engineers, the



Profile

Riprap shall consist of 6" diameter stone placed as shown. Depth of apron shall equal the pipe diameter and riprap shall be a minimum of 12" in thickness.

Riprap apron plan

Figure 4.6. Rigid downpipe (USEPA 1985)

USEPA and the USDA. Design procedures for the various measures are similar and require the same types of input data. An initial calculation for most surface-water control measures is the volume and rate of rainfall runoff. Data needed for this calculation include the following:

Drainage area

Topography

Rainfall amount for design storm
Type of rainfall (intensity, duration)
Soil characteristics
Type of vegetative cover

These data are dependent on the site and local climate. From this information the peak rate of discharge for the site or for subareas of the site can be predicted. This discharge rate dictates the capacity of ditches, conduits and other water conveyances. Manning's equation for open-channel flow is generally used to size water conveyances for the required flow.

If slope stability or erosion is a problem, then diversions, terraces, grading, chutes, vegetation, riprap, or other measures may be necessary to decrease the slope length and/or decrease water velocity. Estimates of soil erosion are generally made using the Universal Soil Loss Equation (USLE) (USDA 1978). Data input to the USLE include the slope length, slope grade, rainfall intensity, cover, soil type, and management practices. Erosion-control practices such as terraces, diversion, improved vegetative cover, etc. can be employed to reduce the erosion rate to a tolerable range.

The design value that has the greatest influence on the cost of surface control measures is the quantity of soil to be moved for installation of the various measures. Standard engineering practices can be used to compute this value given the topography of the site, the soil characteristics, and the specifications of the control measures. Soil characteristics important to the design of surface-water control measures are:

Type -- USCS or USDA classification
Grain size
Organic content
Nutrient and pH levels
Water content
Permeability
Runoff characteristics
Depth of subsurface impermeable strata
Depth to seasonal high water table

For details regarding design of surface-water control measures, the reader is referred to USEPA (1985), Ehrenfeld and Bass (1983), Lee et al. (1985b), and Soil Conservation Service (1977).

Evaluation Factors. Surface-water control measures are well established and in the short term are very reliable. Long-term continuous reliability is dependent on frequent inspection, maintenance, and performance checks. Lack of quality control during construction and lengthy periods of time before establishment of vegetation detract from reliability of these controls. Surface-water controls are designed on the basis of a selected frequency-of-occurrence storm, usually 10 or 25 years. Storms exceeding the design rainfall are possible and could cause failure of the control. The consequences of failure of a surface-water control measure are dependent on the site and the amount of contaminants released.

Surface-water controls can be easily and rapidly implemented on dewatered sites using readily available equipment and materials and local contractors (USEPA 1985). For confined disposal facilities that do not have provisions for dewatering, specialized equipment would be required to implement earthmoving techniques commonly used for constructing surface-water control measures.

Surface-water control measures that are properly engineered and constructed are very effective in managing surface water. Compared to a site without surface-water controls, a site with an adequate surface-water control system should measurably reduce release of sediment and contaminants. The magnitude of the reduction depends on site conditions.

Surface-water controls produce positive effects on the environment by reducing erosion and aiding in containment of contaminants.

No unusual safety precaution are required for surface-water control measures installed for dewatered sites. Construction of control measures on wet dredged material may be dangerous for equipment operators.

Most surface-water control measures require periodic inspection and maintenance, particularly during periods of heavy rainfall. Vegetation must be managed to prevent erosion of ditches and berms. Accumulations of sediment deposited in ditches and along terraces and diversions must be removed.

Costs of surface-water control measures have been summarized by USEPA (1985) as shown in Tables 4.8 and 4.9. Costs of earthwork is dependent on site conditions and regional economics. Working with wet dredged material will increase costs above those shown in the tables. Consequently, all cost estimates for surface-water control measures should be determined on a site-specific basis.

Table 4.8

Unit Costs Associated with Grading Site for Covering Disposal*

Description	Unit Cost	Reference Source**
Topsoil (sandy loam) from borrow pits, excavation, hauling, spreading, and grading (within 25 miles); labor, materials, and equipment	\$15/yd^3	1
On-site excavation, hauling, spreading, and compaction of earth (1,000-5,000 ft haul); labor and equipment only	\$2.02-3.86/yd^3	1
Sandy loam topsoil; material only	\$2.25/yd^3	1
Excavate, haul 2 miles, spread and compact loam, sand, or loose gravel (with front-end loader); labor, material, and equipment	\$6.65-6.72/yd^3	1
Grading, site excavation, and fill (no compaction);		2
75 hp dozer, 300 ft haul	\$3.39/yd^3	
300 hp dozer, 300 ft haul	\$2.34/yd^3	
Field density compaction testing of soils	\$104/day	1

* Source: USEPA (1985)

** Entries in this column indicate references cited by USEPA (1985): 1 and 2 represent McMahon (1984) and Godfrey (1984), respectively.

Regulatory agencies generally require that uncontaminated surface-water runoff be segregated from contaminated surface water or site drainage water. Since design for these surface water controls is site specific, most regulatory design requirements are not specified other than that they conform to good engineering practice and that they handle water from a particular design storm. Typical design storms for runoff control are the 10-year/24-hour or the 25-year/24-hour storms.

Surface-water controls create little adverse public reaction. Care in minimizing destruction of vegetation during construction and giving attention

Table 4.9

Unit Costs Associated with Surface Water Diversion and Collection Structures*

Description	Applicable Structures**	Cost	Reference Cost Data Source†
Excavation, hauling, grading (spreading and compaction)	All	See Table 4.9	
Trench excavation	D/B; D/D/W; BT; L; DT/B		
o Loam, sand, and loose gravel			
1-6 ft deep, 1/2:1 sides		\$0.84 - \$1.00/yd^3	1
6-10 ft deep		\$0.84 - \$0.99/yd^3	1
o Compacted gravel and till			
1-6 ft deep, 1/2:1 sides		\$0.84 - \$1.18/yd^3	1
6-10 ft deep		\$0.84 - \$1.06/yd^3	1
Building embankments; spreading, shaping, compacting	All		
o Material delivered by scraper		\$0.42 - \$0.83/yd^3	1
o Material delivered by back dump		\$0.89 - \$1.31/yd^3	1
Placement of ditch liner pipe, 1/3 section	D/D/W; drainage benches; C/D		
15-in. radius		\$15/ft	1
18-in. radius		\$20/ft	1
24-in. radius		\$30/ft	1

(Continued)

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* Source: USEPA (1985).

** D/B, dikes and berms; D/D/W, ditches, diversion, and waterways; BT, bench terraces; C/D, chutes and downpipes; L, levees; DT/B, drainage trenches and basin, SB, sediment basins.

† Entries in this column indicate references cited by USEPA (1985): 1-McMahon (1984); 2-Godfrey (1984); 3-personal communication, C. Klikas, Environetics, Inc., Bridgeview, IL (1985); and 4-Virginia SWCC (1980) updated to 1985 dollars using Engineering News-Record Construction Index.

(Sheet 1 of 3)

Table 4.9 (Continued)

Description	Applicable Structures**	Cost	Reference Cost Data Source†
Catch basin sump, 3 ft x 4 ft x 1.5 ft	L; DT/B	$217.77 each	1
Corrugated galvanized steel underdrain pipe, asphalt-coated perforated;	DT/B		
12-in. diameter, 16 gauge		$21/ft	1
18-in. diameter, 16 gauge		$30/ft	1
Corrugated galvanized metal pipe, with paved invert	C/C; SB		
18-in. diameter, 14 gauge		$34.12/ft	1
36-in. diameter, 12 gauge		$86.83/ft	1
48-in. diameter, 12 gauge		$65.12/ft	1
Steel sheet piling;	L (seepage control)		
15-ft deep, 22 lb/ft^2		$\$10.65/ft^2$	2
20-ft deep, 27 lb/ft^2		$\$12.35/ft^2$	2
25-ft deep, 38 lb/ft^2		$\$15.70/ft^2$	2
Backflow preventer; gate valves, automatic operation, flanged, 10 in. diameter	L (drainage control)	$9,250 each	2
Floating baffles	SB	$15 - $50/ft	3
Sump pumps, 10-ft head, automatic	L (backwater drainage)		
Bronze		$25 - $505 each	2
Cast Iron		$145 - $292 each	2
Revegetation, mulching, maintenance	D/B; D/D/W; BT; L	See table	2,3

(Continued)

(Sheet 2 of 3)

Table 4.9 (Concluded)

Description	Applicable Structures**	Cost	Reference Cost Data Source†
Loose gravel, excavation, loading, hauling 5 miles, spreading and compacting	All (slope protection; drainage)	\$8 - \$8.50/yd^{3}	1
Stone riprap; dumped from trucks, machine-placed	All (slope protection; channel & outlet stabilization)	\$21/yd^{3}	2
Soil testing:	All (preconstruction evaluation)		
liquid and plastic limits		\$30/test	2
hydrometer analysis specific gravity		\$50/test	2
moisture content		\$7.15/test	2
permeability		\$65/test	2
Proctor compaction		\$110 - \$120/test	2
shear tests			
triaxial		\$150 - \$280/test	2
direct shear		\$95 - \$260/test	2
Temporary diversion dike	D/B	\$1.31 - \$2.62/ linear foot	4
Temporary sediment construction, drainage area:			
1-25 acres		\$394 - \$2,082	4
50-75 acres		\$3,942 - \$6,470	4
75-100 acres		\$6,470 - \$8,340	4
100-125 acres		\$8,340 - \$10,913	4
Sediment removal from basins	SB	\$3.95 - \$9.10/yd^{3}	4
Paved flume, installed	C/D; SB	\$26.30 - \$39.92/yd^{2}	4
Level spreader construction	D/B; D/D/W; BT; C/D	\$3.23 - \$6.47/ linear foot	4

(Sheet 3 of 3)

to visual quality will ensure that these measures are acceptable to the public.

Liners

Lining a site is a technique designed to contain leachate within the site and minimize groundwater contamination. A variety of liner materials are available for use in confined disposal operations. Principal characteristics, advantages, and disadvantages of liners and flexible membranes are listed in Table 4.10. Soil liners are suitable for use as the only liner in most dredged material upland and nearshore sites. However, in certain upland applications, a combination of synthetic membrane and soil liner may be required to achieve maximum containment of contaminants. To ensure continued effectiveness of the liners whether soil or flexible membrane, they must be compatible with the dredged material and leachate they are to contain and be properly installed. (Phillips et al. 1985)

Flexible Membranes. Synthetic membrane technology is new and a variety of synthetic materials and compounds are being manufactured, tested, and marketed (Table 4.10). The various membranes being produced vary not only in physical and chemical properties but also in installation procedures, costs, and chemical compatibility with waste fluids. The liners range in thickness from 20 to 140 mil and are made from polymers of rubber, plastics such as PVC, polyolefins, and thermoplastic elastomers.

Since the prime purpose of the liner is to prevent leachate from escaping the disposal site, the physical integrity and chemical compatibility of the liner with the leachate and dredged material must be ensured. Potential incompatible combinations of wastes and liners include:

- Polyvinyl chloride (PVC) tends to be dissolved by chlorinated solvents.
- Chlorosulfonated polyethylene can be dissolved by aromatic hydrocarbons.
- Asphaltic materials may be dissolved by oily wastes.

Expected life of synthetic liners is less than 30 years. In general, most polymeric material tend to swell when exposed to fluids. Crosslinking or vulcanizing a polymer or rubber will reduce its ability to swell in a solvent. Swelling usually has adverse effects on a polymer material. Some of the major effects of swelling are:

- Softening.
- Loss of tensile and mechanical strength and elongation.

Table 4.10

Principal Characteristics, Advantages, and Disadvantages of Liners and Flexible Membranes*

Liner Material	Characteristics	Range of Costs**	Advantages	Disadvantages
Soils:				
Compacted clay soils	Compacted mixture of onsite soils to a permeability of 10^{-7} cm/sec	L	High cation exchange capacity; resistant to many types of leachate	Organic or inorganic acids or bases may solubilize portions of clay structure
Soil-bentonite	Compacted mixture of onsite soil, water, and bentonite	L	High cation exchange capacity; resistant to many types of leachate	Organic or inorganic acids or bases may solubilize portions of clay structure
Admixes:				
Asphalt-concrete	Mixtures of asphalt cement and high quality mineral aggregate	M	Resistant to water and effects of weather extremes; stable on side slopes; resistant to acids, bases, and inorganic salts	Not resistant to organic solvents; partially or wholly soluble in hydrocarbons; does not have good resistance to inorganic chemicals; high gas permeability
Asphalt-membrane	Core layer of blown asphalt blended with mineral fillers and reinforcing fibers	M	Flexible enough to conform to irregularities in subgrade; resistant to acids, bases, and inorganic salts	Ages rapidly in hot climates; not resistant to organic solvents, particularly hydrocarbons
Soil asphalt	Compacted mixture of asphalt, water, and selected in-place soils	L	Resistant to acids, bases, and salts	Not resistant to organic solvents, particularly hydrocarbons
Soil cement	Compacted mixture of Portland cement, water, and selected in-place soils	L	Good weathering in wet-dry/freeze-thaw cycles; can resist moderate amount of alkali, organics and inorganic salts	Degraded by highly acidic environments

(Continued)

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* Source: USEPA (1985).

** L - $1 to $4 installed costs per sq. yd. in 1981 dollars; M - $4 to $8 per sq. yd.; H - $8 to $12 per sq. yd. Adapted from Technologies and Management Strategies for Hazardous Waste Control, Office of Technology Assessment, Congress of the US (1983).

(Sheet 1 of 3)

Table 4.10 (Continued)

Liner Material	Characteristics	Range of Costs**	Advantages	Disadvantages
Polymeric membranes:				
Butyl rubber	Copolymer of isobutylene with small amounts of isoprene	M	Low gas and water vapor permeability; thermal stability; only slightly affected by oxygenated solvents and other polar liquids	Highly swollen by hydrocarbon solvents and petroleum oils; difficult to seam and repair
Chlorinated polyethylene	Produced by chemical reaction between chlorine and high density polyethylene	M	Good tensile strength and elongation strength; resistant to many inorganics	Will swell in presence of aromatic hydrocarbons and oils
Chlorosulfonated polyethylene	Family of polymers prepared by reacting polyethylene with chlorine and sulfur dioxide	H	Good resistance to ozone, heat, acids, and alkalis	Tends to harden on aging; low tensile strength; tendency to shrink from exposure to sunlight; poor resistance to oil
Elasticized polyolefins	Blend of rubbery and crystalline polyolefins	L	Low density; highly resistant to weathering, alkalis, and acids	Difficulties with low temperatures and oils
Epichlorophydrin rubbers	Saturated high molecular weight, aliphatic polethers with chloromethyl side chains	M	Good tensile and tear strength; thermal stability; low rate of gas and vapor permeability; resistant to ozone and weathering; resistant to hydrocarbons, solvents, fuels, and oils	None reported
Ethylene propylene rubber	Family of terpolymers of ethylene, propylene, and nonconjugated hydrocarbon	M	Resistant to dilute concentrations of acids, alkalis, silicates, phosphates, and brine; tolerates extreme temperatures; flexible at low temperatures; excellent resistance to weather and ultraviolet exposure	Not recommended for petroleum solvents or halogenated solvents
Neoprene	Synthetic rubber based on chlorprene	H	Resistant to oils, weathering, ozone and ultraviolet radiation; resistant to puncture, abrasion, and mechanical damage	None reported

(Continued)

(Sheet 2 of 3)

Table 4.10 (Concluded)

Liner Material	Characteristics	Range of Costs**	Advantages	Disadvantages
Polyethylene	Thermoplastic polymer based on ethylene	L	Superior resistance to oils, solvents, and permeation by water vapor and gases	Not recommended for exposure to weathering and ultraviolet light conditions
Polymeric membranes:				
Polyvinyl chloride	Produced in roll form in various widths and thicknesses; polymerization of vinyl chloride monomer	L	Good resistance to inorganics; good tensile, elongation, puncture, and abrasion-resistant properties; wide ranges of physical properties	Attacked by many organics, including hydrocarbons, solvents and oils; not recommended for exposure to weathering and ultraviolet light conditions
Thermoplastic elastomers	Relatively new class of polymeric materials ranging from highly polar to nonpolar	M	Excellent oil, fuel, and water resistance with high tensile strength and excellent resistance to weathering and ozone	None reported
Portland cement	Hydraulic cement of silica, lime, and alumina	H	Excellent base for waste-handling equipment	Cracking

(Sheet 3 of 3)

- Increased permeability and potential for creep.
- Increased susceptibility to polymer degradation.

Synthetic membranes are also subject to biological and ultraviolet light degradation. Membrane installations may be difficult in areas of tidal fluctuation or high groundwater table. Synthetic membranes are subject to leaks at field-jointed seams and are not self-sealing if punctured. Physical and chemical integrity is highly site specific and depends upon liner compatibility with both dredged material and leachate.

Table 4.11 shows the range of synthetic membrane costs in confined disposal areas.

Soil Liners. Soil liners are generally adequate for most dredged material disposal sites and can be used on the sides and bottom of confined disposal areas containing contaminated material. In general, clay is a good liner material that is not only relatively inert to chemical attack but will also act as a filter, sorbing many contaminants from the leachate (Kelley 1982). Unfortunately the relative chemical compatibility of clay soil with leachate and the sorption capability of clay soil are based on limited data and experience and depend on the characteristics of the clay and contaminants in the dredged material. Soil liners if allowed to dry will crack and lose integrity. Soil liners are subject to differential settlement and bioturbation prior to filling. Once ion exchange sites are filled within the liner, soluble contaminants will slowly migrate through the liner by diffusion. Compatibility testing of clay with contaminated dredged material has not been considered to date. Additional laboratory testing and field work are needed to address the capabilities and limitations of clay liners. However, accumulation of a database adequate for generalizations that could be applied to a specific site is unlikely.

Construction of soil liners to achieve remolded permeability of 1×10^{-7} cm/sec or less is recommended. The soil may be obtained onsite, from selected borrow areas, or from off-site sources. If available soils do not have the required low permeability, they can be blended with clay soils, bentonite, or other additives. Prepared bentonite formulations would probably be required for sediment containing a high salt content. Soil liners should be a minimum of 3-ft thick (Phillips et al. 1985).

Soil liners cost approximately $5.00 per in-place cubic yard for an upland site.

Table 4.11

Representative Costs for Synthetic Liners

Type	Cost/sq ft*
Geotextile Fabrics	$0.11-0.33
Membrane liners	
Nonreinforced materials:	
30-mil PVC	$0.25 - 0.30
30-mil CPE	0.35 - 0.40
30-mil Butyl/EPDM	0.45 - 0.50
30-mil Neoprene	0.70 - 0.75
100-mil HDPE	1.00 - 1.50
Reinforced materials	
36-mil Hypalon	$0.50 - 0.55
60-mil Hypalon	0.80 - 0.90
36-mil CPER	0.50 - 0.55

* Prices for membrane liners from Watersaver, Inc., based upon 400,000 sq ft installations.

Groundwater Controls

Groundwater-control technologies are usually considered as remedial actions where sites containing hazardous materials have released contaminants to the groundwater. Ideally, adequate site investigation and installation of appropriate controls at a newly selected disposal site will avoid groundwater contamination and hence the need for groundwater controls. Therefore, this discussion will represent a brief overview of groundwater controls and refer the reader to other documents such as USEPA (1985) and USEPA (1984) for more detailed information.

Control of groundwater contamination involves one of four options: (1) containment of a plume; (2) removal of a plume after measures have been taken to halt the source of contamination; (3) diversion of groundwater to prevent clean groundwater from flowing through a source of contamination or to prevent contaminated groundwater from contacting a drinking water supply; or

(4) prevention of leachate formation by lowering the water table beneath a source of contamination. Remedial technologies for controlling groundwater contamination problems are generally placed in one of three categories: (1) groundwater pumping, involving extraction of water from or injection of water into wells to capture a plume or alter the direction of groundwater movement; (2) subsurface drains, consisting of gravity collection systems designed to intercept groundwater; or (3) low-permeability barriers, consisting of a vertical wall of low-permeability material constructed underground to divert groundwater flow or minimize leachate generation and plume movement. These technologies can be used singularly or in combination to control groundwater contamination (USEPA 1985).

Groundwater Pumping. Groundwater pumping techniques involve the active manipulation and management of groundwater in order to contain or remove a plume or to adjust groundwater levels in order to prevent formation of a plume. Types of wells used in management of contaminated groundwater include wellpoints, suction wells, ejector wells, and deep wells. The selection of the appropriate well type depends upon the depth of contamination and the hydrologic and geologic characteristics of the aquifer (USEPA 1985).

Subsurface Drains. Subsurface drains include any type of buried conduit used to convey and collect aqueous discharges by gravity flow. Subsurface drains essentially function like an infinite line of extraction wells. They create a continuous zone of influence in which groundwater within this zone flows towards the drain. Subsurface drainage components include the following (USEPA 1985):

- Drain pipe or gravel bed--for conveying flow to a storage tank or wet well. Pipe drains are used most frequently at hazardous waste sites. Gravel bed or french drains and tile drains are used to a more limited extent.
- Envelope--for conveying flow from the aquifer to the drain pipe or bed.
- Filter--for preventing fine particles from clogging the system, if necessary.
- Backfill--to bring the drain to grade and prevent ponding.
- Manholes or wet wells--to collect flow and pump the discharge to a treatment plant.

Subsurface Barriers. The term subsurface barriers refers to a variety of methods whereby low-permeability cutoff walls or diversions are installed below ground to contain, capture, or redirect groundwater flow in the vicinity of a site. The most commonly used subsurface barriers are slurry walls, particularly soil-bentonite slurry walls. Less common are cement-bentonite or concrete (diaphragm) slurry walls, grouted barriers, and sheet piling cutoffs. Grouting may also be used to create horizontal barriers for sealing the bottom of contaminating sites (USEPA 1985).

Slurry walls. Slurry walls are the most common subsurface barriers because they are a relatively inexpensive means of vastly reducing groundwater flow in unconsolidated earth materials. The term slurry wall can be applied to a variety of barriers all having one thing in common: they are all constructed in a vertical trench that is excavated under a slurry. This slurry, usually a mixture of bentonite and water, acts essentially like a drilling fluid. It hydraulically shores the trench to prevent collapse and, at the same time, forms a filter cake on the trench walls to prevent high fluid losses into the surrounding ground. Slurry wall types are differentiated by the materials used to backfill the slurry trench. Most commonly, an engineered soil mixture is blended with the bentonite slurry and placed in the trench to form a soil-bentonite (SB) slurry wall. In some cases, the trench is excavated under a slurry of portland cement, bentonite, and water, and this mixture is left in the trench to harden into a cement-bentonite (CB) slurry wall. In the rare case where great strength is required of a subsurface barrier, precast or cast in place concrete panels are constructed in the trench to form a diaphragm wall (USEPA 1985).

Sheet Piling. Sheet piling made of wood, precast concrete, or steel can be used to form a partial groundwater barrier. Wood is an ineffective water barrier, however, and concrete is used primarily where great strength is required. Steel is the most effective in terms of groundwater cutoff and cost. Steel sheet piling can be employed as a groundwater barrier much like slurry walls. Because of costs and unpredictable wall integrity, however, it is seldom used except for temporary dewatering for other construction or as erosion protection where some other barrier, such as a slurry wall, intersects flowing surface water. One of the largest drawbacks of sheet piling, or any other barrier technology requiring pile driving, is the problem caused by rocky soil. Damage to or deflection of the piles is likely to render any such wall ineffective as a groundwater barrier (USEPA 1985).

Leachate Collection

Disposal sites for dredged material must accommodate the interstitial water associated with the sediment, dilution water that may be mixed with the sediment by the dredging operation, and precipitation or other sources of water added to the disposal area surface. As this water percolates downward to the bottom of the disposal site, it may become contaminated. This possibility may require lining the bottom of the site to prevent contamination of groundwater. Without an outlet for excess water, the diked containment area becomes a stoppered bathtub and unless evaporation/transpiration is great enough to eliminate the excess, the liquid level will either increase to the point of overflowing or will exert sufficient head at the bottom of the site to cause discharge to the groundwater.

A leachate collection system designed for groundwater control is usually a network of perforated pipes placed under and around the perimeter of the site. The pipes drain to a sump or series of sumps from which the leachate may be withdrawn either by gravity if topography allows or by pumping. Spacing and sizing of the pipes depends on the allowable leachate head in the site and the rate at which water must be removed. Detail design of a leachate collection system for groundwater control is described in USEPA (1983).

Dewatering

An underdrainage system allows collection of excess leachate for treatment or disposal and reduces the probability of groundwater contamination. Underdrainage is a dewatering method which may be used individually but usually in conjunction with trenching of the surface. If controls for sediment contaminants dictate emplacement of a cover for the site, dewatering may be required in order to get the surface layer dry enough for construction of the cover.

Underdrainage systems must be installed prior to disposal. Collector pipes are place in either a naturally occurring or a previously artificially placed layer at the bottom of the site. Free water percolating through the dredged material migrates into the previous underdrainage layer and is removed by the collector pipes. Two mechanisms exist for dewatering and densifying of fine-grained dredged material using pervious underdrainage layers: gravity underdrainage or vacuum-assisted underdrainage. The gravity underdrainage technique consists of providing free drainage at the base of the dredged material. Downward flow of water from the dredged material into the underdrainage layer takes place by gravity. Vacuum-assisted underdrainage is similar to gravity underdrainage, but a partial vacuum is maintained in the underdrainage layer by vacuum pumping.

Advantages and disadvantages of the two methods were discussed by Haliburton (1978) and are presented in Table 4.12. Field experience with underdrainage systems for dewatering/densification of dredged material was reported by Hammer (1981). Vacuum-assisted underdrainage improved the dewatering process compared to a control site with no underdrainage and a gravity underdrainage site.

The underdrainage system begins to function as soon as dredged material is placed in the containment area. Free water that might otherwise be discharged through surface outlets is collected by the underdrains and collector system. An important benefit of underdrainage is the consolidation of the dredged material caused by seepage and weight of the densified dredged material itself (Haliburton 1978).

Design of an underdrainage layer for use with dredged material is somewhat different than design of a normal pervious filter. A continuous flow condition is usually not maintained in the underdrainage layer. Water essentially drips from the dredged material, and the static water level in the underdrainage layer is at the flowline of the collector pipe system. Fine-grained dredged material placed in confined disposal areas tends to exhibit individualized particle behavior, and it is necessary to choose a filter material that will resist both filter clogging and piping of the fine-grained dredged material through the filter (Haliburton 1978).

General criteria for selection of a proper underdrainage material are that it be essentially free draining and free of fines (5 percent or less passing the U.S. No. 200 sieve) and the material minimize penetration and piping of the fine-grained dredged material during filter skin formation. Laboratory tests confirmed by field testing showed that either standard well-graded concrete sand or fine uniform sand worked satisfactorily, as did filter fabric with openings equivalent to U.S. No. 70 to No. 100 sieve size placed over any porous and free-draining layer (pea gravel, crushed stone, mussel shell, etc.). Such laboratory testing is recommended prior to selection of an actual site-specific filter design (Haliburton 1978).

Sand obtained from new work dredging or as a part of maintenance dredging is usually deposited near the disposal area dredge pipe location, and then it

Table 4.12

Advantages and Disadvantages of Underdrainage Dewatering Methods*

Method	Advantages	Disadvantages
Gravity underdrainage	1. Relatively low cost. 2. Sand from required dredging or naturally occurring pervious foundation material may be utilized. 3. Can be used in conjunction with other densification techniques. 4. Filters the dredged material effluent. 5. Can be used in conjunction with surface drying and vegetative growth.	1. Possible construction problems if placement of pervious material is required. 2. Underdrainage layer may occupy storage space in disposal area. 3. Must have collector pipes in order to be effective.
Vacuum-assisted underdrainage	1. Cost of adding vacuum pumps to underdrainage system is low. 2. Results in higher effective stress in dredge material. 3. Can be used in conjunction with other densification procedures.	1. Maintenance required during operation. 2. Energy required to operate. 3. Possible problems from leakage that could lessen magnitude of desired vacuum.

Source: Haliburton (1978).

is essentially washed by the progressive sedimentation process. In many cases, this material will be suitable for use as an underdrainage layer; thus, possible availability and suitability of such material should be one of the initial factors investigated. Comparative data have shown that use of such sand is often extremely cost-effective (Haliburton 1978).

Site Security

Any time contaminated sediment is being dredged, transported, or disposed, site security for the protection of safety and health of the public and of workers must be addressed. In addition to the time when the site is being filled, site security must be considered for the time after disposal is completed. The extent of security measures will depend on the nature and concentration of contaminants, the migration pathways affected by the contaminants, the risk to humans and wildlife, and future use of the site. For unusual conditions, where justified by the risk presented by the nature and location of the site, a site-specific safety plan may be developed in accordance with guidance presented in EM 1110-1-505 (OCE 1986).

A minimum requirement for adequate protection of public health and safety is a site-security plan that provides for measures to prevent direct human contact. Fencing and warning signs are standard recommendation for confined disposal facilities that are accessible to the public. As a minimum, facilities handling contaminated sediment should be fenced during operation of the site and until a cover is developed and vegetated. Once the final cover is established, a risk assessment will be required to determine if security measures must be maintained at the site.

Fencing at sites handling contaminated materials should be nonclimbable chain-link type. If the site is near a heavily populated area, then additional precautions such as guards, etc., may be necessary.

Treatment of Dredge Material Slurries

Solids Separation and Classification Processes

This section describes equipment and methods used to separate solids from slurries and/or to classify contaminated soil or slurries according to grain size. The objective of separating solids from slurries is to attain two distinct waste streams: a substantially liquid waste stream that can be subsequently treated for removal of dissolved and fine suspended contaminants and a concentrated slurry of solids and minimal liquid that can be dewatered and treated.

Classification of particles according to grain size may be undertaken for one of two reasons. The first reason is that more efficient use can be made of equipment and land area by taking advantage of the differences in settling velocity of different sized particles. For example, where only limited land space is available, settling basins may be used to remove sand and gravel with a high settling velocity and then high-rate gravity settlers could be used to remove fine-grained particles.

There is recent evidence to suggest that classification by grain size is important in managing contaminated soil and sediment because of the apparent tendency of contaminants to absorb preferentially onto fine-grained material such as clay and organic matter. The separation of solids by grain-size level of contamination could prove to be extremely beneficial to the overall management of contaminated sediment.

The most appropriate solids separation method for a given site depends upon several factors, including the following: volume of contaminated solids; composition of sediment, including gradation, percent clay, and percent total solids; types of dredging or excavation equipment used, which determines the feed rate to solids separation and, in the case of slurries, the percent solids; and site location and surroundings.

Solids separation methods addressed in this section include settling basins, clarifiers, sieves and screens, hydraulic and spiral classifiers, and cyclones.

Settling Basins. A settling basin, as described in this section, is an impoundment basin, clarifier, or other container that provides conditions conducive to allowing suspended particles to settle from a liquid by gravity. The slurry is introduced into the basin and settling of solids occurs as the slurry is introduced into the length of the basin. Flow out of the opposite end of the basin is reduced in its solids content.

The size of an impoundment basin or clarifier is ideally determined by dividing the critical settling velocity by the overflow rate. The critical settling velocity is a function of the diameter and specific gravity of the smallest particle size requiring removal and the viscosity of the water. However, ideal settling conditions are never achieved and the actual design of the required surface area must make allowance for turbulence, short circuiting, and scour velocity. Detailed procedures for sizing sedimentation basins can be found in EM 1110-2-501 (OCE 1978), TR D-78-10(Palermo et al. 1978), as well as most wastewater engineering handbooks.

Settled solids accumulate on the bottom of settling basins where they are temporarily stored. As the volume of accumulated solids increases, the effective size of the basin decreases, reducing the basin's effectiveness or efficiency. Accumulated solids must be periodically or continuously removed in order for the basin to perform as intended.

An impoundment basin is an earthen impoundment or diked area that is lined in a manner that is appropriate for protecting underlaying groundwater. An adjustable weir is provided to control overflow rate. A typical impoundment basin is illustrated in Fig. 4.7.

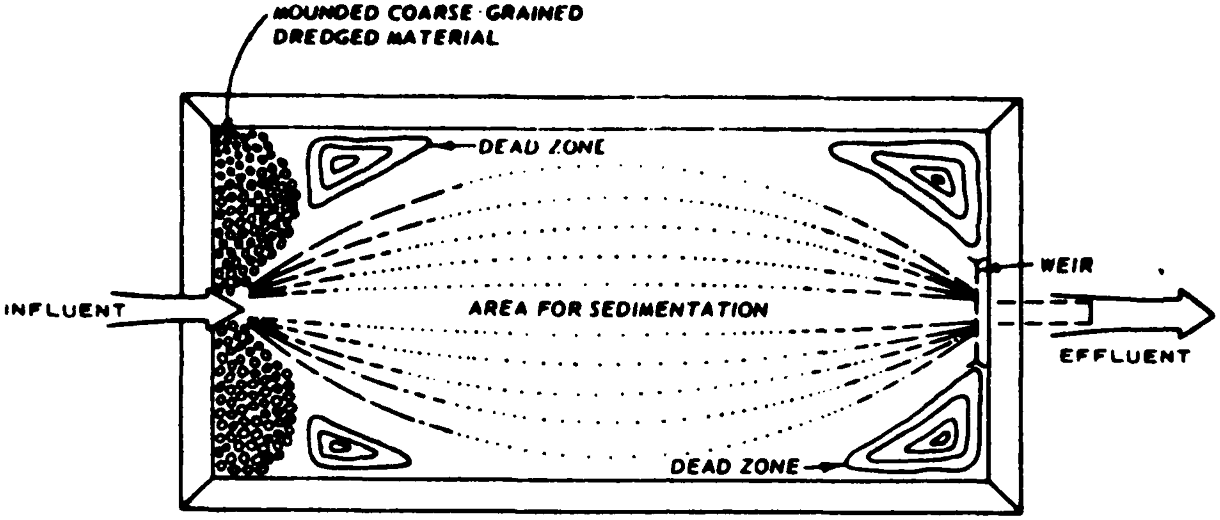
Multiple basins or a single basin separated into compartments by bulkheads can be used in parallel to allow continuous sediment/water separation while accumulated solids are being removed from individual basins. Multiple basins can also be connected in series in order to separate solids according to grain size. Each basin would be designed to retain sediments of increasingly smaller grain size.

Impoundment basins are used to remove particles in the size range of gravel down to fine silt (10 to 20 microns with flocculants) (Mallory and Nawrocki 1974). They are also used to provide temporary storage of dredged material and to classify sediment particles according to grain size.

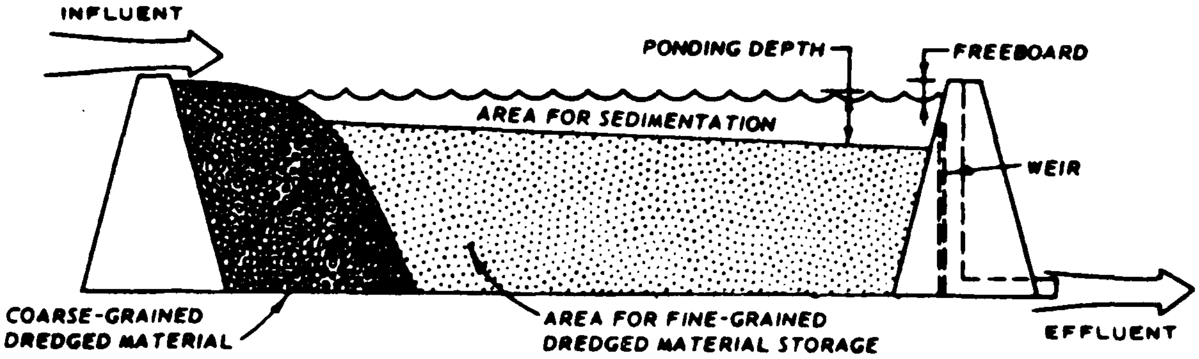
Impoundment basins are particularly well suited for large-scale dredging operations, provided there is adequate land space available for their construction. They are not suitable for congested areas or for areas where adequate measures cannot be taken to protect groundwater supplies (e.g., high groundwater table).

A major limitation with the use of impoundment basins is that, unlike clarifiers, they have no mechanism for solids collection. Therefore, mechanical dredges (e.g., clamshells, backhoes) are typically used to remove the settled solids if the basin is to be used on a continuous basis. This greatly increases the operational costs associated with use of impoundments.

Conventional clarifiers are rectangular or circular settling basins that are typically equipped with built-in solids collection and removal mechanisms. Typically, in a rectangular clarifier a flow with relatively high suspended solids is introduced at one end of the clarifier; solids settle along the



PLAN



CROSS SECTION

Figure 4.7. Typical impoundment basin

length of flow; and a flow with relatively low suspended solids leaves the clarifier through trough-type overflow weirs. In most rectangular clarifiers, flights extending the width of the tank move the sludge toward the effluent end of the tank, corresponding to the direction of flow of the density current. Circular clarifiers are of two general types. With the center-feed type, the waste is fed into a center well and the effluent is pulled off at the weir along the outside. With a peripheral-feed tank, the effluent is pulled off at the tank center.

Figure 4.8 illustrates a center-feed type clarifier. The circular clarifier can be designed for center sludge withdrawal or vacuum withdrawal over the entire tank bottom.

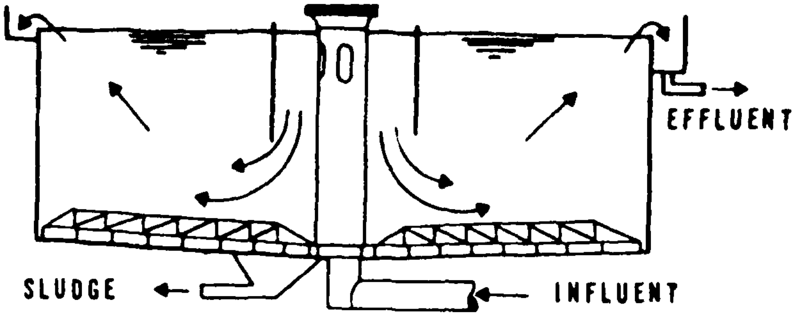
Many clarifiers are equipped with separate zones for chemical mixing and precipitation, flocculation, and settling.

Clarifiers are able to remove particles down to 10 to 20 microns (Mallory and Nawrocki 1974) in diameter, with the use of flocculants. They can also be used to produce a thickened sludge with a solids concentration of about 4 to 12 percent (Metcalf and Eddy 1979) and to separate solids by grain size. This would be accomplished by connecting clarifiers in series and providing a retention time sufficient to remove materials of a certain grain size.

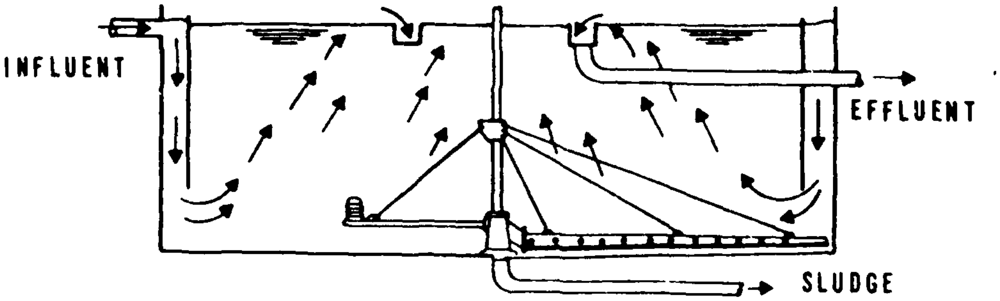
Clarifiers are best suited to small- to moderate-scale operations or to large-scale operations where impoundment basins will not adequately protect groundwater supplies. Clarifiers can be barge mounted for solids separation during dredging operations.

Circular clarifiers are generally more efficient in solids removal. However, rectangular tanks are more suitable for barge-mounting and where construction space is limited. In addition a series of rectangular tanks is cheaper to construct due to the shared wall concept.

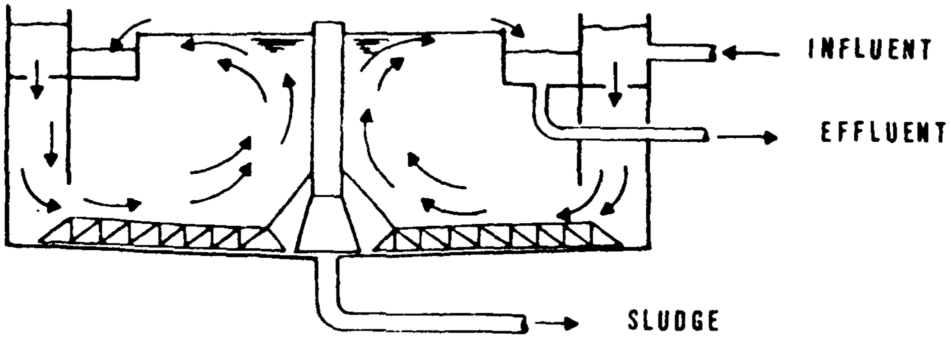
High-rate clarifiers use multiple stacked plates, tubes, or trays to increase the effective settling surface area of the clarifier and decrease the actual surface area needed to effect settling. Figure 4.9 illustrates a high-rate clarifier. High-rate clarifiers allow a higher flow rate per unit of actual surface area (loading rate) than do conventional clarifiers, thus the name "high-rate clarifiers." The trays, plates, or tubes also induce optimum hydraulic characteristics for sedimentation by guiding the flow, reducing short circuiting, and promoting better velocity distribution.



(a) CIRCULAR CENTER-FEED CLARIFIER WITH
A SCRAPER SLUDGE REMOVAL SYSTEM



(b) CIRCULAR RIM-FEED, CENTER TAKE-OFF CLARIFIER WITH A
HYDRAULIC SUCTION SLUDGE REMOVAL SYSTEM



(c) CIRCULAR RIM-FEED, RIM TAKE-OFF CLARIFIER

Figure 4.8. Typical clarifier design

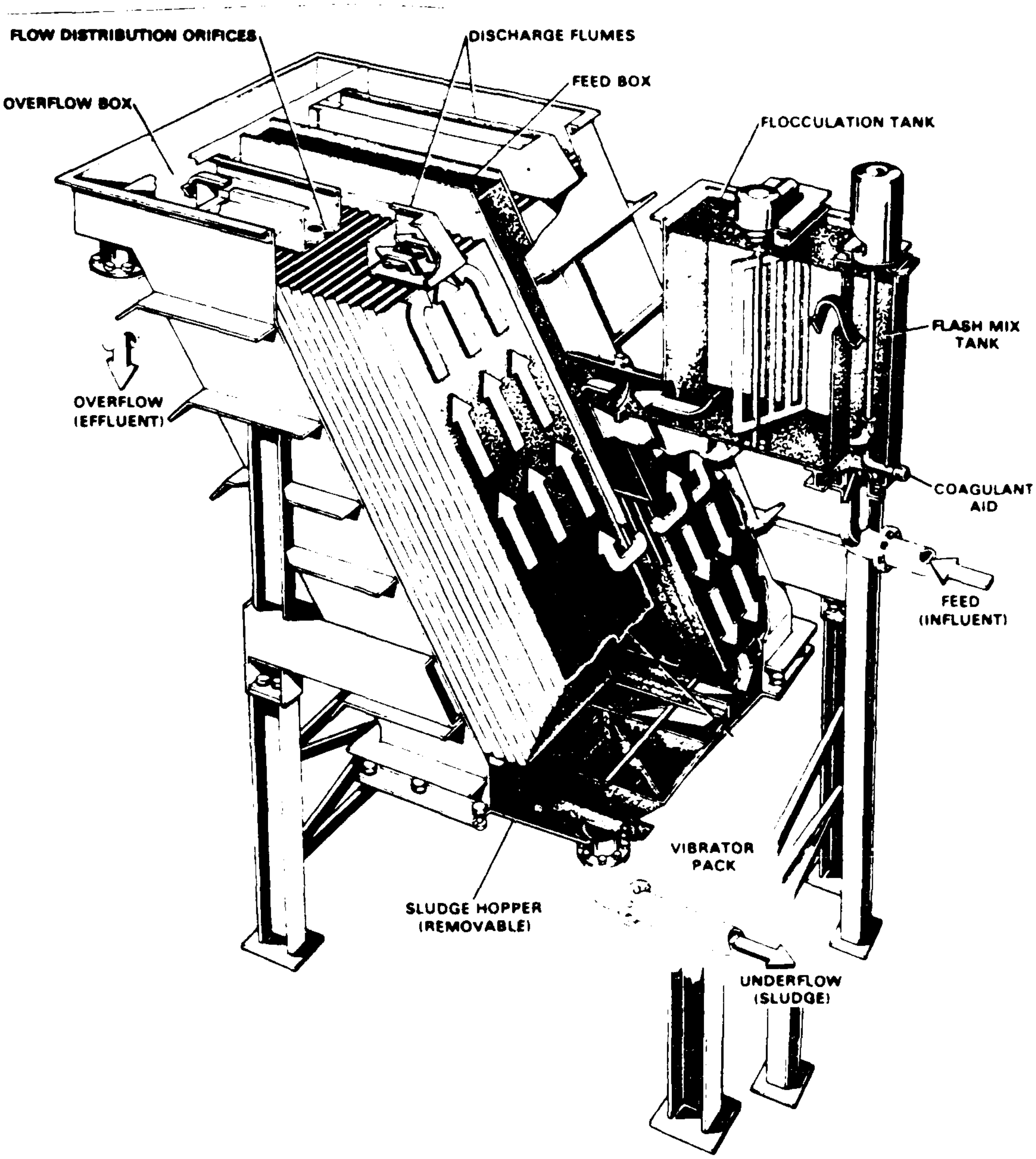


Figure 4.9. High-rate clarifier

High-rate clarifiers are able to handle between 2 to 10 times the loading rate of conventional clarifiers and therefore require limited land use (Jones et al. 1978). Package units capable of handling 1,000 to 2,000 gpm are available and are easily transportable by truck or barge.

High-rate clarifiers are best suited to small- to moderate-scale operations or to large-scale operations where construction of earthen impoundments will not adequately protect groundwater. High-rate clarifiers are particularly applicable to operations where land space is limited and where barge mounting of clarifiers is required.

High-rate clarifiers are not suitable for removal of particles larger than 0.1 in. or less than 10 microns. Use of high-rate gravity settlers has not been demonstrated for applications in solid/water separation, and they are generally used in applications with lower solids concentrations (Mallory and Nawrocki 1974). There is the possibility that cohesive sediment or soil may clog the channels, tubes, or plates (Jones et al. 1978).

Sedimentation employing impoundment basins and conventional clarifiers is a well-established technology for removing particles ranging in size from gravel down to fine silt. However, proper flocculation is essential to ensure removal of silt-sized particles. Sedimentation methods have not been widely employed for classifying solids according to particle size. They can be expected to be less effective in classifying solids than other methods described in this section (e.g., classifier, cyclones, and screens).

Impoundment basins have a high capital and operating cost unless solids are left in place. For this reasons their use is generally limited to large-scale operations. Impoundment basins also pose the greatest potential for secondary impacts of all solids separation methods; contaminants may leach into groundwater if the liner system is not properly designed and the large surface area of the impoundment can result in volatilization of contaminants and localized air pollution problems.

Both standard and high-rate clarifiers can be mounted on a barge in areas of limited space. High-rate clarifiers with their relatively small space requirements may be the only suitable sedimentation methods in congested areas. Clarifiers and impoundment basins are easy to operate and maintain.

Only impoundment basins have been used to treat dredged material slurries. There is some concern about the technical feasibility of using standard and high-rate clarifiers for direct treatment of dredged material slurry.

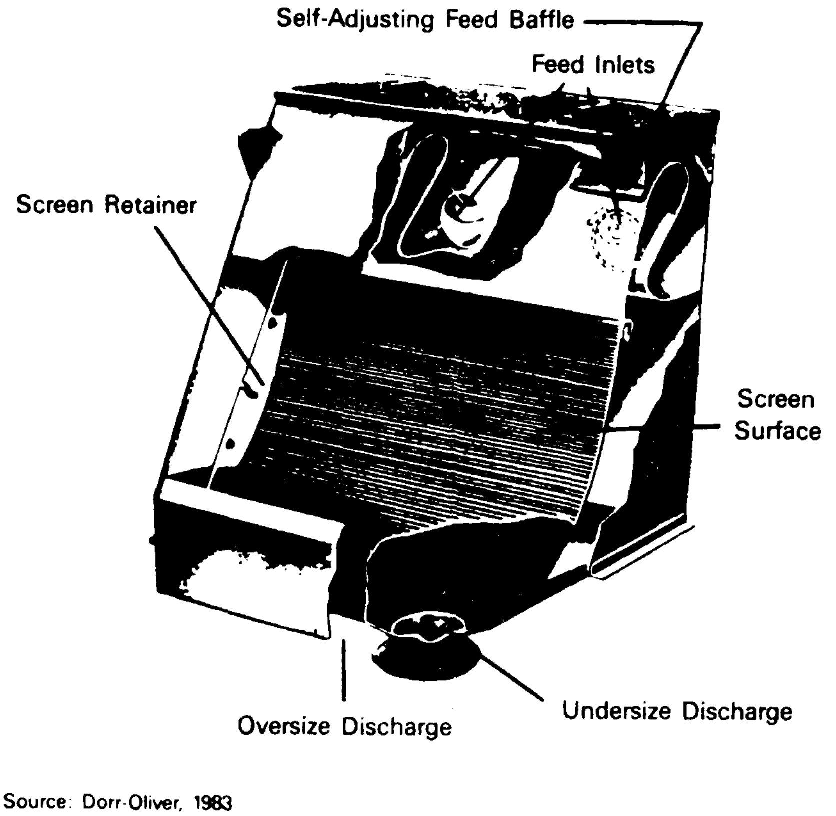
Stationary Screens and Sieves. Sieves or screens consist of bars, woven wire, or perforated-plate surfaces that retain particles of a desired size range while allowing smaller particles and the carrying liquid to pass through the openings in the screening surface. Several types of screens and sieves have application for solids separation at dredging or dredged material disposal sites.

Grizzlies consist of parallel bars that are frame-mounted on an angle to promote materials flow and separation. Hoppers are provided beneath the grizzly to collect removed material. Bar spacing is generally 1 to 5 in. apart depending upon the desired separation. Both fixed and vibrating grizzlies are available. Grizzlies generally have a maximum width of 6 to 9 ft and a length of 12 to 18 ft (Mallory and Nawrocki 1974).

Grizzlies are used primarily for scalping, i.e., removing a small amount of oversized material from a waste stream that is predominantly fines. They are generally limited to separating materials which are 2 in. in diameter or coarser. Another major function of the grizzly is to reduce velocity of a slurry for subsequent processing operations (Mallory and Nawrocki 1974).

Grizzlies offer a reliable method for removing coarse material from slurries. By doing so, they significantly improve the reliability and performance of subsequent solids separation methods and also reduce maintenance costs by minimizing the amount of abrasive material that reaches the screen, cyclone, etc. Grizzlies contain no moving parts and are tough and abrasion resistant. Therefore, maintenance requirements are minimal. Space requirements are also minimal, and they can be installed in almost any area. They can easily be arranged in series or parallel to accommodate very high flows or achieve classification of coarse materials.

Stationary or fixed screens differ from moving screens in that they have no moving parts. A continuously curved surface and the velocity of the slurry across the surface provide a centrifugal force that holds the slurry against the screens and allows for separation. One type of fixed screen which has potential application for solids separation from dredged material slurries is the wedge-bar screen. A typical wedge-bar screen is illustrated in Fig. 4.10. The hydrosieve, a modified wedge-bar screen that uses water pressure to encourage solids separation, is also used.



Source: Dorr-Oliver (1983)

Figure 4.10. Typical wedge-bar screen

The wedge-bar screen is similar in design to a grizzly insofar as it consists of parallel bars that are frame-mounted on a curved deck. However, in the case of the wedged-bar screen, bar spacing is very close to effect fine-particle separation. As the material enters the feed inlet, a series of baffles in the feed box spread the material so that the slurry is evenly fed over the width of the curved screen deck. The slurry flows through the feed inlet at the top of the feed box and flows tangentially down the surface of the screen. The continuously curved surface together with the velocity across the surface provides a centrifugal force that holds the slurry against the screen surface. As the slurry strikes the sharp edge of the wedge bar, small particles are sliced off and directed downward through the slots along with most of the liquid. Dewatered oversized material slides on top of the screen surface and is discharged. The slicing action of the wedge bars sizes the undersize particles at a smaller dimension than the slots themselves and helps to minimize blinding. For example, for a slot width of 1 mm, the thickness of the slurry layer being shaved off is about 1/4 mm. This 1/4 mm thick cut can transport particles of up to 1/2 mm in size; plus 1/2 mm solids pass over the screen (Hoffman-Muntner Corporation, 1978, Dorr-Oliver 1980, Dorr-Oliver 1983). Wedge-bar screens normally come in sizes of 2 to 6 ft wide, with capacities of 30 to 220 gpm/ft^2.

The hydrosieve is a modification of the conventional wedge-bar screen in which the pressure of a water spray encourages more efficient separation. The water pressure helps to remove fines that are adhering to coarse grain-sized materials and breaks up clumps of material that tend to clog the screen. Hydrosieves with capacities of up to 1500 gpm are available.

Wedge-bar screen and hydrosieves are used to separate particles in slurry by grain size. The wedge-bar screen is generally less efficient in separating solids than the vibrating screen; the oversized material typically carries a considerable amount of fines. The hydrosieve minimizes this problem by employing a pressure spray that washes the fines from the coarser material. Wedge-bar screens may be used ahead of vibrating screens. This provides a higher solids-separation efficiency than the vibrating screen alone (Allis Chalmers undated).

The wedge-bar screen offers a very low cost method for separating solids according to grain size. However, the effectiveness of the separation methods is not as good as that achieved using vibrating screens or cyclones. Nevertheless, use of a water spray with a wedge-bar screen (hydrosieve) can significantly improve separation efficiency by removing fines which are sorbed to sand and gravel. The wedge-bar screen contains no moving parts and is extremely easy to operate and maintain. It is also more resistant to abrasion than the vibrating screen. It is compact and requires a minimal amount of space.

Moving Screens. Screening of fine particles from dry material is frequently accomplished using moving screens. Types of moving screens include:

a. Vibrating screens.

b. Revolving screens.

c. Gyratory screens.

Vibrating screens are more widely used than other screen types, particularly for fine particle separation, because of their larger capacity per unit of screen area and their higher efficiency (Perry and Chilton 1973). Only the vibrating screen will be described in this section.

Vibrating screens consist of a plane screening surface, usually stretched tautly and set into a rectangular frame having sufficient sidewalls to confine the material flow. Figure 4.11 illustrates a typical vibrating screen. They may be composed of one, two or three screening decks. This allows for progressively finer separation and lower space requirements. Screens are usually inclined at a slope of approximately 20° from horizontal, although horizontal screens are also available. Vibration is produced by circular motion in a vertical plane. By vibration, the bed of material tends to develop a fluid state. Larger particles remain on top of the bed while smaller particles sift through the voids and find their way to the bottom. Once the fine particles have sifted through the bed of material, the vibrating action increases the probability that the small particles will pass through the screen. An inclined screen allows the material to cascade down the screen surface, increasing the probability that small particles will pass through (Allis Chalmers undated). Vibrating screens typically range in size from about 3 to 10 ft wide and 6 to 30 ft long. Solids handling capacity ranges from 300 to 950 tph.

The function of vibrating screens is to separate particles by grain size. The oversized particles are substantially dewatered during the separation. Typically, vibrating screens are used to separate materials in the size range of 1/8 in. up to 6 in. However, high-speed vibrating screens are also available for separating finer particles in the size range of 4 to 325 mesh (Chilton and Perry 1973, Mallory and Nawrocki 1974). Although separation efficiencies are high with the vibrating screen, some fine particles are invariably carried over with the coarse particles. Conventional vibrating screens are best suited for handling dry materials. Wet or sticky materials tend to blind the screen. Larger openings can be used where blinding is a problem, but this reduces the efficiency of the size separation. Vibrating screens with heated decks are also available to reduce moisture content, although they are not cost-effective for waste streams with a high moisture content. Because of these limitations, the conventional vibrating screens are not well suited for handling dredged material slurries. Where the moisture

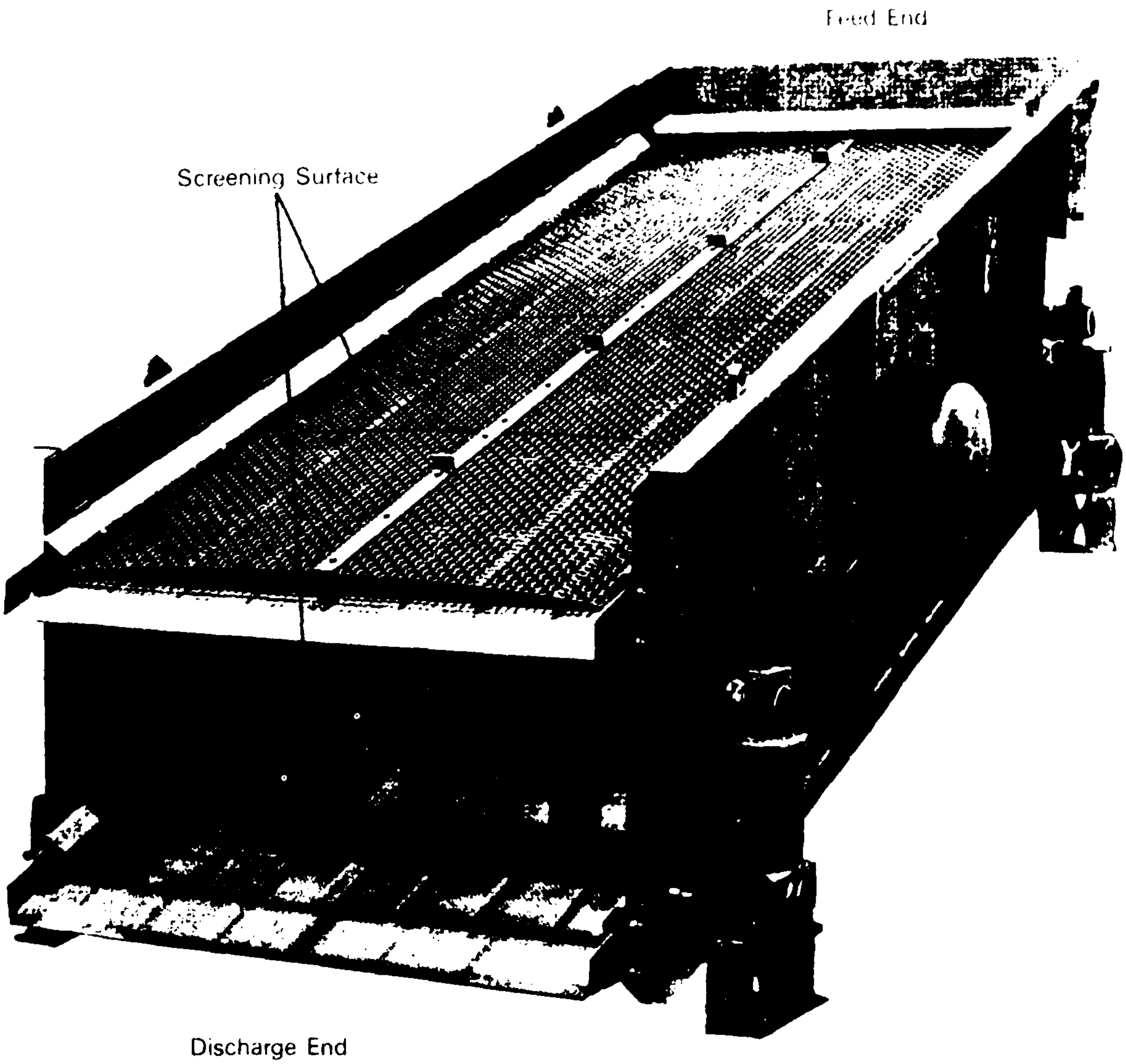


Figure 4.11. Typical vibrating screen

content of the material is high and would result in blinding, wet screening with sprays can be used. Water is generally sprayed at 3 to 6 gpm per ton at a minimum of 20 psi to discourage blinding (Allis Chalmers undated).

The presence of abrasive material in the feed may result in the need for frequent screen replacement, thereby increasing maintenance costs. Therefore, wastes should be carefully prescreened using a grizzly or wedge-bar screen.

Relative to other types of moving screens, vibrating screens generally are the most efficient and have the lowest space requirements and lowest maintenance costs. Vibrating screens are the most efficient of the moving screens for separating solids according to grain size. However, their reliability is adversely affected by the fact that wet or sticky material tends to blind the screen. A water spray applied to a vibrating screen can significantly reduce blinding. The effectiveness of vibrating screens should be determined on a case-by-case basis.

The presence of abrasive material can result in the need for frequent screen replacement, thereby increasing maintenance costs.

Vibrating screens are relatively compact. They can be installed in areas where space is limited and are well suited for use in mobile treatment systems.

Costs for vibrating screens vary with the size and capacity of the screens. The capital cost for a 10-ft long, 5-ft wide, 5-ft high screen with a capacity of 200 tph is about $25,000. Operation and maintenance costs for vibrating screens are relatively low compared to other types of moving screens.

Hydraulic Classifiers. Hydraulic classifiers are commonly used to separate sand and gravel from slurries and classify them according to grain size. A typical hydraulic classifier is shown in Fig. 4.12. These units consist of elevated rectangular tanks with v-shaped bottoms to collect the material. Discharge valves that are located along the bottom of the tank are activated by motor driven vanes that sense the level of solids as they accumulate. The principal of operation is simple. The slurry is introduced into the feed end of the tank. As the slurry flows to the opposite end, solids settle out according to particle size as a result of differences in settling velocity. Coarse materials settle out first near the feed end and materials are progressively finer along the length of the tank. Manually adjusted splitter gates below the discharge valves can be used to selectively direct materials of specific grain sizes to subsequent handling and treatment (Eagle Iron Works 1981, Mallory and Nawrocki 1974). Classifying tanks are generally available in sizes ranging from 8 to 12 ft wide and 20 to 48 ft long (Mallory and Nawrocki 1974). Solids handling capabilities are generally limited to 250 to 350 tph (Mallory and Nawrocki 1974, Eagle Iron Works 1981).

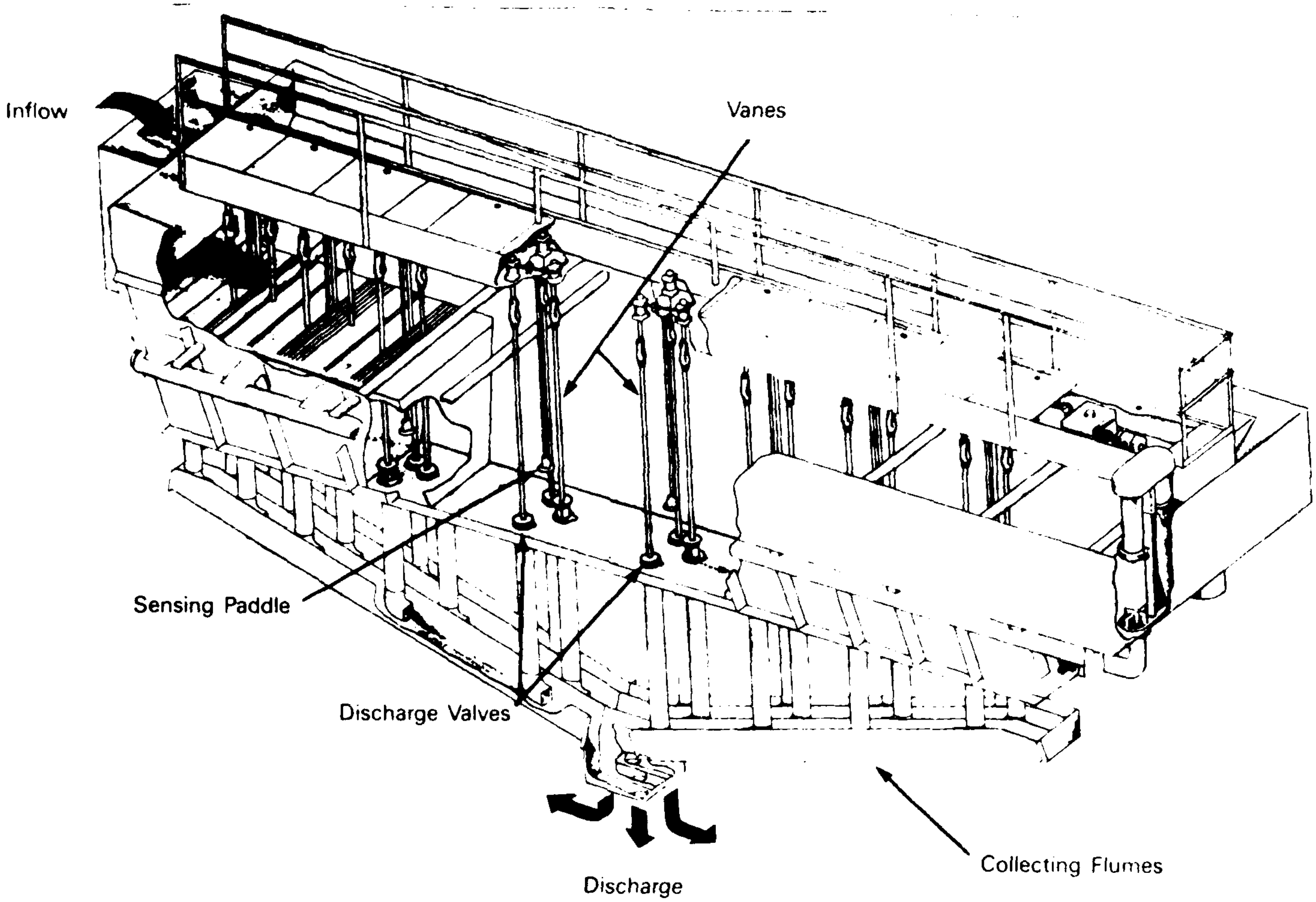


Figure 4.12. Typical hydraulic classifier

Hydraulic classifiers are used to remove sand- and gravel-size particles from slurries and to classify the removed materials according to grain size. Materials are recovered from the classifier at about 30 percent moisture content (USEPA 1985). They are capable of removing and classifying materials within the size range of 3/8 in down to about 150 to 200 mesh (105 to 74 microns) (Mallory and Nawrocki 1974, Eagle Iron Works 1981). The upper limitation of 3/8 in. is handled by prescreening the wastes to remove all large materials. Other solids separation techniques are required to classify the fine-grained materials (<200 mesh). Another limitation is that some fines will be removed with the sand and gravel fraction. This limitation is frequently overcome by directing the solids to a spiral classifier where they are washed to remove the fine-grained materials. Hydraulic classifiers have a relatively low solids handling capacity and are not well suited for handling large volumes of flow or high-solids concentrations. A single average sized tank with dimensions of 36 ft by 10 ft, for example, can handle 5300 gpm when separating material down to 100 mesh and only 1400 gpm when separating material down to 200 mesh (Eagle Iron Works 1981).

Because of the inability of hydraulic classifiers to handle large volumes of flow, a combination of solids separation methods may be advisable to reduce the number of hydraulic classifiers needed for a large solids handling operation. One possibility for reducing the number of classifiers needed would be to use these units to separate only those particles larger than 105 microns. Cyclones, hydrocyclones, or hydrosieves could then be used to remove the fine sand fraction (Mallory and Nawrocki 1974).

Hydraulic classifiers offer an effective method for operating and classifying particles ranging in size from fine gravel to fine sand. Some fines are inadvertently removed with the sand and gravel, and the effectiveness of the separation can be improved by washing the collected solids in a spiral classifier to remove the fines.

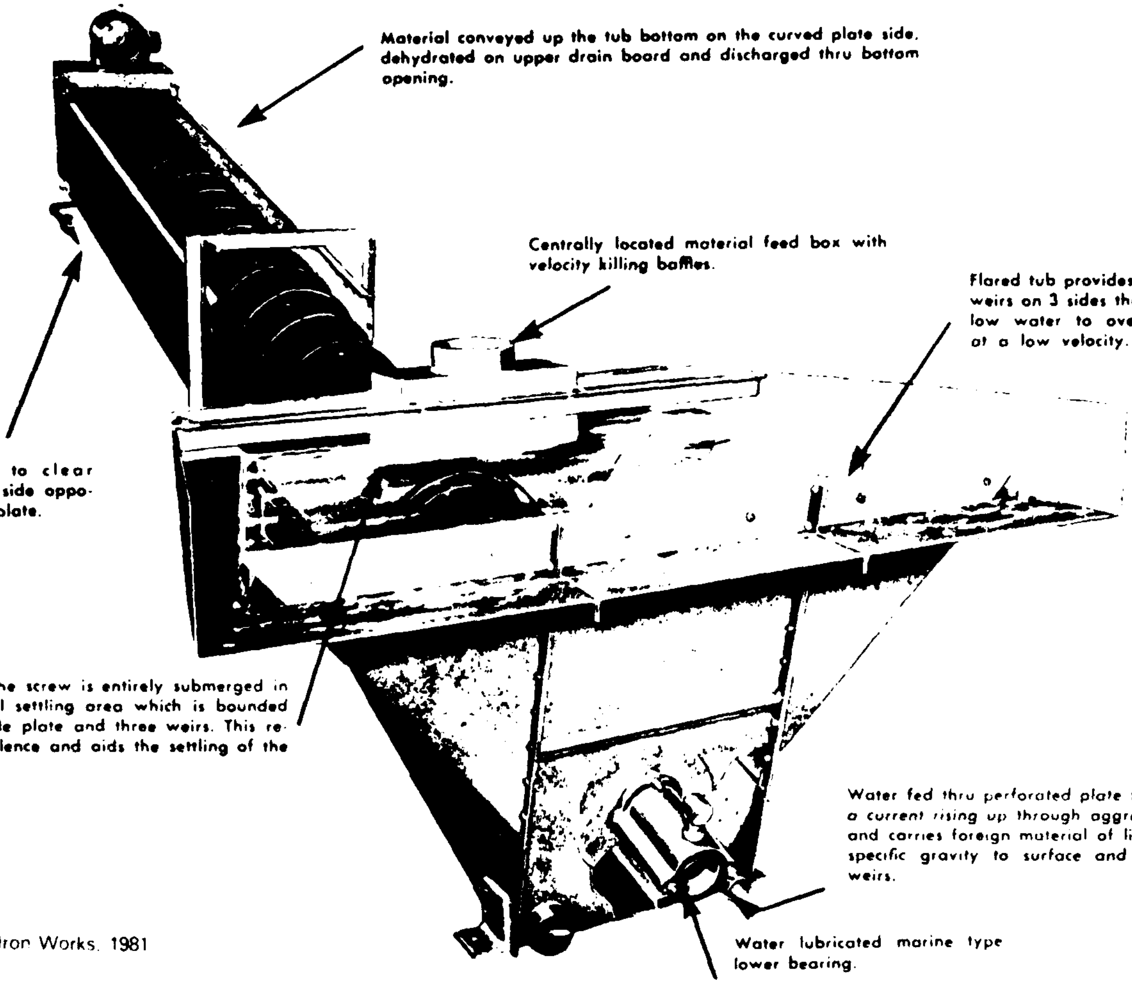
Hydraulic classifier tanks are generally designed and sized to be truck mounted for mobile system applications. Start-up and shut-down can be accomplished quickly. Maintenance requirements are fairly simple.

Use of hydraulic classifiers can be easily integrated with other solids separation methods and this is advisable where large flows are involved or where classification of fine-grained materials (clay, silt, is required.

Costs for hydraulic classifiers vary with size and capacity of the classifier. For a size range of 24 to 49 ft long, 8 to 12 ft wide, and 8 ft deep; and a feed rate of 200 to 350 tph, the initial cost ranges from $30,000 to $76,000 (Eagle Iron Works 1981, Mallory and Nawrocki 1974).

Spiral Classifiers. The spiral classifier consists of one or two long rotating screws mounted on an incline within a rectangularly shaped tub. It is used primarily to wash adhering clay and silt from sand and gravel fractions. Figure 4.13 shows a typical configuration of a spiral classifier.

The screw conveys settled solids from a hydraulic classifier up an incline to be discharged through an opening at the top of the tub. Fines and materials of low specific gravity are separated from sand and gravel through agitation and the abrading and washing action of the screw, and they are



Material conveyed up the tub bottom on the curved plate side, dehydrated on upper drain board and discharged thru bottom opening.

Centrally located material feed box with velocity killing baffles.

Flared tub provides long weirs on 3 sides that allow water to overflow at a low velocity.

Flushing water to clear drain trough on side opposite the curved plate.

Note that the screw is entirely submerged in the material settling area which is bounded by the baffle plate and three weirs. This reduces turbulence and aids the settling of the aggregate.

Water fed thru perforated plate forms a current rising up through aggregate and carries foreign material of lighter specific gravity to surface and over weirs.

Water lubricated marine type lower bearing.

Source: Eagle Iron Works, 1981

Figure 4.13 Typical spiral classifier

removed along with the wastewater overflow at the bottom of the tub. The tumbling and rolling action caused by the continuous screw grinds particles against each other and removes any deleterious material coating the sand particles. This tumbling action also aids in dewatering materials by breaking the moisture film on the sand particles. As the moisture is relieved of surface tension, it is free to drain from the material (Eagle Iron Works 1982). The sand that is finally discharged is substantially dewatered.

In general, the greater the length of the tub, the higher the degree of dewatering, and the greater the screw diameter, the larger the capacity of the spiral classifier (Eagle Iron Works 1982). Classifiers are available which are capable of handling up to 950 tph.

Spiral classifiers are used primarily to wash, dewater, and classify sand and gravel up to 3/8 in. in diameter. They are not a singularly viable solids separation technology, but they are effective when used together with the hydraulic classifier. Spiral classifiers have a large capacity and are completely portable.

Spiral classifiers improve the efficiency of solids separation achieved with the hydraulic classifier by removing fine-grained materials attached to coarser particles.

Spiral classifiers are generally designed to be mounted on trailers for easy transport and use in mobile systems. Start-up and shut-down can be accomplished quickly, and maintenance requirements are simple.

Costs for spiral classifiers vary with size and configuration. For a size range of 22 to 34 ft long, 8 to 19 ft wide, and 8 to 12 ft high, the initial costs of a spiral classifier ranges from $14,000 to $77,000 for a single-screw type and from $37,000 to $150,000 for a double-screw type. Operational and maintenance costs vary with the type of power utilized; it can be electricity, gas, or diesel fuel (Eagle Iron Works 1982, Mallory and Nawrocki 1974).

Cyclones and Hydrocyclones. Cyclones and hydrocyclones are separation devices in which solids that are heavier than water are separated by centrifugal force. The major components of a hydrocyclone are shown in Fig. 4.14. A hydrocyclone consists of a cylindrical/conical shell with a tangential inlet for feed, an outlet for the overflow of slurry, and an outlet for the underflow of concentrated solids. Cyclones and hydrocyclones contain no moving parts. The slurry is fed to the unit with sufficient velocity to create a vortex action that forces the slurry into a spiral and, as the rapidly rotating liquid spins about the axis, smaller-sized particles remain suspended in the liquid and are discharged through the overflow outlet. Larger and heavier particles of solids are forced outward against the wall of the cone by centrifugal force within the vortex. The solids spiral around the wall of the cyclone and exit through the apex at the bottom of the cone (Dorr-Oliver 1984).

Cyclones are available in an extremely wide range of sizes. The smallest units handle flows of only a few gallons per minute, while the largest units

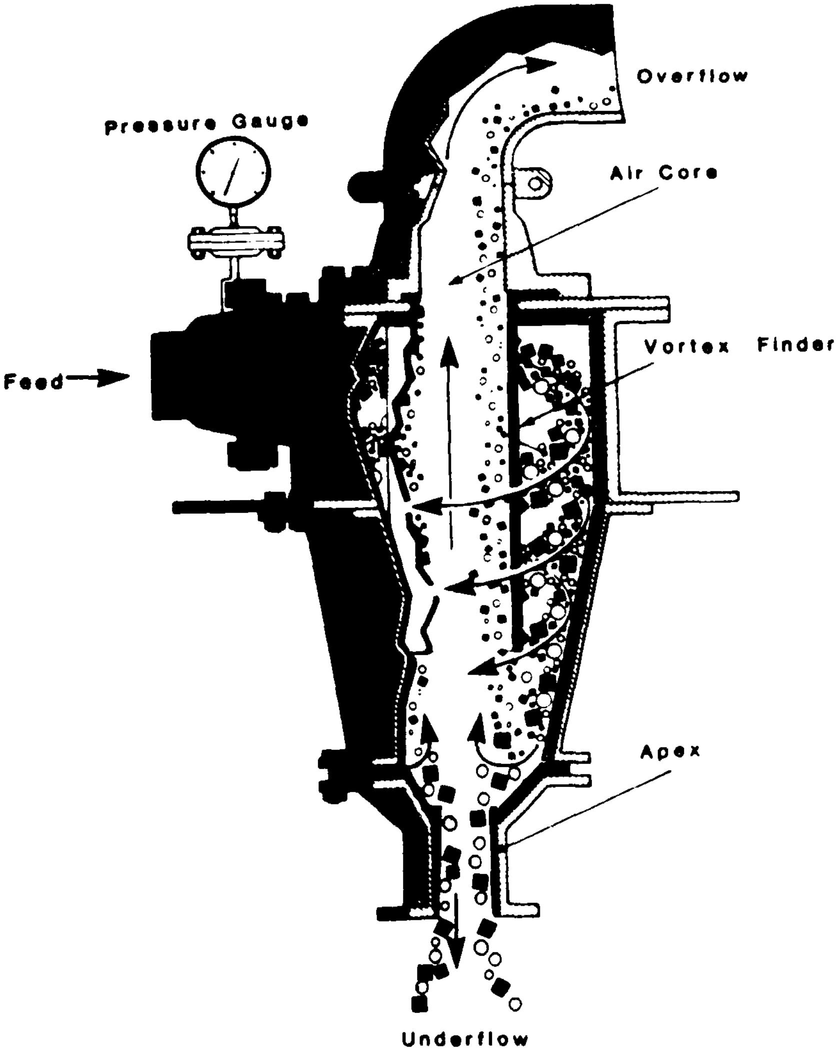


Figure 4.14. Typical cyclone

can handle between 2000 and 7000 gpm, depending upon slurry composition (Dorr-Oliver 1984, Krebs Engineers undated). However, cyclones do not scale-up as many other equipment types do. In general, the larger the cyclone diameter and inlet, the coarser the separation and the greater the cyclone capacity, and the smaller the diameter and inlet, the finer the separation and the lower the hydraulic capacity. In order to remove small particles from large volume slurries, it is necessary to use multiple small-diameter cyclones connected in parallel. Banks of multiple cyclones, manufactured as a single unit with a single feed pipe, are commercially available.

Cyclones can also be connected in series or in various staging arrangements to accomplish different objectives. For example, a high degree of particle size separation can be achieved by employing a bank of cyclones in series with decreasing cyclone size and particle size removal in the direction of flow. It is also possible to achieve a higher underflow concentration and a more clarified overflow by staging the cyclones. The first stage of cyclones could be used to classify the solids according to the designed grain size. The second-stage overflow cyclone could serve as a clarifier, and the underflow cyclone could serve as the concentrator. However, the maximum underflow concentration achievable with cyclones is about 60 percent, since some liquid is necessary for solids discharge (Dorr-Oliver undated).

It should be noted that cyclones are available that can handle some variation in flow rate and particle size by interchanging certain parts of the cyclone. For example, it is possible to add or delete sections to the cone or to change the size of the vortex finder.

Cyclones are available for separating or classifying solids over a broad particle size range, from 2000 microns down to 10 microns. However, for treating dredge material slurries, they would be used primarily to remove smaller size particles from slurries and in situations where a sharp separation by particle size is needed. They are particularly applicable to situations where space is limited.

Cyclones are generally not effective for slurries with a solids concentration greater than 30 percent, for highly viscous slurries, or for separation of particle sizes with a specific gravity of less than about 2.5 to 3.2 (Krebs Engineers undated). Slurries with a high clay content exhibit high pseudoplasticity or high viscosity and cannot be effectively removed using cyclones or hydrocyclones (Oklahoma State University 1973).

Cyclones are highly vulnerable to clogging by oversized particles, and a high degree of prescreening (or use of progressively smaller cyclones in series) may be needed to avert clogging.

Cyclones offer an effective means of separating and classifying solids over a broad range of particle size, provided the solids concentration is not too high and the slurry is not too viscous. Cyclones are flexible insofar as they can easily be arranged in parallel to accomplish fine size separation or in various series or staging arrangements to improve classification of the overflow or concentration of the underflow. They can also be easily integrated with other solids separation methods. However, each individual cyclones is capable of handling only very limited variations in flow rate and particle size.

The capital and operating costs of cyclones are relatively low. They are simple to operate and easy to maintain since they contain no moving parts. Liners require periodic replacement but this can be done easily.

Cyclone assemblies take up less space than most solids-separation equipment and are well suited for tight locations. Because of their compactness and simplicity of operation, cyclones are also well suited for inclusion in mobile treatment systems.

The cost of cyclones varies widely according to the size and the number of cyclones placed in series. The feed rate can vary from a few gallons per minute up to several thousand gallons per minute, and the size of each cyclone can vary from 1/2 in. to 30 in. in diameter. Initial costs for cyclones can be as low as $5,000 or indefinitely high, depending on the configuration (Hoffman Muntnor Corp. 1978; Krebs Engineers undated).

Solidification/Stabilization

Solidification and stabilization are terms which are used to describe treatment which accomplishes one or more of the following objectives (USEPA 1982b):

a. Improves waste handling or other physical characteristics of the waste.

b. Decreases the surface area across which transfer or loss of contained pollutants can occur.

c. Limits the solubility or toxicity of hazardous waste constituents.

Solidification is used to describe processes where these results are obtained primarily, but not exclusively, by production of a monolithic block of waste with high structural integrity. The contaminants do not necessarily interact chemically with the solidification reagents, but are mechanically locked within the solidified matrix. Contaminant loss is minimized by reducing the surface area. Stabilization methods usually involve the addition of materials that limit the solubility or mobility of waste constituents even though the physical handling characteristics of the waste may not be improved

(USEPA 1982b, Cullinane and Jones 1985). Methods involving combinations of solidification and stabilization techniques are often used.

Solidification/stabilization methods can be categorized as follows:

a. Cement solidification.

b. Silicate-based processes.

c. Sorbent materials.

d. Thermoplastic techniques.

e. Surface encapsulation.

f. Organic polymer processes.

g. Vitrification.

Detailed discussions of solidification/stabilization methods can be found in Guide to the Disposal of Chemically Stabilized and Solidified Waste (USEPA 1982b) and Technical Handbook for Solidification/Stabilization of Hazardous Waste (Cullinane and Jones 1985).

These documents should be consulted for detailed information on these processes. However, it should be noted that the state-of-the-art of solidification/stabilization methods is advancing rapidly. Many manufactures are marketing processes which involve the use of various combinations of alkaline earth materials (e.g., lime, cement kiln dust, silicaceous materials, cement) often together with organic polymers and proprietary chemicals.

Cement solidification involves mixing the wastes directly with Portland cement, a very common construction material. The waste is incorporated into the rigid matrix of the hardened concrete. Most solidification is done with Type I Portland cement, but Types II and V can be used for sulfate or sulfite wastes. This method physically or chemically solidifies the wastes, depending upon waste characteristics (USEPA 1982b). The end product may be a standing monolithic solid or may have a crumbly soil-like consistency, depending upon the amount of cement added.

Most contaminated sediment slurried in water can be mixed directly with cement, and the suspended solids will be incorporated into the rigid matrix. Although cement can physically incorporate a broad range of waste types, most wastes will not be chemically bound and are subject to leaching.

Cement solidification is most suitable for immobilizing metals because at the pH of the cement mixture, most multivalent cations are converted into insoluble hydroxides or carbonates. However, metal hydroxides and carbonates are insoluble only over a narrow pH range and are subject to solubilization and leaching in the presence of even mildly acidic leaching solutions (e.g., rain). Portland cement alone is also not generally effective in immobilizing organics.

The end product of cement solidification may not be acceptable for disposal without secondary containment regardless of whether the wastes are organic or inorganic in nature. Another major disadvantage is that cement-based solidification results in wastes that are twice the weight and volume of the original material, thereby increasing transportation and disposal costs (USEPA 1982b). Because of these limitation, Portland cement is generally used only as a setting agent in other solidification processes, particularly the silicate-based processes.

Another problem with cement solidification is that certain contaminants can cause problems with the set, cure, and permanence of the cement waste solid unless the wastes are pretreated. Some of these incompatible wastes are (USEPA 1982b):

a. Sodium salts of arsenate, borate, phosphate, iodate, and sulfide.
b. Salts of magnesium, tin, zinc, copper, and lead.
c. Organic matter.
d. Some silt and clay.
e. Coal or lignite.

Major advantages to the use of cement include its relatively low cost and the use of readily available mixing equipment.

Cement costs range from $60 to $90 per ton at the mill. However, capital expenditure and transportation will vary widely depending on the site and the waste. Cost information for specific wastes should be obtained from vendors.

Silicate-based processes refer to a very broad range of solidification/stabilization methods that use a siliceous material together with lime, cement, gypsum, and other suitable setting agents. Extensive research is currently underway on the use of siliceous compounds in solidification. Many of the available processes use proprietary additives and claim to stabilize a broad range of compounds from divalent metals to organic solvents. The basic reaction is between the silicate material and polyvalent metal ions. The silicate material that is added in the waste may be fly ash, blast furnace slag, or other readily available pozzolanic materials. Soluble silicates such as sodium silicate or potassium silicate are also used. The polyvalent metal ions that act as initiators of silicate precipitation and/or gelation [illegible] either from the waste solution or the added setting agent, or both. The setting agent should have low solubility and a large reserve capacity of metallic ions so that it controls the reaction rate. Portland cement and lime are most commonly used because of their good availability. However, gypsum, calcium carbonate, and other compounds containing aluminum, iron, magnesium, etc. are also suitable setting agents. The solid that is formed in these processes varies from a moist claylike material to a hard dry solid similar in appearance to concrete.

Some of the additives used in silicate-based processes include (Cullinane and Jones 1985):

a. Selected clays to absorb liquid and bind specific anions and cations.

b. Emulsifiers and surfactants that allow the incorporation of immiscible organic liquids.

c. Proprietary absorbents that selectively bind specific wastes. These materials may include carbon, zeolite materials, and cellulosic sorbents.

There are a number of silicate-based processes that are currently available or in the research stages. Manufacturers' claims differ significantly in terms of the capabilities of these process for stabilizing different wastes constituents. A number of these processes are described below.

The Chemfix process uses soluble silicates with cement as the setting agent. Research data shows that the process can stabilize sludges containing high concentrations of heavy metals even under very acidic conditions (Spencer et al. 1982).

The Envirosafe I process uses fly ash as the source of silicates and lime as the alkaline earth material. This method has been shown to stabilize oil bearing sludge (49% oil and grease) and neutralize inorganic metal sludge. Success was demonstrated by use of compressive strength tests (using ASTM methods) and leach tests (Smith and Zenobia 1982).

The DCM cement shale silicate process is a proprietary process formulated by Delaware Custom Material, Inc., State College, PA. It involves use of cement, and emulsifier for oily wastes, and sodium silicate. Testing by Brookhaven National Laboratories showed that the process could stabilize oily wastes with up to a [illegible] percent volumetric loading (Clark et al. 1982). Manufacturers claim that the process can be used to solidify wastes containing acids, organic solvents and oils (Hayes and Granlund, undated).

PQ Corporation of Lafayette Hill, Pennsylvania, has done extensive research on the use of silicates. Their research describes successful stabilization of a mixed heavy metal/organic sludge; a waste containing high levels of organics and petroleum by-products; and a waste containing organic solvents using modifications of the process that involves the use of sodium silicates (Spencer, et al. 1982).

There is considerable research data to suggest that silicates used together with lime, cement, or other setting agents can stabilize a wide range of materials including metals, waste oil, and solvents. However, the feasibility of using silicates for any application must be determined on a site-specific basis particularly in view of the large number of additives and different sources of silicates that may be used. Soluble silicates such as sodium and potassium silicate are generally more effective than fly ash, blast furnace slag, etc.

There is some data to suggest that lime-fly ash materials are less durable and stable to leaching that cement-fly ash materials (Cullinane and Jones 1985).

Common problems with lime-fly ash and cement-fly ash materials relate to interference in cementitious reactions that prevent bonding of materials. Materials such as sodium borate, calcium sulfate, potassium dichromate, and carbohydrates can interfere with the formation of bonds between calcium silicate and aluminum hydrates. Oil and grease can also interfere with bonding by coating waste particles (Cullinane and Jones 1985). However, several types of oily sludges have been stabilized with silicate-based processes.

One of the major limitations with silicate-based processes is that a large amount of water which is not chemically bound will remain in the solid after solidification. In open air, the liquid will leach until it comes to some equilibrium moisture content with the surrounding soil. Because of this water loss, the solidified product is likely to require secondary containment.

Silicate-based processes can employ a wide range of materials, from those which are cheap and readily available to highly specialized and costly additives. The services of a qualified firm are generally needed to determine the most appropriate formulation for a specific waste type.

Commercial cement mixing and handling equipment can generally be used for silicate-based processes. Equipment requirements include chemical storage hoppers, weight or volume-based chemical-feed equipment, mixing equipment, and waste-handling equipment. Ribbon blenders and single- and double-shaft mixers can be used for mixing. A number of mobile trailer-mounted systems are available.

Solidification can also be accomplished in situ using a lagoon or mixing pit. This would involve the use of common construction machinery such as a backhoe or pull shovel to mix the waste and reagents. However, the ability of in-situ solidification to prevent leaching of contaminants would need to be demonstrated on a case-by-case basis.

No costs for the solidification/stabilization of dredged material are available. It should be emphasized that actual costs are highly waste and site specific and that specific site and/or waste characteristics could change these cost estimates by several fold.

Sorbents include a variety of natural and synthetic solid materials that are used to eliminate free liquid and improve the handling characteristics of wastes. Commonly used natural sorbent materials include fly ash, kiln dust, vermiculite, and bentonite. Synthetic sorbent materials include activated carbon that sorbs dissolved organics; Hazorb (product of Dow Chemical), which sorbs water and organics; and Locksorb (product of Radecca Corp.), which is reportedly effective for all emulsions (Cullinane and Jones 1985).

Sorbents are widely used to remove free liquid and improve material handling. Some sorbents have been used to limit the escape of volatile organic compounds. They may also be useful in waste containment when they modify the chemical environment and maintain the pH and redox potential to limit the solubility of wastes (Cullinane and Jones 1985). Although sorbents prevent drainage of free water, they do not necessarily prevent leaching of contaminants, and secondary containment is generally required.

The quantity of sorbent material necessary for removing free liquid varies widely depending on the nature of the liquid phase, the solids content of the waste, the moisture level in the sorbent, and the availability of any chemical reactions that take up liquids during reaction. It is generally necessary to determine the quantity of sorbent needed on a case-specific basis.

Sorbents have not been used for immobilization of contaminants in dredged material. There are no costs available for this application.

Thermoplastic solidification involves sealing wastes in a matrix such as asphalt bitumen, paraffin, or polyethylene. The waste is dried, heated, and dispensed through a heated plastic matrix. The mixture is then cooled to form a rigid but deformable solid. Bitumen solidification is the most widely used of the thermoplastic techniques.

Thermoplastic solidification involving the use of an asphalt binder is most suitable for heavy metal or electroplating wastes. Relative to the cement solidification, the increase in volume is significantly less and the rate of leaching significantly lower. Also, thermoplastics are little affected by either water or microbial attack.

High equipment and energy costs are principal disadvantages of thermoplastic solidification. Another problem is that the plasticity of the matrix-waste mixture generally requires that containers be provided for transporation and disposal of materials which greatly increases the cost.

Thermoplastic solidification requires specialty equipment and highly trained operators to heat and mix the wastes and solidifier. The common range of operating temperatures is 130 to 230°C. The energy intensity of the operation is increased by the requirement that the waste be thoroughly dried before solidification. Therefore, thermoplastic solidification is not practical for dredged material.

Surface encapsulation describes those methods that physically micro or macroencapsulate wastes by sealing them in an organic binder or resin. Surface encapsulation can be accomplished using a variety of approaches. Three methods which have been the subject of considerable research.

One process involves the microencapsulation of wastes with polyethylene and forming the waste into a block jacketed by high-density polyethylene. Another simpler approach is to load the contaminated soil into a high-density polyethylene overpack. Another process involves the use of an organic binder to seal a cement-solidified mass.

Encapsulation processes are extremely expensive, estimated between $80 and $100/ton and are not believed to be economical for application to dredged material.

Vitrification of wastes involves combining the wastes with molten glass at a temperature of 1,350°C or greater. However, the encapsulation might be done at temperatures significantly below 1,350°C (a simple glass polymer such as boric acid can be poured at 850°C). This melt is then cooled into a stable noncrystalline solid (USEPA 1982b).

This process is quite costly and so has been restricted to radioactive or very highly toxic wastes. To be considered for vitrification, the wastes should be either stable or totally destroyed by the process temperature.

Of all the common solidification methods, vitrification offers the greatest degree of containment. Most resultant solids have an extremely low leach rate. Some glasses, such as borate-based glasses, have high leach rates and exhibit some water solubility. The high energy demand and requirements for specialized equipment and trained personnel greatly limit the use of this method.

Glassification of wastes is an extremely energy-intensive operation and requires sophisticated machinery and highly trained personnel. No cost information was available for glassification.

Evaluation of the technical feasibility and effectiveness of solidification/stabilization methods must be determined on a case-by-case basis. Commercial firms specializing in these processes should be consulted whenever solidification/stabilization is being considered. Samples of the solidified product will need to be subjected to extensive leaching tests unless a reliable, effective means of secondary containment is to be used. It should be noted that secondary containment is recommended with most of the previously described methods (except microencapsulation and glassification for some waste types). Similarly, where the end product is intended to be a monolithic block, samples must be subjected to compressive strength tests.

Solidification/stabilization methods run the gamut from those that use simple, safe, readily available equipment (cement and most silicate-based processes) to those that require highly sophisticated, costly, and specialized equipment (e.g., glassification and thermoplastic techniques). Use of these high technology processes should be limited to wastes that cannot be treated cost effectively using any other methods. Regardless of the simplicity of some of the equipment, professionals trained in these processes should be consulted since formulations including proprietary additives are very waste specific.

Solidification/stabilization methods have not been applied on a large scale to immobilization of contaminants in dredged material slurries. Myers ([illegible]) has performed laboratory-scale studies using cement and pozzolan based technology for stabilization of dredged material solids following dewatering.

Thermal Destruction Processes

Thermal destruction is a treatment method that uses high temperature oxidation under controlled conditions to degrade a substance into products that generally include CO_2, H_2O vapor, SO_2, NO_x, HCl gases and ash. The hazardous products of the thermal destruction/incineration such as particulates, SO_2, NO_x, HCl, and products of incomplete combustion require air pollution control equipment to prevent release of undesirable species into the atmosphere. Thermal destruction methods can be used to destroy organic contaminants in liquid, gaseous, and solid streams.

The most common incineration technologies applicable to the treatment of dredged material slurries include: liquid injection, rotary kiln, fluidized bed, and multiple hearth. Of these, only the rotary kiln, fluidized bed, and multiple-hearth technologies have any possible application for the treatment of dredged material slurries. The operating principles and general application of these technologies are summarized in Table 4.13.

Emerging technologies for the thermal destruction of wastes include (Monsanto Research Corp. 1981, Keitz and Lee 1983, Lee 1983, State of California 1981): molten salt, wet air oxidation, plasma arch torch, circulating bed, high-temperature fluid wall, pyrolysis, supercritical water, advanced electric reactor, and vertical tube reactor. These technologies are not applicable to the treatment of dredged material slurries at this time.

Because of the cost of incineration and the extremely low fuel value of most dredged material slurries, it is doubtful that thermal destruction technologies would ever be an economically viable option for treating dredged material slurries. However, projects involving small volumes of highly contaminated material may be candidates for application of thermal destruction technologies. Therefore, the three most applicable technologies are briefly discussed below.

Rotary Kiln. Rotary kilns are capable of handling a wide variety of solid and liquid wastes including contaminated sediment. Rotary kiln incinerators are cylindrical refractory-lined shells. They are fueled by natural gas, oil, or pulverized coal. Most of the heating of the waste is due to heat transfer with the combustion product gases and the walls of the kiln. The basic type of rotary kiln incinerator, illustrated in Fig 4.15, consists of the kiln and an afterburner (Kiang and Metry 1982).

Table 4.13

Summary of Commonly Used Incineration Technologies*

Type	Process Principle	Application	Combustion Temperature °F	Residence Time
Rotary kilns	Waste is burned in a rotating refractory-lined cylinder	Any combustible solid, liquid, or gas	1500-3000	Seconds for gases to hours for liquids and solids
Multiple hearth	Wastes descend through several grates to be burned in increasingly hotter combustion zones	Sludges and granulated solid wastes	1400-1800	Up to several hours
Fluidized-bed	Waste is injected into an agitated bed of heated inert particles. Heat is efficiently transferred to the wastes during combustion	Organic liquids, gases and granular or well processed solids	1400-1600	Seconds for gases and liquids, minutes for solids

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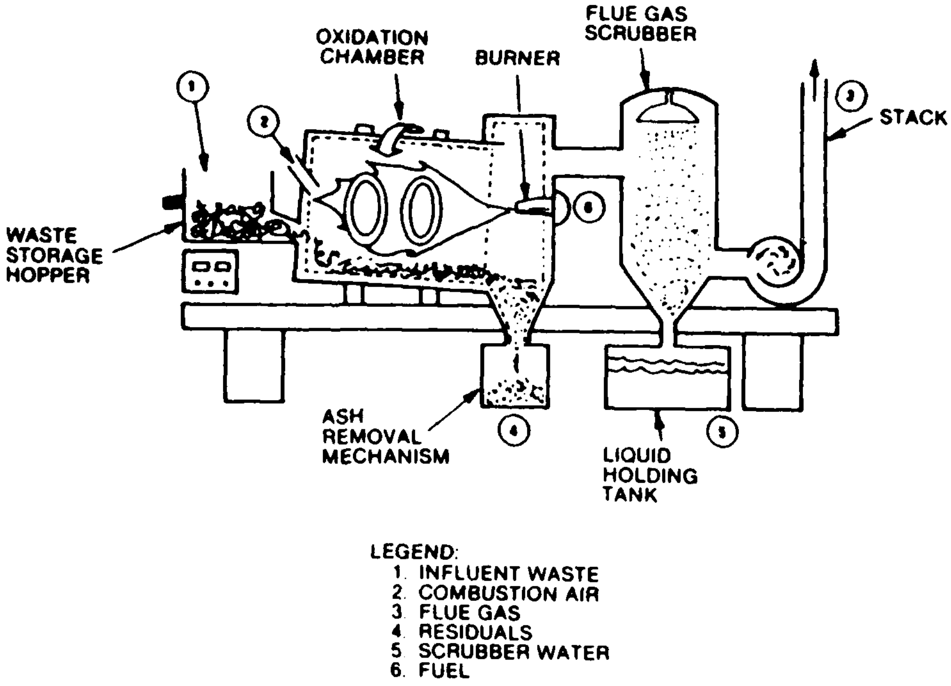
* Source: State of California (1981).



Source: Ghassami, Yu, and Quinlivan, 1981

Figure 4.15. Rotary kiln incinerator

Materials to be incinerated are injected into the kiln at the higher end and are passed through the combustion zone as the kiln rotates. The rotation creates turbulence and improves combustion. Rotary kilns often employ afterburners to ensure complete combustion. Most rotary kilns are equipped with wet scrubber emission controls.

The residence time and temperature depend upon combustion characteristics of the waste. Residence times can range from a few seconds to an hour or more for bulk solids. Combustion temperatures range from 1500 to 3000°F.

Rotary kilns are capable of burning materials in any physical form, can incinerate solids and liquids independently or in combination, and can accept materials feed without any preparation (Monsanto 1981). Contaminants that have been treated in rotary kilns include PCBs, tars, obsolete munitions, polyvinyl chloride wastes, and bottoms from solvent reclamation operations (State of California 1981).

Because of their ability to handle any physical form, and their high incineration efficiency, rotary kilns are the preferred method for treating mixed solid residues (Lee et al. 1982).

The limitations of rotary kilns include susceptibility to thermal shock, the necessity for very careful maintenance, the need for additional air due to leakage, high particulate loadings, relatively low thermal efficiency, and a high capital cost for installation (Monsanto Research Corp. 1981).

Multiple Hearth. A multiple-hearth incinerator consists of a refractory-lined steel shell, a rotating central shaft, a series of solid flat hearths, a series of rabble arms with teeth for each hearth, an air blower, material-feed and ash-removal systems, and fuel burners mounted on the walls (Monsanto Research Corp. 1981). Figure 4.16 illustrates the components of the multiple hearth. It can also be equipped with an afterburner, liquid waste burners, and side ports for air injection. Temperature in the burning zone ranges from 1400 to 1800°F and residence time may be very long.

The multiple-hearth incinerator can be used for the disposal of all forms of combustible materials, including sludges, tars, solids, liquids, and gases. The incinerator is best suited for materials such as sludges. The principal advantages of multiple-hearth incineration include high residence time for low volatile materials, ability to handle a variety of materials, ability to evaporate large amount of water, high fuel efficiency, and the utilization of a variety of fuels. The greatest disadvantages of the technology include susceptibility to thermal shock; inability to handle materials containing ash, which fuses into large rocklike structures; and wastes requiring very high temperatures. Also, control of the firing of supplemental fuels is difficult. The multiple-hearth incinerator has high maintenance and operating costs (Monsanto Research Corp. 1981, State of California 1981).

Fluidized Bed. The fluidized-bed incinerator illustrated in Fig. 4.17 consists of a cylindrical vertical refractory-lined vessel containing a bed of inert granular material, usually sand, on a perforated metal plate. Combustion air is introduced through a plenum at the bottom of the incinerator and rises vertically, fluidizing the bed and maintaining turbulent mixing of bed particles. Material to be incinerated is injected into the bed and combustion occurs within the bubbling bed. Heat is transferred from the bed into the injected material. Auxiliary fuel is usually injected into the bed. Bed temperatures vary from 1400 to 1600°F. Since the mass of the heated turbulent

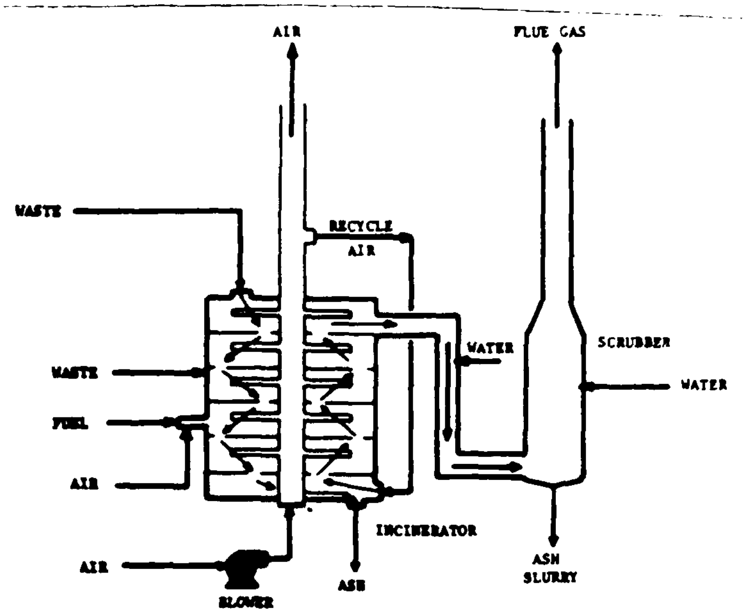


Figure 4.16. Multiple hearth incinerator

bed is much greater than the mass of the materials being incinerated, heat is rapidly transferred to these materials; a residence time of a few seconds for gases and a few minutes for liquids is sufficient for combustion (State of California 1981).

The residence time is long enough to allow the solid materials to become small and light enough to be carried off as particulates. Suspended fine particulates are usually separated in a cyclone when exhaust gases pass through air pollution control devices before being released into the atmosphere.

Fluidized bed incinerators are a relatively new design, presently being applied for liquid, solid, and gaseous combustible wastes. The most typical materials treated in fluidized beds include slurries and sludges. Some wastes require pretreatment prior to entering the reactor. The pretreatment may involve drying, shredding, and sorting. The fluidized bed handles the same waste that can be treated in the rotary kiln (Monsanto Research Corp. 1981).

Fluidized beds are typically used for the disposal of municipal wastewater treatment plant sludges, oil refinery waste, and pulp and paper mill waste. There are no data on the use of fluidized bed for incineration of

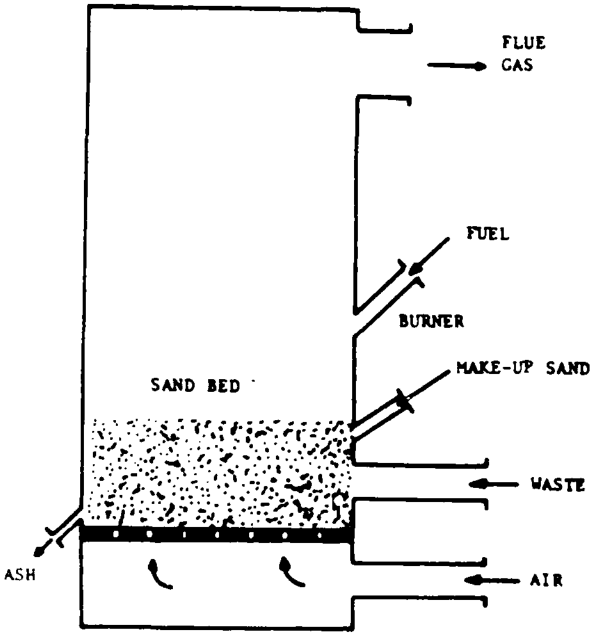


Figure 4.17. Fluidized bed incinerator

contaminated sediment. The technology has been used for pharmaceutical wastes, phenolic wastes, and methyl methacrylate (State of California 1981).

It is particularly well suited for incineration of materials with a high moisture content, sludges, and wastes containing large quantities of ash. Because of the low bed temperature, the exhaust gases are usually low in nitrogen oxides (Kiang and Metry 1982).

The advantages of the fluidized bed incinerator include simple design, minimal NO_x formation, long life of the incinerator, high efficiency, simplicity of operation, and relatively low capital and maintenance costs. It also has the ability to trap some gases in the bed, reducing the need for and the cost of an emission control system. The disadvantages include difficulty in removing residual materials from the bed, a relatively low throughput capacity, and the difficulty in handling residues and ash from the bed.

Treatment of Dredged Material Solids

Dredged material solids are those solid materials remaining after initial or final dewatering of the dredged material slurry. Treatment of the dredged material solids can be accomplished before or after placement in a disposal area. When these technologies are applied prior to placement in a disposal area, they are preceded by mechanical dewatering devices such as screens or cyclones.

Treatment Prior to Placement

A variety of treatment technologies can be applied to dredged material solids prior to placement in the disposal area. In addition to the thermal destruction and solidification/stabilization technologies that can be used to treat dredged material slurries, five major categories of contaminated soil treatment technologies have been identified (USEPA 1985). These technologies include:

a. Extraction.
b. Immobilization.
c. Degradation.
d. Attenuation.
e. Reduction of volatilization.

Applicability and reliability of these technologies are compared in Table 4.14.

Extraction. Extraction techniques actually remove the undesired contaminant from the solids by dissolution in a fluid that is subsequently recovered and treated either on site or at another location. This technology offers a more or less permanent solution to the contamination problem. The problem of ultimate disposal of the contaminants is, however, moved to another location and another set of processes. The ultimate treatment of the contaminated extraction fluid can often be carried out under more favorable conditions, at significantly lower risk, and at reduced costs. Variables affecting this technology include: the solubility of the contaminants in the solvent selected, the concentration of contaminants, and the rate of dissolution of the adsorbed contaminants.

Extraction technologies involve the elutriation of organic and/or inorganic constituents from the soil for recovery or treatment. The soil is contacted with an appropriate solvent, and the elutriate is collected, treated,

Table 4.14

Summary of Treatment Technologies for Dredged Material Solids*

Technology	Wastes Amenable to Treatment	Status	Ease of Application	Potential Level of Treatment	Reliability
EXTRACTION	Soluble organics and inorganics	Laboratory	Easy-Difficult	Variable	Good
IMMOBILIZATION					
Sorption (heavy metals) Agri. products	Heavy metals	Field	Easy-Difficult	High	Retreatment required
Activated carbon	Heavy metals	Conceptual	Easy-Difficult	Unknown	Unknown
Tetren	Heavy metals	Laboratory	Easy-Difficult	High	Unknown
Sorption (organic)					
Soil moisture	Organics, non-volatile, $K_d < 10$	Conceptual	Easy-Difficult	High	Retreatment required
Agri. products	Organics	Laboratory	Easy-Difficult	High	Retreatment required
Activated carbon	Organics, low water solubility	Field	Easy-Difficult	Low-High	Unknown
Ion Exchange					
Clay	Cationic components	Laboratory	Easy-Difficult	High	Good
Synthetic resins	Certain cationic and anionic compounds	Laboratory	Easy-Difficult	Variable	Unknown
Zeolites	Heavy metals	Conceptual	Easy-Difficult	Unknown	Unknown

(Continued)

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* Source: Arthur D. Little, Inc. (1976).

Table 4.14 (Continued)

Technology	Wastes Amenable to Treatment	Status	Ease of Application	Potential Level of Treatment	Reliability
Precipitation					
Sulfides	Heavy metals	Conceptual	Difficult	High	Fair
Carbonates, phosphates, and hydroxides	Heavy metals	Laboratory	Easy-Difficult	Unknown	Retreatment required
DEGRADATION					
Oxidation					
Soil catalyzed reactions	Aliphatic organics, other organics	Limited field	Easy-Difficult	Variable	Good
Oxidizing agents	Various organics	Limited field	Moderate-Difficult	High	Good
Reduction					
Organics	Chlorinated organics, unsaturated aromatics, aliphatics	Limited field	Easy-Difficult	High	Retreatment required
Chromium	Hexavalent chromium	Limited field	Easy-Difficult	High	Retreatment required
Selenium	Hexavalent selenium	Limited field	Easy-Difficult	High	Retreatment required
Sodium reduction	PCB, dioxin, halogenated compounds	Conceptual	Moderate	High	Good
Polymerization	Aliphatics, aromatics, oxygenated organic compounds	[illegible]	Moderate-Difficult	Variable	Unknown

(Continued)

Table 4.14 (Continued)

Technology	Wastes Amenable to Treatment	Status	Ease of Application	Potential Level of Treatment	Reliability
Modification of soil Properties (biodegradation					
Soil moisture	Organics	Field (agri.)	Easy-Difficult	Low-High	Retreatment required
Soil oxygen-aerobic	Organics	Field	Easy-Difficult	Low-High	Retreatment required
Soil oxygen-anaerobic	Halogenated organics	Conceptual	Moderate-Difficult	Low-High	Retreatment required
Soil pH	Organics	Field	Easy-Difficult	High	Retreatment required
Nutrients	Organics	Field	Easy-Difficult	High	Retreatment required
Nonspecific soil amendments	Organics, arsenite wastes	Laboratory	Easy-Difficult	Low-High	Retreatment required
Analog enrichment for cometabolism	Some organics with analogs	Laboratory	Easy-Difficult	Low-High	Unknown
Exogenous acclimated or mutant micro-organisms	Various organics	Field	Easy-Difficult	High	Retreatment required
Cell-free enzymes	Organics	Laboratory	Difficult	High	Unknown
Photolysis					
Proton donors	Some organics, including [illegible] Kepone, [illegible]	Field	Easy-Difficult	High	Unknown
Enhance volatilization	Volatile organics	Conceptual	Easy-Difficult	High	Good

(Sheet 3 of 4)

Table 4.14 (Concluded)

Technology	Wastes Amenable to Treatment	Status	Ease of Application	Potential Level of Treatment	Reliability
ATTENUATION					
Metals	Metals	Field	Easy-Difficult	High	Good
Organics	Organics	Limited field	Easy-Difficult	High	Good
REDUCTION OF VOLATILIZATION					
Soil vapor volume	Volatile organics and inorganics	Laboratory	Easy-Difficult	Low-Medium	Retreatment required
Soil cooling	Volatile organics	Expt., limited field	Difficult	Low-Medium	Retreatment required

(Sheet 4 of 4)

and/or recycled back into the site. Extraction solutions may include water, acidic aqueous solutions (sulfuric, hydrochloric, nitric, phosphoric, and carbonic acid), basic solutions (sodium hydroxide), and surfactants (alkylbenzene sulfonate). Water can be used to extract water-soluble or water-mobile constituents. Acidic solutions are used for metals recovery and for basic organic constituents including amines, ethers, and anilines. Basic solutions are used for metals, including zinc, tin, and lead, and for phenols, complexing, and chelating agents. Surfactants can be used for hydrophobic organics.

Both organic and inorganics are amenable for treatment by extraction technology. Extraction technology is currently at the laboratory stage. Studies have been conducted to determine appropriate solvents. The anticipated level of treatment is variable; however, once the contaminants are removed, no additional retreatment is necessary. No cost information is available concerning extraction technologies.

Immobilization. Immobilization technologies are designed to capture the contaminants within the soil mass. Immobilization reduces the tendency of the contaminant to enter the ground water, surface water, or atmospheric exposure pathways. The immobilized contaminants, however, remain in the soil, leaving the possibility for exposure via direct contact or contaminant migration under changed conditions. The three major classes of immobilization technology are sorption, ion exchange, and precipitation.

Sorption technologies are designed to capture the contaminants on soil particles or adsorptive soil amendments. Sorption can be applied to both organic and inorganic contaminants. Sorption of a contaminant refers to the processes that result in a higher concentration of the contaminant at the surface or within the solid phase than is present in the bulk solution of soils. Actual sorption mechanisms are often unknown; however, it is believed that sorption is the major general retention mechanism for many organic compounds and metals. Sorbed compounds or ions are in equilibrium with the soil solution and are capable of desorption.

Theoretically, the addition of organic matter to a contaminated soil should remove metals from the soil solution, thus preventing their leaching into the groundwater. Organic materials most conducive for use with contaminated soils include agricultural products and by products and activated carbon.

Agricultural products and by products (e.g., animal manures, plant residues, and food processing wastes) have been used extensively as soil conditioners. The use of such waste materials for removal of metals from soil has not been extensively studied. Sewage sludges from municipal areas often contain high concentrations of heavy metals and should be avoided. Waste materials may also contain soluble organic matter that chelates metals and increases their mobility. Maximum sorption of metals by organic matter is obtained when the soil pH is greater than 6.5. The addition of organic materials may result in a decreased pH, requiring continual pH adjustment by liming. Potentially, the addition of agricultural products or byproducts may be an effective method for immobilizing metals in soil. However, agricultural products and by products are highly susceptible to microbial activity. Degradation of the materials may result in the release of metals and the long term treatment achievable is probably much smaller than the short term unless treatments are continued. Reliming is likely to be a necessity as well, since mineralization of the organics would tend to reduce the pH of the soil system. Another important factor in the competition of the metals with organics, which are also sorbable on organic materials.

Wastewaters contaminated with heavy metals are amenable to treatment with activated carbon. However, the addition of activated carbon to contaminated soils as an adsorbent is still conceptual in nature. The potential achievable treatment levels for metals in soil is unknown because of competition with organics, the complicated nature of the soil system, and the lack of research on this technology. The reliability of the technology is unknown and desorption may be a problem in the long term because of competition by organics in the soil and pH changes.

Chelation of heavy metals with tetraethylenepentamine (tetran) to form stable metal chelates has been proposed. To be effective, this technology must be applied to soil relatively high in clay. If tetran is applied to an organic soil low in clay, the tetran-metal complex will remain in the soil solution and will be susceptible to leaching. This technology is conceptual in nature, based on limited laboratory and greenhouse studies. The long-term stability and factors affecting the process are not well understood. In general, this technology cannot be considered reliable at this time.

Ion exchange is a means for immobilizing inorganic contaminants similar to sorption. Initially, mobile metal ions exchange positions with innocuous cations and become bound to clay particles in the soil system. Many heavy metal contaminants are tightly bound by common clay minerals. The activity of natural ion exchange materials in soil can be enhanced by admixing synthetic or other natural ion exchange materials. Synthetic resins can be tailored to be highly selective for particular metals.

The addition of natural clay to soil contaminated with cationic compounds has been proposed as an effective immobilization technology. Cationic compounds, both organic and inorganic, are amenable to this treatment. However, this technology may not be effective if the cations to be immobilized are in relatively low concentrations when compared to other cations (e.g., Ca^{++}, Na^{+}, and K^{+}). The latter cations may overwhelm the exchange capacity of the clay and low concentrations of the former cations, including those with higher affinities, and will not be significantly exchanged. Laboratory studies have been conducted demonstrating immobilization of pesticides by clays. When applied, this technology is expected to cause immobilization of some cations. However, the effectiveness may not be as high as anticipated from theory or laboratory studies.

Conceptually, synthetic ion exchange resins can be added to contaminated soil as an immobilization agent. With the right choice of resins, both cations and anions (organic or inorganic) can be immobilized on synthetic resins. The rate of application (mass per volume of soil) should be determined in short-term treatability studies. The achievable treatment level is dependent on resin characteristics and competition from naturally occurring ions in the contaminated soil. The long-term effectiveness of this technology and stability of resins in soil systems is unknown at this time. The availability and cost of resins limit their use in large-scale contaminant control projects.

A variety of natural exchange materials (zeolites) are highly selective for particular metals. Clinoptilolite ($Cu < Zn < Cd < Pb$) and mordenite ($Ni < Zn$; and $Co < Cu < Mn$) both show selective exchange of heavy metals. As with all ion exchangers, sorption of metals by zeolites is affected by pH, competing reactions, choice of solvent, presence of complexing agents, solution ionic strength, and type of ions present. The effect of these variables upon the overall ion exchange performance of zeolites is generally less complex and more predictable than with resin exchangers. This technology is conceptual for immobilization of heavy metals in soil systems. It has been used in agricultural systems for the retention of ammonium and potassium. The technology looks promising for use in soil, but research is required to investigate the long-term potential for metal immobilization.

Another immobilization technology for metals in soil is precipitation. Theoretically, precipitation occurs when the solubility product of the ions forming the precipitate is exceeded in the solution. Metals may be precipitated as sulfides, carbonates, phosphates, and hydroxides.

Heavy metals will react with sulfide ions to form insoluble metal sulfides. The extent of metal sulfide precipitation is a function of pH, type of metal, sulfide content, and interfering ions. A high salt content in the soil will reduce the theoretical extent of precipitation. Metal sulfides are the least soluble of the metal compounds likely to form in the soil system. Competition from other anion species would be negligible. The high stability of metal sulfides makes it possible to precipitate metals even in the presence of organic liquids such as chelating agents. On the other hand, some heavy metals will form soluble sulfide complexes: ZnS_2^{-2}, HgS_2^{-2}, HgS_2H^-, [illegible], and [illegible]. The complexed metal may be more mobile than the free metal ion.

Sulfide precipitation employing several sources of sulfide have been used effectively in wastewater treatment. The sodium salts of sulfide (Na_2S and NaHS) are highly soluble, so that concentrated solutions of sulfide can be prepared. However, addition of Na may have adverse effects on soil physical properties. Calcium sulfide (CaS) has been used, but must be prepared as a slurry because of its low solubility. Iron sulfide (FeS) can reduce Cr^{+6} to Cr^{+3}.

Sulfide precipitation in a natural soil system may be important for regulating the solution concentration of heavy metals only under reduced conditions. Sulfides are oxidized to form soluble metal sulfates under aerobic soil conditions, i.e., the condition occurring in upland and higher elevations of nearshore sites. The treatment of contaminated soil by precipitation of sulfides is purely conceptual at this time.

Theoretically, many metals form insoluble compounds with carbonates, phosphates, and hydroxides. Carbonates ($CaCO_3$), superphosphate ($Ca(H_2PO_4)_2$), and lime (CaO and $Ca(OH)_2$) have been used as soil amendments in attempts to immobilize metals. For maximum effectiveness, soil pH must be maintained over time, which may require continuous treatment. Heavy metals may also form soluble phosphate, carbonate, and hydroxide complexes. These complexes may be more mobile than the free metal ion. If arsenic is present in the soil system, the use of phosphate may cause the release of arsenate to the soil solution. High salt concentrations and the presence of chelating agents and other competing reactions may reduce the performance of this technology. Little is known about using precipitation as a means of treating contaminated soil. The kinetics of metals precipitation in soil may limit its effectiveness.

Degradation. Degradation is a family of technologies that convert the contaminant species into an innocuous or less toxic compound or compounds. Degradation is primarily applicable to organic compounds; however, it may be applied to inorganic species in a limited number of cases, e.g., reduction of Cr^{+6} to Cr^{+3}. Degradation may also be used in combination with immobilization technologies, e.g., precipitation of the Cr^{+3} produced above in the hydroxide form.

Degradation may be accomplished by either chemical or biological means. Chemical degradation techniques convert contaminant species by promoting the natural capacity of the soil to support oxidation or reduction reactions or by adding suitable reagents. Biological techniques utilize the action of microorganisms to break down organic compounds into innocuous or less toxic metabolic products.

Chemicals naturally undergo reactions in soil that may transform them into more or less toxic products or that may increase or decrease their mobility in the soil. These reactions may be classified as oxidation reactions, reduction reactions, and polymerization reactions.

Chemical oxidation is a process in which the oxidation state of an atom is increased. Oxidation reactions within the soil matrix may occur through management of natural processes in the soil or through addition of an oxidizing agent to the soil complex. Oxidation is usually more applicable for treating organics because metals usually become more mobile at higher oxidation states. Arsenic is an exception.

Organic wastes that are water soluble and have half-cell potentials below the redox potential of a well-oxidized soil are amenable to soil catalyzed reactions. This technology incorporates the addition of clay to the contaminated soil. Greater oxidation of contaminants is expected in less saturated soil. The level of treatment with soil-catalyzed reactions is variable depending on the oxidation potential of the contaminants and the aeration of the soil. The oxidation of a compound does not guarantee less mobile or less toxic compounds. Care must be taken that oxidation of the contaminant will not produce substances that will cause more problems than the parent compounds.

Oxidizing reagents may be utilized to degrade organic constituents in soil systems. Two powerful oxidizing reagents that have been successfully used in wastewater treatment are ozone and hydrogen peroxide. Organic wastes are amenable to treatment by the addition of oxidizing agents, subject to considerations of the production of more toxic or more mobile oxidation products. There has been little experience in using this technology in soil-based systems. The potential level of treatment is high for contaminants susceptible to oxidation, in soil without large quantities of competing oxidizable substances, and for limited areas of contamination. This technology should be considered as conceptual in nature.

Chemical reduction is a process in which the oxidation state of an atom is decreased. Reduction of chemicals may occur naturally within the soil system or reducing agents may be added to degrade reducible compounds.

Reducing agents and conditions vary with organics and metals. Chemical reduction of toxic organics using catalyzed metal powders and sodium borohydride has been demonstrated. Chlorinated organics, unsaturated aromatics and alphatics, and other organics susceptible to reduction will be amenable to this technology. This technology has only been demonstrated in small field plots; however, the potential appears to be high for use in small areas of contamination or for soil without large quantities of competing constituents.

Hexavalent chromium has been reduced to less toxic trivalent chromium using acidification agents (sulfur) and reducing agents (leaf litter, acid compost, or ferrous iron). After reduction, liming can be used to precipitate the Cr^{+3}. Caution is required, however, since trivalent chromium can be oxidized to Cr^{+6} under conditions prevalent in many soils, e.g., under alkaline and aerobic conditions in the presence of manganese. This technology has been field tested and has a high treatment potential.

Soil containing hexavalent selenium (SeO_4^{-2}) that does not contain significant amounts of other metallic contaminants is amenable to reduction technology. However, the mobility of selenium increases with increasing pH. Therefore, for soils that contain selenium as well as other metals, selenium could not be treated if increased pH were required as part of the treatment for the other metals. This technology is conceptual in nature and studies have been limited to those involving the basic chemistry of selenium in soil.

Several processes have been developed to detoxify PCBs and potentially dioxins. All employ sodium-based chemical reagents to remove chlorine from the PCB and dioxin molecules. The technology has been applied to the treatment of PCB-contaminated oils, but is still in the developmental stage with respect to soil contamination. The proposed reagents are strong reducing agents and may react with excess soil moisture and organic matter.

It has been demonstrated that naturally occurring iron and sulfates in contaminated soil may catalyze initial polymerization of contaminants. Treatment solutions containing sulfate-related constituents have been successfully used in polymerization reactions in soil. This technology is conceptual in nature and its reliability is unknown.

Biodegradation is an important process causing the breakdown of organic compounds. It is a significant loss mechanism in soil in the mineralization process by which organics are converted to inorganics.

Micro-organisms, principally bacteria, actinomycetes, and fungi, are the most significant group of organisms involved in biodegradation, and soil environments contain a diverse microbial population. The parameters influencing the rate of biodegradation are of two types:

a. Those that determine the availability and concentration of the compound to be degraded or that affect the microbial population and activity.
b. Those that control the reaction rate.

Important parameters affecting biodegradation include pH, temperature, soil moisture content, soil oxygen content, and nutrient concentration, among many others (Bonazountas and Wagner 1981).

A variety of biodegradation methods have been proposed including:

a. Modification of soil properties.
b. Addition of organic amendments.
c. Analog enrichment for co-metabolism.
d. Augmentation with exogenous acclimated or mutant microorganisms.
e. Application of cell free enzymes.

In general, these technologies are in various states of development and other than the techniques using modification of soil properties and augmentation with mutant microorganisms have not been applied on the field scales. The reliability and level of treatment of most of these technologies is unknown.

Attenuation. The basic principle of attenuation is the mixing of contaminated soil with clean soil to reduce the concentration of contaminants. The process is potentially applicable to both organics and inorganics; however, acceptable concentration limits have been established only for heavy metals. Attenuation may be accomplished by mixing clean and contaminated dredged material. This technology is highly reliable under most conditions. The mixing of sediment or the addition of other soil or clay to the soil system may alter the natural properties. As a result, the effectiveness of this technology may vary for different compounds. The layering of contaminated and clean dredged material in a disposal site is an example of attenuation.

Treatment After Placement

Three basic technologies are available for treating contaminated dredged material after initial placement in the disposal site: in situ treatment, excavation and offsite disposal, and onsite treatment (excavation, treatment, and replacement).

In Situ Treatment. In situ treatment technologies incorporate those concepts presented in the previous section with the exception that the dredged material has been placed in the disposal area prior to treatment. Obviously this complicates and limits some of the available technologies. The primary limitation is the general requirement for all the technologies that chemical reagents must be mixed with the contaminated soil. In general, the application of reagents will range from easy to difficult depending on the trafficability of the site, the depth of contamination, and the areal extent of contamination.

An additional technology, not previously discussed, yet available for application to dredged material after placement, is the reduction of volatilization to reduce or control air emissions or to retain compounds within the soil for longer periods of time to allow for in-place treatment. Three methods for reducing volatilization from a site have been proposed: reduction of soil vapor pore volume, use of physical/chemical barriers, and soil cooling.

Reduction of soil vapor pore volume for volatilization control is accomplished by modifying the soil to reduce the partitioning of a compound into the vapor phase and subsequently reduce its rate of volatilization.

Modifications include compaction and water addition to reduce the air-filled pore spaces within the soil. This technology is useful for most volatile organic (e.g., benzene, gasoline, phenol) and inorganic (e.g., H_2S, NH_3, and methyl mercury) compounds and are especially applicable to those compounds with a high vapor-phase mobility potential and a low water-phase partition potential. This technology is at the laboratory stage of development and decreases in volatilization of compounds due to water addition and increase in bulk density have been demonstrated in simulated landfills. There is a potential for increased liquid-phase mobility. Re-treatment is required for continued effective reduction of volatilization.

Soil cooling may be used to decrease the temperature of the soil to reduce the vapor pressure of volatile contaminants and thus reduce their volatilization rate. This technology could be used in conjunction with other techniques to enhance treatment through retention of compounds for longer periods of time within the soil. Soil temperatures can be lowered by using cooling agents continuously applied to the soil or through modifications to the soil surface. Experimental and limited field applications have been conducted on liquid spills; however, no reports are available on soil surface cooling for vapor mitigation. Soil cooling by surface modification is used in agricultural operations. Cooling agents are more effective than soil modifications, but are not likely to be practical because of cost. Long-term reliability requires continuous treatment.

Onsite Treatment. Onsite treatment utilizes the concepts presented above, however, the dredged material must be rehandled, i.e. excavated, treated, and replaced in the same disposal area.

Offsite Disposal. Offsite disposal includes the concept of temporary storage with subsequent disposal in another permanent disposal area or reuse of the materials for some productive purpose. This concept is discussed in detail in the section on reuse of dredged material.

Summary of Dredged Material Solids Treatment Methods

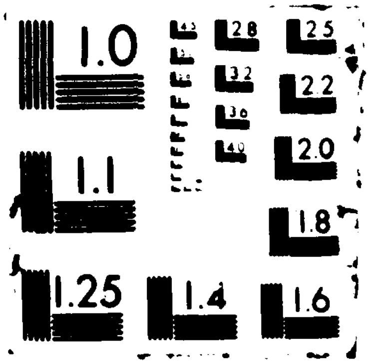
Conceptually, dredged material solids can be treated with a variety of technologies. Among these are incineration, solidification/stabilization, extraction, immobilization, degradation, attenuation, and reduction of volatilization. Incineration, although a demonstrated technology for organics destruction is believed to be far too costly for the treatment of contaminated dredged material. In addition, the technology has limited application for treating dredged material solids contaminated with heavy metals. Solidification stabilization technologies have been demonstrated at the field scale for hazardous wastes and at the laboratory scale for dredged material. However, this technology has not been proven for the containment of organics or in the marine environment. The remaining technologies are in various stages of development for application to hazardous waste sites and, although they may have some potential for application to dredged material solids, are many years away from being demonstrated technologies.

Treatment of Site Waters

A variety of physical, chemical, and biological processes have been developed for municipal and industrial water and waste treatment requirements. Many of these processes have potential in treating site waters generated by the disposal of contaminated dredged material at confined nearshore and upland disposal sites. However, few processes have actually been required or applied to dredged material disposal. Among the processes widely applied in confined disposal are plain sedimentation for solids and sediment-bound contaminant removal, and chemical clarification and filtration for enhanced removal of particulate (suspended solids) and sorbed metals and organics. Use of activated carbon for removal of soluble organics has received some limited application to dredged material. Other processes not previously applied to dredged material include organics oxidation, dissolved solids removal methods (e.g., distillation), and volatiles stripping. This section describes and discusses each process in terms of demonstrated or potential removal efficiencies for solids, sediment-bound contaminants, soluble organics and metals, dissolved salts, and volatiles.

The water discharged from a disposal site will vary in quantity and quality over time. Site effluent will be produced in large quantities for hydraulically dredged sediment during the dredging process. This effluent will usually be of lower contaminant concentration than that found in the interstitial water and will almost always be of lower contaminant concentration than that of future water discharges from the site. Runoff water will be produced during site dewatering and periods of precipitation on the site. Runoff will be of concern primarily during the dewatering and prior to placement of a surface cap on the site. Runoff water may be of higher contaminant

AD-A184 930 GUIDELINES FOR SELECTING CONTROL AND TREATMENT OPTIONS 3/8
FOR CONTAMINATED DREDGED MATERIAL(U) ARMY ENGINEER
WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR..
UNCLASSIFIED M J CULLINANE ET AL. SEP 86 F/G 24/3 NL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1.4
1.6

concentration than the original site effluent. Leachate water is produced as water moves through the dredged material and out the sides and bottom of a disposal site. This water is produced in the smallest quantities but may contain relatively high contaminant concentrations and may persist for a long period of time. Leachate treatment usually requires collection via drains placed under the site (underdrains). This section applies mainly to treatment of site effluent, long-term site runoff, and leachate.

Because the liquid streams from dredged material sites are so diverse in volume, type, and concentration of contaminants, a wide variety of treatment processes may be applicable at dredged material disposal sites. This section addresses those processes that are considered most applicable. Rarely will any one unit treatment process be sufficient for site water treatment. Therefore, the discussions that follow include information on unit treatment processes that are frequently used in combination and any pretreatment requirements that are a prerequisite to effective use of each treatment process.

Aqueous treatment at disposal sites can be accomplished using one of four general approaches:

a. Onsite treatment using a mobile treatment system.
b. Onsite construction and operation of treatment systems.
c. Pretreatment followed by discharge to a publicly owned treatment works (POTW).
d. Hauling of water to an offsite treatment facility.

Mobile treatment systems and systems constructed onsite have broadest applicability. Waters discharged to POTWs often require extensive pretreatment in order for the facility to meet its NPDES permit conditions. Other factors that determine the feasibility of POTW discharge include whether the facility has the hydraulic capacity to handle the water, whether accepting the water will result in additional monitoring requirements or process changes, and the potential for opposition in the community. Hauling water offsite for treatment is limited to all but very small wastewater volumes.

Treatment of site waters from the disposal of contaminated dredged material will be analogous to treatment of liquid wastes from industrial processes. The principal liquid waste management alternatives incorporate either joint treatment or separate treatment. The concept of joint treatment involves the collection and transporation of liquid wastes to an offsite facility owned and operated by a separate entity, i.e., municipality, sewerage district, or industry. The concept of separate treatment usually involves the construction and operation of onsite collection and treatment facilities capable of meeting required discharge standards. Advantages often cited for joint treatment are reduced capital investment, operational costs, and operating responsibilities. These may be totally or partially offset by stringent pretreatment, metering, and monitoring requirements; transport of the collected wastes to the joint treatment facility; and substantial user fees imposed by the owner/operator of the joint treatment facility. Major advantages of a separate treatment system include the retention of ownership and operational control of the treatment facilities and separate treatment facilities may be more economical to control. Major disadvantages of separate treatment include the need to meet stringent discharge requirements, operational problems caused by seasonal or periodic waste generation, the expense of construction and operation, and maintenance of a skilled labor force.

Regardless of the general concept of liquid stream treatment, it may be necessary to treat the liquid wastes prior to discharge to either a joint treatment facility (pretreatment) or to the environment. Table 4.15 lists water-treatment methods and indicates those which have been applied at dredge material disposal sites. The treatment processes can be grouped into various levels of treatment, depending upon a particular class of contaminant being removed. Six levels of treatment were identified and are defined as follows:

a. Level I is the removal of suspended solids and particulate-bound contaminants.

b. Level II is additional treatment for removal of soluble metals.

c. Level III is further processing to remove soluble organics.

d. Level IV is treatment for removal of nutrients.

e. Level V is the purification of the wastes by dissolved solids removal.

f. Level VI is disinfection.

The relationships between levels of treatment are illustrated by means of the process-substitution diagram shown in Fig. 4.18. Increasing levels of treatment result in increasing percentages of contaminant removal. A comparison of the relative efficiencies of the treatment levels is given in Table 4.16. The qualitative ranges of soluble concentrations remaining after each treatment level and percent removals are based on actual monitoring of

Table 4.15

Listing of Water-Treatment Processes

Treatment Process	Proven Method	Proven Not Demonstrated	Applied to Dredged Material	Not Applied to Dredged Material
Suspended solids				
Plain sedimentation	X		X	
Chemical clarification	X		X	
Filtration	X		X	
Soluble metals				
Precipitation	X		X*	
Soluble organics				
Adsorption	X		X	
Ozonation	X			X
Dissolved solids				
Distillation	X			X
Reverse osmosis	X	X		X
Electrodialysis	X			X
Ion exchange	X			X
Volatiles				
Stripping	X			X
Leachate[b]				
Biological	X			X
Physical/chemical	X**			X

* Limited success on pilot scale.

** Potential for use of existing municipal or industrial process for treatment offsite.

disposal sites for Levels I and II (where applicable) and on best-available water-treatment technology for Levels III and V. It should be noted that the estimates made for soluble organics and soluble metals removals past Level I are mean values and represent a grouping of contaminants with large ranges of solubility and treatability. The data in Table 4.16 should be viewed as preliminary for planning purposes only and, as such are presented to illustrate potential levels of removals. Actual removal-efficiency data on Puget Sound sediment would have to be obtained through site-specific testing, evaluations, and demonstrations.

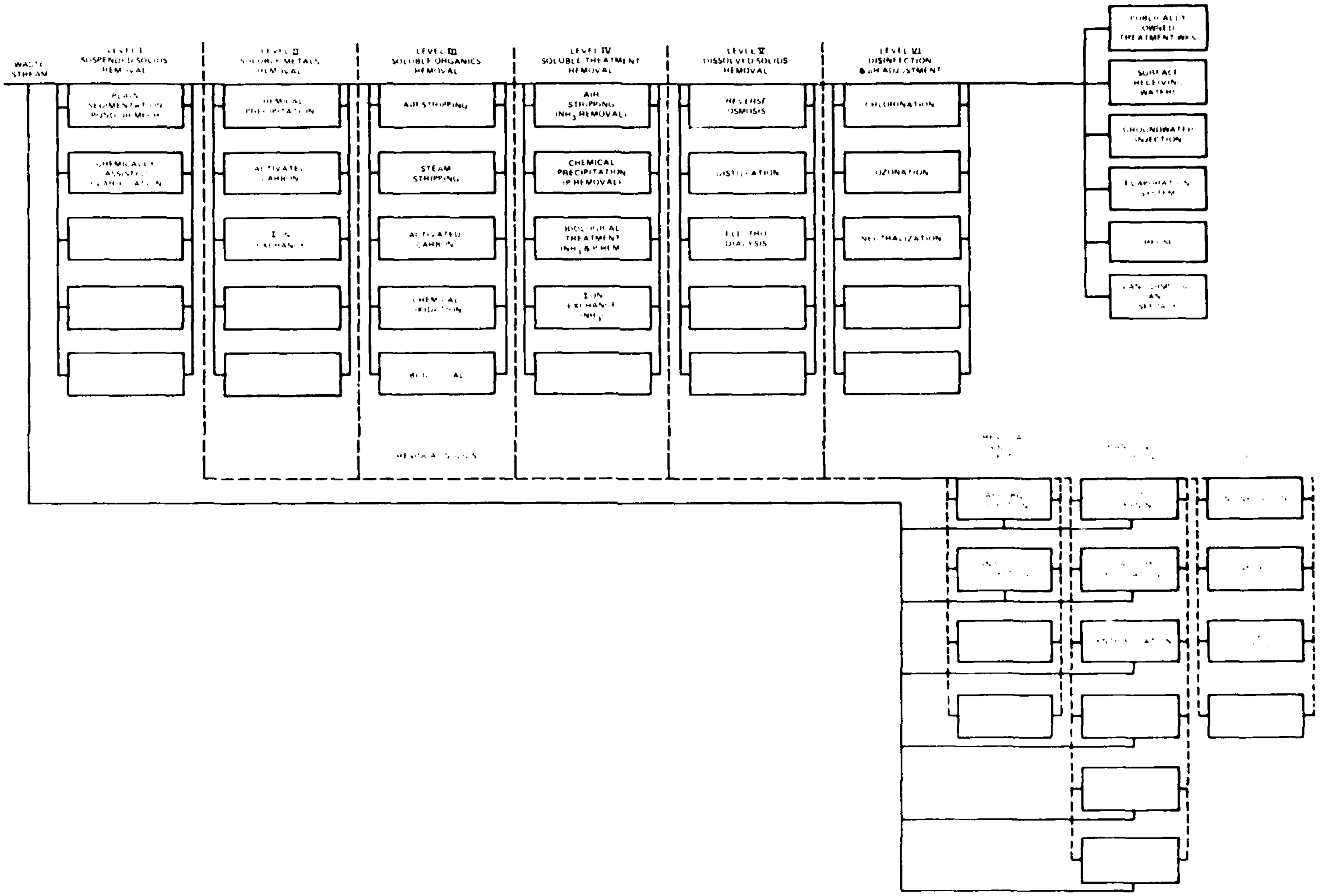


Figure 4.18. Disposal site water treatment process-substitution diagram

Table 4.16

Contaminant Removal Efficiency of Water Treatment Levels*

Level	Class of Contaminant	Percent Removal	Water Concentration Remaining
I	Solids	99.9+	mg/ℓ range
	Metals	80 to 99+	ppb to ppm range**
	Organics	50 to 90+	ppb to ppm range**
II	Metals	99+	ppb range**
	Organics	50 to 90	ppb to ppm range**
III	Metals	99+	ppb range†
	Organics	95+	ppb range†
IV	Nutrients	90 to 98+	mg/ℓ range
V	Metals	99+	highest quality attainable
	Organics	99+	highest quality attainable
VI	Pathogens	90 to 99+	

* Assumes influent strength defined by dredged sediment that are not classifiable as "extremely hazardous waste" under RCRA (i.e., low saturation influents).

** Concentrations based on Hoeppel et al. (1978) and Palermo (in preparation).

† Concentrations based on capability of best-available treatment technology.

Level I Treatment

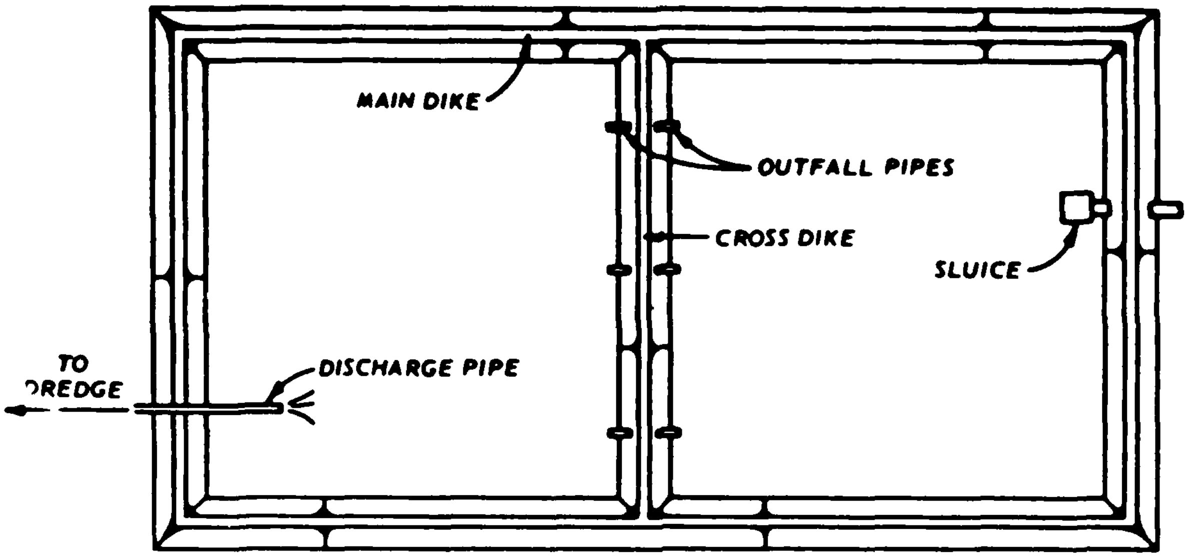
Plain Sedimentation. Many of the contaminants present in the flow from a dredging operation will be removed during the plain sedimentation occurring within a confined disposal area. Confined disposal areas are used to retain dredged material solids while allowing the carrier water to be released from the disposal area. The effluent may contain levels of both dissolved and particulate-associated contaminants.

Release of supernatant waters from confined disposal sites occurs after a retention time of up to several days. Actual withdrawal of the supernatant is governed by the hydraulic characteristics of the ponded area and discharge weir. This effluent is normally characterized by its suspended solids concentration and rate of outflow. Flow over the weir is controlled by the static head and the effective weir length provided. To promote sedimentation, the inflow slurry is encouraged to pond; a minimum ponding depth of 2 ft is recommende[illegible] a continuous disposal activity. Ponding depths less than 2 ft may be ac[illegible]le if the dredging occurs intermittently. The depth of pond water is controlled by elevation of the weir crest. Minimum freeboard requirements and mounding of coarse-grained material result in a ponded surface area that is smaller than the total surface area enclosed by the dikes. Dead spots in corners and other hydraulically inactive zones further reduce the effective surface area, where sedimentation occurs, to considerably less than the ponded surface area. Spur dikes (internal dikes) can be used to improve settling efficiency by modifying flow patterns through the site, modifying currents, and allowing more time for settlement (Fig. 4.19).

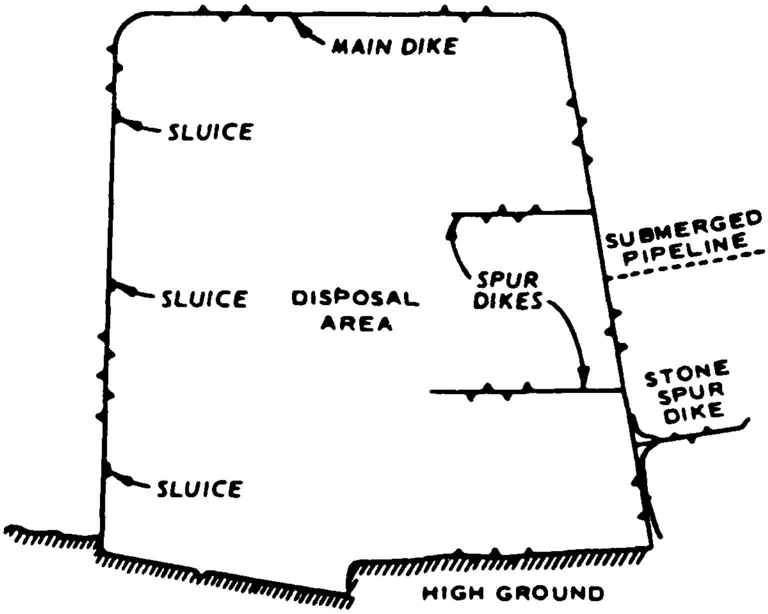
Several expedient measures can be employed to enhance retention of the suspended solids within a containment area of a given size before effluent discharge to receiving waters. They include intermittent pumping, increasing the depth of ponded water, increasing the effective length of the weir, temporarily discontinuing dredging operations, or decreasing the size of the dredge.

Properly designed and operated confined disposal areas can be extremely efficient in retaining suspended solids and associated contaminants. This is especially true if the dredging is conducted in a saltwater environment as is the case for Commencement Bay. Palermo (1984) found that retention efficiency for suspended solids in three saltwater disposal areas was above 99.9 percent (inflow solids concentrations on the order of 100 g/ℓ and effluent suspended solids concentrations on the order of tens of mg/ℓ). Similar high retention of the total concentration of metals was observed, varying from 84.5 to 99.9 percent. These data are in agreement with Hoeppel et al. (1978) and other investigators. Hoeppel et al. (1978) described similar retention for organics, such as PCB and DDT, that remain closely associated with particles. Typical concentrations of various contaminants remaining in the effluent following plain sedimentation are available in Hoeppel et al. (1978) and Palermo (1984).

<u>Chemically-Assisted Clarification.</u> Flocculation is used to describe the process by which small, unsettleable particles suspended in a liquid medium are made to agglomerate into larger, more settleable particles. The mechanisms by which flocculation occurs involve surface chemistry and



a. DIKED DISPOSAL AREA WITH CROSS DIKE



b. DIKED DISPOSAL AREA WITH SPUR DIKES

Figure 4.19. Dikes for modifying flow patterns

particle-charge phenomena. In simple terms, these various phenomena can be grouped into two sequential mechanisms (Kiang and Metry 1982):

a. Chemically-induced destabilization of the requisite surface-related forces, thus allowing particles to stick together when they touch.
b. Chemical bridging and physical enmeshment between the now nonrepelling particles, allowing for the formation of large particles.

Flocculation involves three basic steps:

a. Addition of flocculating agent to the waste stream
b. Rapid mixing to disperse the flocculating agent
c. Slow and gently mixing to allow for contact between small particles.

Typically, chemicals used to cause flocculation include alum, lime, various iron salts (ferric chloride, ferrous sulfate), and organic flocculating agents, often referred to as "polyelectrolytes." These materials generally consist of long-chain, water-soluble polymers such as polyacrylamides. They are used either in conjunction with the inorganic flocculants, such as alum, or as the primary flocculating agent. A polyelectrolyte may be termed cationic, anionic, or ampholytic, depending upon the type of ionizable groups, or nonionic if it contains no ionizable groups. The range of physical/chemical characteristics (e.g., density, viscosity, toxicity, and molecular weight) of the several thousand available polymers is extremely broad.

The inorganic flocculants, such as alum, lime, or iron salts, make use of precipitation reactions. Alum (hydrated aluminum sulfate) is typically added to aqueous waste streams as a solution. Upon mixing, the slightly higher pH of the water causes the alum to hydrolyze and form fluffy gelatinous precipitates of aluminum hydroxide. These precipitates, partially due to their large surface area, enmesh small particles and thereby create larger particles. Lime and iron salts also have a tendency to form large fluffy precipitates or floc particles. Many precipitation reactions, such as the precipitation of metals from solution by the addition of sulfide ions, do not readily form floc particles, but rather precipitate as very fine and relatively stable colloidal particles. In such cases, flocculating agents such as alum and/or polyelectrolytes must be added to cause flocculation of the metal sulfide precipitates (Canter and Knox 1985).

Once suspended particles have been flocculated into larger particles, they usually can be removed from the liquid by sedimentation, provided that a sufficient density difference exists between the suspended matter and the liquid.

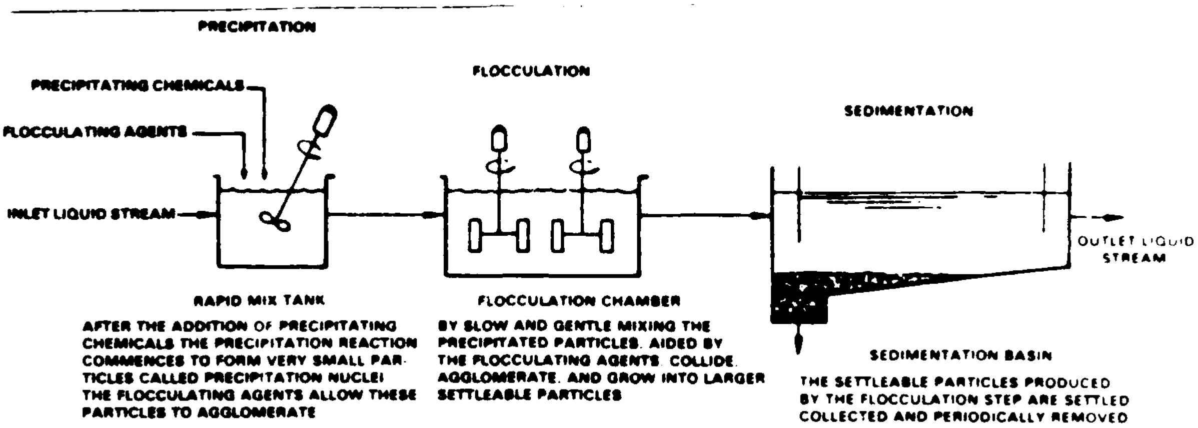
Flocculation is applicable to any aqueous waste stream where particles must be agglomerated into larger more settleable particles prior to sedimentation or other types of treatment. There are no concentration limits for flocculation. Highly viscous waste streams will inhibit settling of solids. Chemical clarification is an effective treatment method to remove turbidity, suspended solids, and adsorbed contaminants from the effluent of a fine-grained dredged material containment area. The process is used following plain sedimentation to reduce the required chemical dosage and, therefore, the cost of treatment and to produce a higher quality effluent than could be produced in a one-stage settling process (Schroeder 1983). However, chemical clarification is an ineffective method for removing soluble contaminants.

The chemical clarification process can be adapted and simplified to perform within the constraints of a normal disposal operation (Schroeder 1983). In this process, a liquid polymeric flocculant is fed into the effluent from the primary containment area at the weir structure. The weir structure and discharge culvert are used to provide the required mixing without mechanical equipment. A small secondary containment area is used for settling and storage of the treated material, eliminating the need for a clarifier and sludge handling equipment. However, a mud pump may be used to pump the settled treated material back into the primary containment area and to reduce the required size of the secondary containment area. A sketch of the treatment process is shown in Fig. 4.20.

Liquid polymeric flocculants are much simpler and less expensive to use than inorganic coagulants such as ferric chloride and alum (Wang and Chen 1977). The treatment system described above is also less expensive than a conventional system requiring a flash mixer, flocculation basin, clarifier, and sludge-handling equipment (Schroeder 1983, and Jones et al. 1978).

Chemical clarification must follow plain sedimentation and will not appreciably remove soluble and volatile contaminants.

Chemical clarification, as applied here, can remove up to 95 percent of the suspended solids and achieve an effluent quality of 25 mg/ℓ suspended solids (Schroeder 1983). Adsorbed contaminants are reduced in proportion to suspended solids removal.



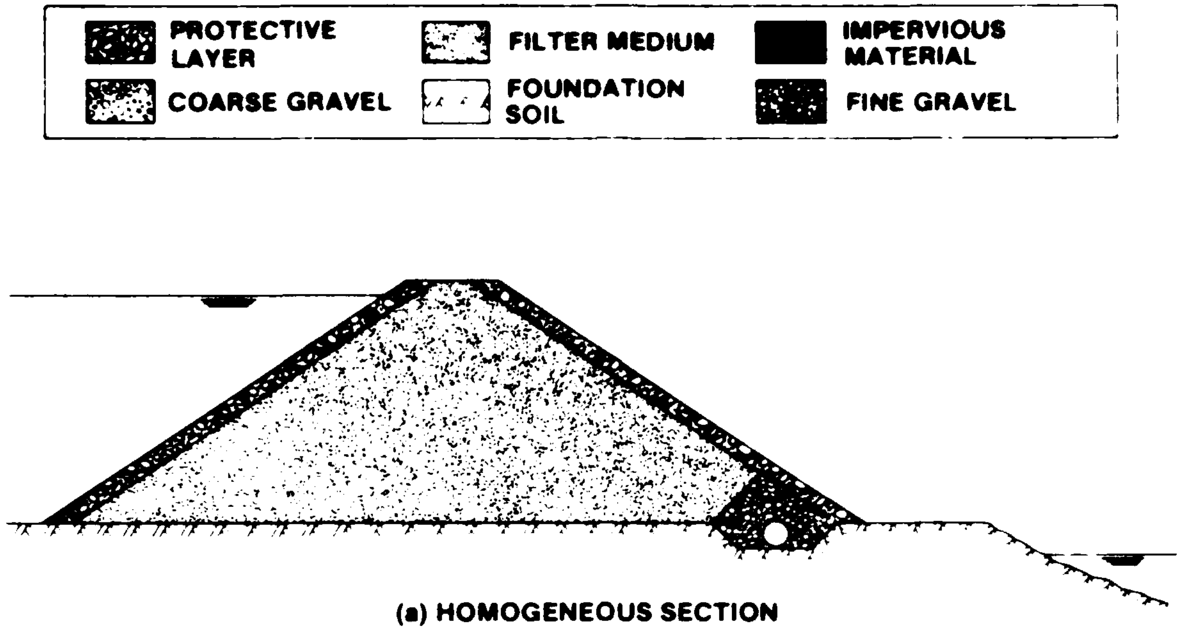
Source: De Renzo, 1978

Figure 4.20. Schematic of chemical clarification facility

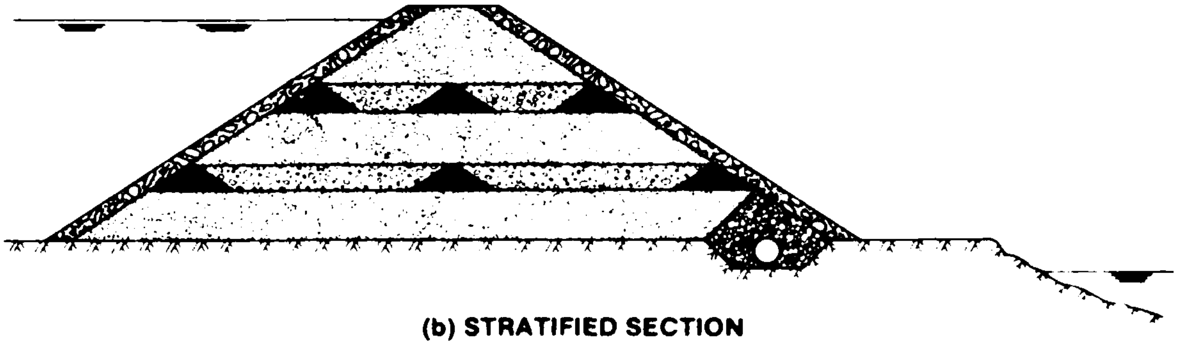
Filtration. Filtration is a treatment process used to provide additional removal of suspended solids and sediment-bound contaminants following plain sedimentation and chemical clarification. The process has been adapted to dredging operations through the use of pervious dikes and sandfill weirs (Krizek et al. 1976).

Pervious dikes should use coarse-grained deep beds that have low clarification efficiency per unit depth but maintain high permeability throughout the filter life. The dike must not clog at the surface or lose its ability to achieve the required clarification. Example pervious dikes are shown in Fig. 4.21. Typically, the dikes are 6 to 10 ft high, and the filter medium is coarse sand (Krizek et al. 1976, and Culp et al. 1978). If the system malfunctions, corrective measures, if at all possible, are extremely expensive. The water to be treated should have less than 1.0 g/ℓ suspended solids deep inside the filter and not at the face to prevent clogging and loss of efficiency (Krizek et al. 1976).

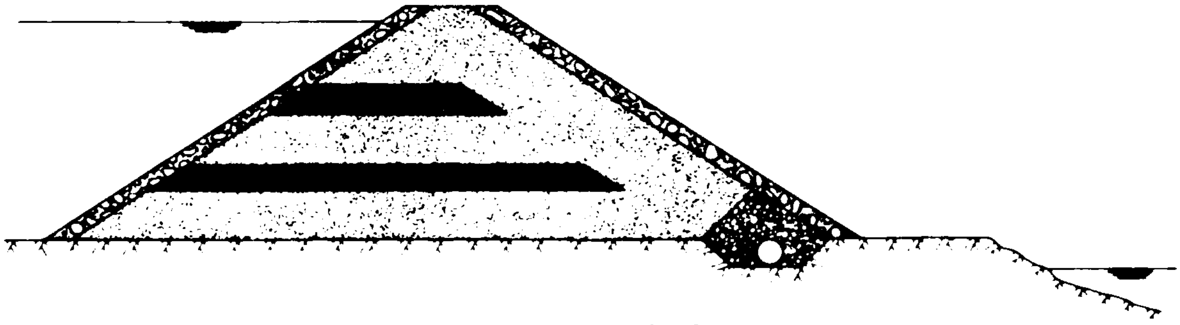
Sandfill weirs consist of several cylindrical or rectangular cells that contain the filter medium and provide filtration in a vertical gravity flow. Sandfill weirs are much more flexible than filter dikes allowing easier replacement and maintenance. Example sandfill weirs are shown in Fig. 4.22. The depth of the filter medium is generally kept as deep as possible to provide better solids retention. The filter medium is generally sand with a



(a) HOMOGENEOUS SECTION

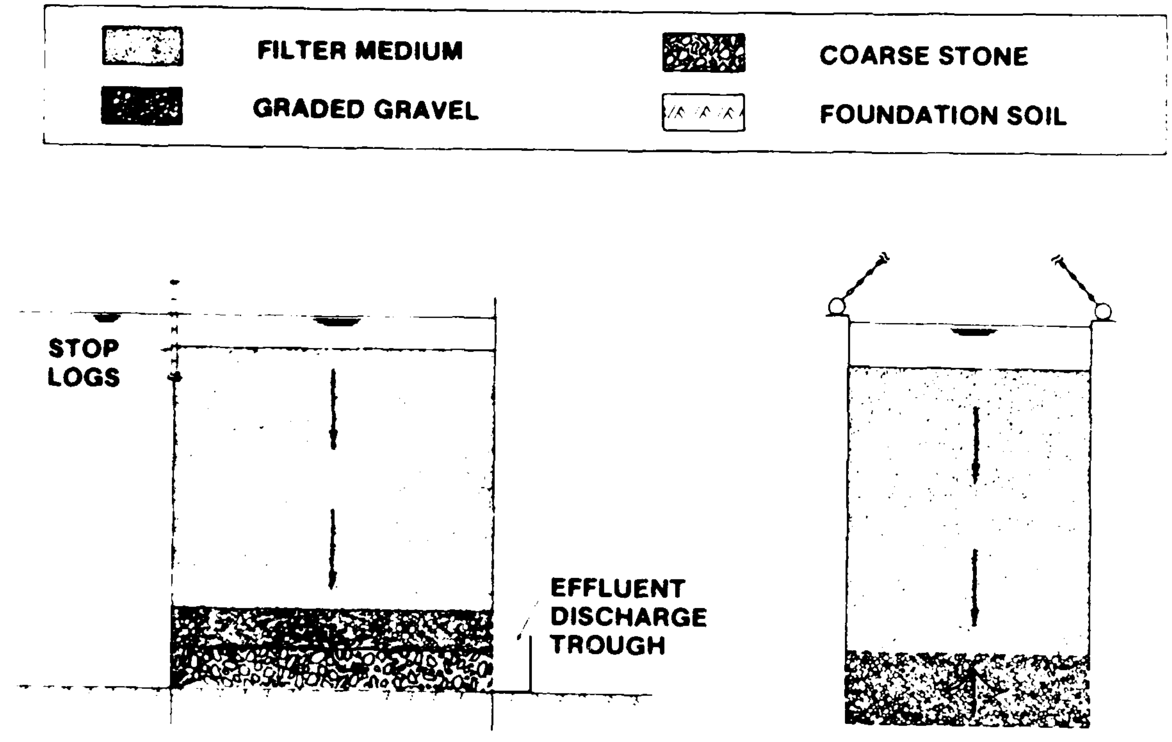


(b) STRATIFIED SECTION



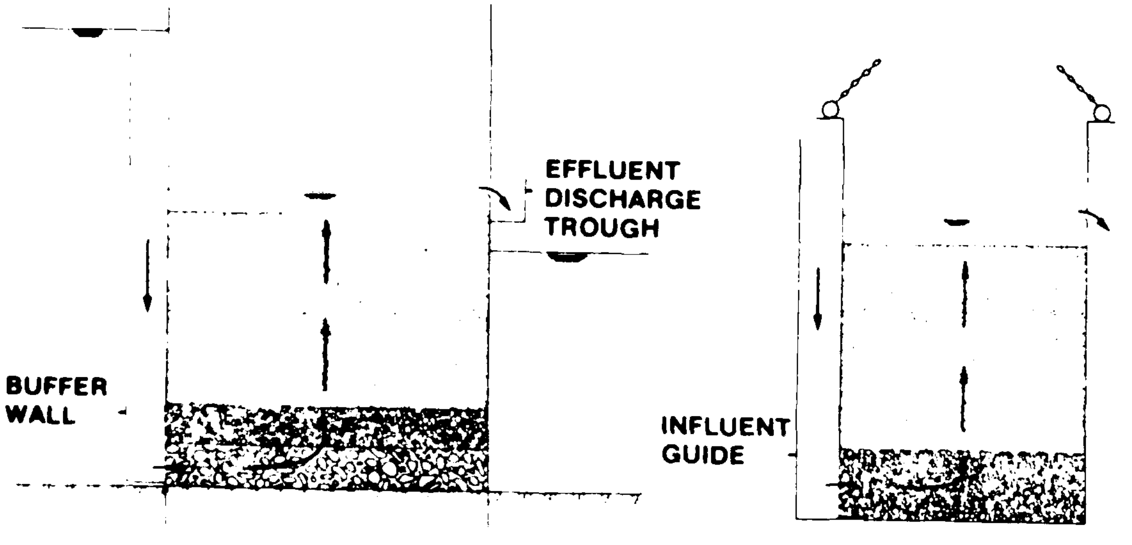
(c) BAFFLED SECTION

Figure 4.21. Pervious dikes



(a) DOWNFLOW WEIR

(c) DOWNFLOW CARTRIDGE



(b) UPFLOW WEIR

(d) UPFLOW CARTRIDGE

Figure 4.22. Sandfill weirs

particle size of about 1 mm (Krizek et al. 1976) Sandfill weirs require excessive maintenance if the influent contains more than 1 g/ℓ suspended solids (Krizek et al. 1976).

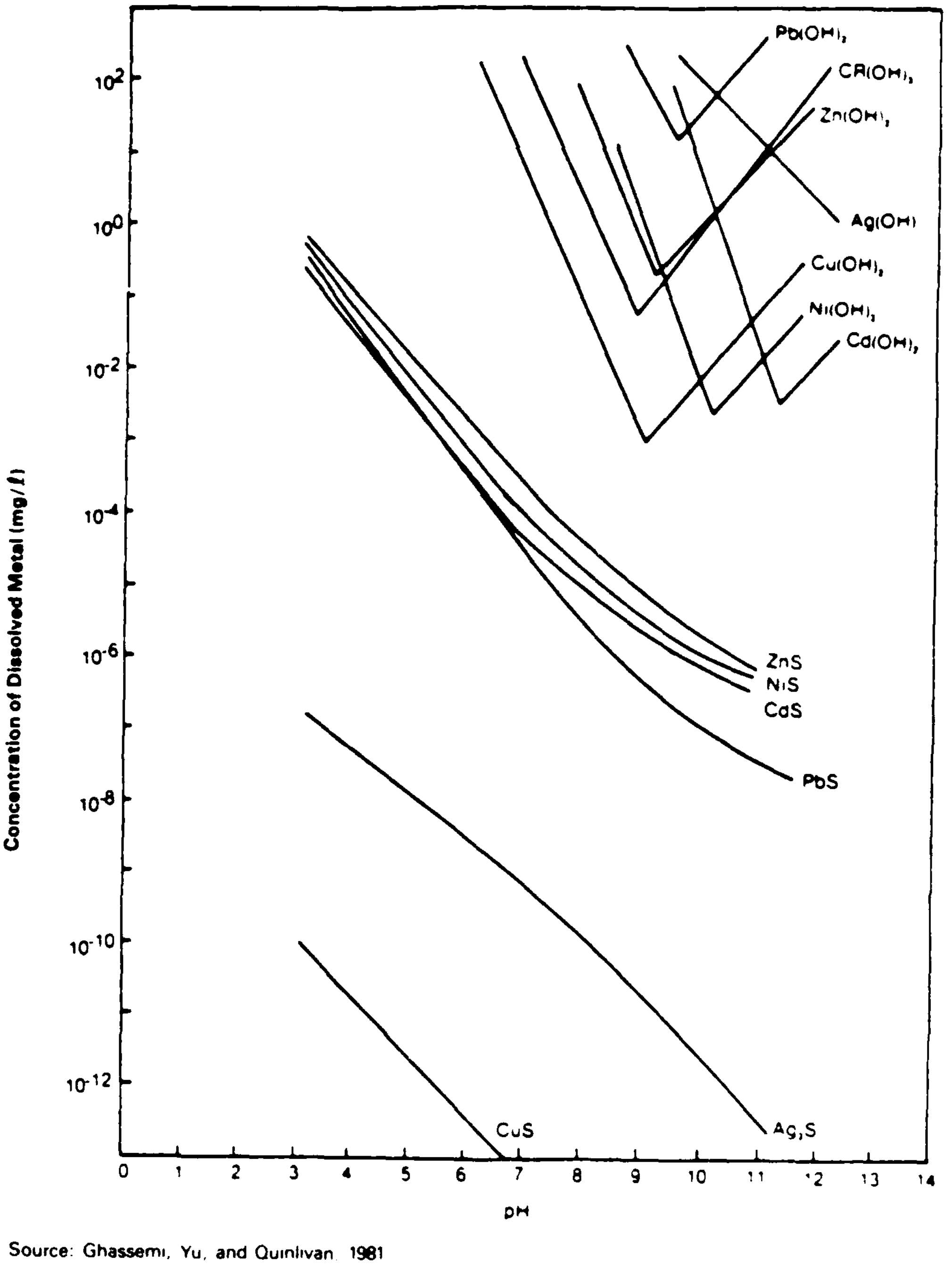
The filtration process can remove 60 to 98 percent of the suspended solids and sediment-bound contaminants. Typically, the effluent suspended solids concentration is reduced to 5 to 10 mg/ℓ in these coarse filters.

Level II Treatment

Chemical Precipitation. Precipitation is a physicochemical process whereby some or all of a substance in solution is transformed into a solid phase. It is based on alteration of the chemical equilibrium relationships affecting the solubility of inorganic species. Removal of metals as hydroxides or sulfides is the most common precipitation application in wastewater treatment. Generally, lime or sodium sulfide is added to the wastewater in a rapid-mixing tank along with flocculating agents (described below). The wastewater flows to a flocculation chamber in which adequate mixing and retention is provided for agglomeration of precipitate particles. Agglomerated particles are separated from the liquid phase by settling in a sedimentation chamber and/or by other physical processes such as filtration.

Although precipitation of metals is governed by the solubility product of ionic species, in actual practice, effluent concentrations equal to the solubility product are rarely achieved. Usually, the amount of lime added is about three times the stoichiometric amount that would be added to reduce solubility due to the common ion effect. Figure 4.23 gives solubilities of various metal hydroxides and sulfides at various pH levels. The metal sulfides have significantly lower solubility than their hydroxide counterparts and more complete precipitation is achieved. Metal sulfides are also stable over a broad pH range. Many metal hydroxides, on the other hand, are stable only over a narrow pH range; metals reach a minimum solubility at a specific pH, but further addition of lime causes the metal to become soluble again. Therefore, dosages of lime need to be accurately controlled. This may be particularly challenging when working with aqueous wastes from waste disposal sites where wide variations in flow rates and quantities of metals are to be removed. The stabilities of metal carbonates are also quite dependent on pH.

Precipitation is applicable to the removal of most metals from wastewater including zinc, cadmium, chromium, copper, fluoride, lead, manganese, and



Source: Ghassemi, Yu, and Quinlivan 1981

Figure 4.23. Solubilities of various metal hydroxides and sulfides

mercury. Also, certain anionic species can be removed by precipitation, such as phosphate, sulfate, and fluoride.

Precipitation is useful for most aqueous hazardous waste aqueous streams. However, limitations may be imposed by certain physical or chemical characteristics. In some cases, organic compounds may form organometallic complexes with metals, which could inhibit precipitation. Cyanide and other ions in the wastewater may also complex with metals, making treatment by precipitation less efficient.

Selection of the most suitable precipitate or flocculant and their optimum dosages is determined through laboratory jar test studies. In addition to determining the appropriate chemicals and optimum chemical dosages, other important parameters which need to be determined as part of the overall design include (Canter and Knox 1985):

a. Most suitable chemical addition system.
b. Optimum pH requirement.
c. Rapid mix requirements.
d. Sludge production.
e. Sludge flocculation, settling, and dewatering characteristics.

Precipitation is a well-established technology and the operating parameters are well defined. The process requires only chemical pumps, metering devices, and mixing and settling tanks. The equipment is readily available and easy to operate. Precipitation can be easily integrated into more complex treatment systems.

The performance and reliability of precipitation depends greatly on the variability of the composition of the waste being treated. Chemical addition must be determined using laboratory tests and must be adjusted with compositional changes of the waste being treated, or poor performance will result.

Precipitation is nonselective in that compounds other than those targeted may be removed. Precipitation is nondestructive and generates a large volume of sludge which must be disposed.

Precipitation poses minimal safety and health hazards to field workers. The entire system is operated at near ambient conditions, eliminating the danger of high pressure/high temperature operation with other systems. While the chemicals employed are often skin irritants, they can easily be handled in a safe manner. Chemical precipitation by lime addition can significantly reduce the total and soluble concentrations of many heavy metals. The pH is raised to above pH 11 forming insoluble metallic hydroxides from the soluble heavy metal species. This process may replace chemical clarification in a treatment scheme. Chemical precipitation follows plain sedimentation and precedes filtration. This process has been widely employed in water and wastewater treatment but has not been examined and adapted for full-scale dredging operations.

The removals are limited by the solubility of the hydroxide form of the heavy metals and the precipitate removal. Some species of heavy metals are not removed by lime addition. Removals are improved if the process is followed by filtration. The effluent pH must be lowered before discharging the water.

Chemical precipitation by lime addition can remove as much as 99.9 percent of certain metals while removing less than 10 percent of other metals such as arsenic. Refer to Table 4.17 for removal efficiencies of specific metals.

Carbon Adsorption. Carbon adsorption removes contaminants from water by contacting the liquid waste stream with a solid activated-carbon adsorbent in granular (most common) or powdered form. Organic and some inorganic species become bound to the surface of the carbon particles (adsorption) and are subsequently removed along with the adsorbent. Although carbon adsorption is normally considered as an organics removal process, some inorganic species (such as antimony, arsenic, bismuth, chromium, tin, silver, mercury, and cobalt) are partially adsorbed (USEPA 1982). A listing of the potential for removal of inorganic material by activated carbon is given in Table 4.18. A more detailed discussion of carbon adsorption is provided under the section on Level III treatment.

Chemical Reduction. Chemical reduction involves addition of a reducing agent that lowers the oxidation of a substance in order to reduce toxicity or solubility or to transform it to a form that can be more easily handled. For example, in the reduction of hexavalent chromium (Cr(VI)) to trivalent chromium (Cr(III)) using sulfur dioxide, the oxidation state of Cr changes from 6+ to 3+ (Cr is reduced) and the oxidization state of S increases from 2+ to 3+ (S is oxidized). The decrease in the positive valence or increase in the negative valence with reduction takes place simultaneously with oxidation in chemically equivalent ratios (Kiang and Metry 1982).

Table 4.17

Removal of Metals by Lime Precipitation*

Metal	Concentration Before Treatment mg/ℓ	Concentration After Treatment mg/ℓ	Final pH	% Removal
Antimony**	-	-	11	90
Arsenic**	-	-	11	<10
	23	23	9.5	0
Barium**		~1.3 (sol)†	11	
Bismuth**		.002 (sol)	11	
Cadmium	Trace		11	~50
	0.0137	0.00075	>11	94.5
Chromium (+6)	0.056	0.050	>11	11
Chromium (+3)	7,400	2.7	8.7	99.9+
	15	0.4	9.5	97
Copper	15,700	0.79	8.7	99.9+
	7	1	8	86
	7	.05	9.5	93
	302	Trace	9.1	99+
	15	0.6	9.5	97
Gold**		<.001 (sol)	11	90+
Iron	13	2.4	9.1	82
	17	0.1	10.8	99+
	2.0	1.2[c]	10.5	40
Lead**	-	<.001 (sol)†	11	90+
	15	0.5	9.5	97
Manganese	2.3	0.1	10.8	96
	2.0	1.1††	10.5	45
	21.0	0.05	9.5	95
Mercury**		Oxide soluble		<10
Molybdenum	Trace	-	8.2	~10
	11	9	9.5	18
Nickel	160	0.08	8.7	99.9+
	5	0.5	8.0	90
	5	0.5	9.5	90
	100	1.5	10.0	99
	16	1.4	9.5	91
Selenium	0.0123	0.0103	>11	16.2
Silver	0.0546	0.0164	>11	97
Tellurium**,‡		(<0.001?)	11	(?90+)

(Continued)

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* Reference: Culp and Culp (1974).

** The potential removal of these metals were estimated from solubility data.

† Barium and lead reductions and solubilities are based upon the carbonate.

†† These data were from experiments using iron and manganese in the organic form.

‡ Titanium and tellurium solubility and stability data made the potential reduction estimates unsure.

Table 4.17 (Concluded)

Metal	Concentration Before Treatment mg/ℓ	Concentration After Treatment mg/ℓ	Final pH	% Removal
Titanium,‡**		(<0.001?)	11	(?90+)
Uranium‡‡		?		?
Zinc		.007 (sol)	11	90+
	17	0.3	9.5	98

---

‡‡ Uranium forms complexes with carbonate ion. Quantitative data were unavailable to allow determination of this effect.

Chemical reduction is used primarily for reduction of hexavalent chromium, mercury, and lead. There are currently no practical applications involving reduction of organic compounds.

Very simple equipment is required for chemical reduction. This includes storage vessels for the reducing agents and perhaps for the wastes, metering equipment for both streams, and contact vessels with agitators to provide suitable contact of reducing agent and waste. Some instrumentation is required to determine the concentration and pH of the waste and the degree of completion of the reduction reaction. The reduction process may be monitored by an oxidation-reduction potential (ORP) electrode (Kiang and Metry 1982).

Chemical reduction is well demonstrated for the treatment of lead, mercury, and chromium. However, for complex waste streams containing other potentially reducible compounds, laboratory- and pilot-scale tests will be required to determine appropriate chemical feed rates and reactor retention times.

Chemical reduction can be carried out using simple, readily available equipment and reagents. Capital and operating costs are low and the process is easy to implement.

Capital costs for chemical reduction include costs for chemical storage, chemical feeding, and chemical mixing. These costs can be approximated using Fig. 4.24.

Chemical Oxidation. Reduction-oxidation (redox) reactions are those in which the oxidation-state of at least one reactant is raised while that of another is lowered. In chemical oxidation, the oxidation state of the treated compound(s) is raised. For example, in the conversion of cyanide to cyanate

Table 4.18

Potential for Removal of Inorganic Material by Activated Carbon

Constituents	Potential for Removal by Carbon
Metals of high sorption potential:	
Antimony	Highly sorbable in some solutions
Arsenic	Good in higher oxidation states
Bismuth	Very good
Chromium	Good, easily reduced
Tin	Proven very high
Metals of good sorption potential:	
Silver	Reduced on carbon surface
Mercury	CH_3H_gCl sorbs easily, metal filtered out
Cobalt	Trace quantities readily sorbed possibly as complex ions
Zirconium	Good at low pH
Elements of fair-to-good sorption potential:	
Lead	Good
Nickel	Fair
Titanium	Good
Vanadium	Variable
Iron	FE^{3+} good, FE^{2+} poor, but may oxidize
Elements of low or unknown sorption potential:	
Copper	Slight, possible good if complexed
Cadmium	Slight
Zinc	Slight
Beryllium	Unknown
Barium	Very low
Selenium	Slight
Molybdenum	Slight at pH 6-8, good as complex ion
Manganese	Not likely, except as MnO_4
Tungsten	Slight
Miscellaneous inorganic water constituents:	
Phosphorus	
P, free element	Not likely to exist in reduced form in water
PO_4^{3-} phosphate	Not sorbed but carbon may induce precipitation $Ca_3(PO_4)_2$

(Continued)

Table 4.18 (Concluded)

Constituents	Potential for Removal by Carbon
Free halogens:	
F_2 fluorine	Will not exist in water
Cl_2 chlorine	Sorbed well and reduced
Br_2 bromine	Sorbed strongly and reduced
I_2	Sorbed very strongly, stable
Halides:	
F^- fluoride	May sorb under special conditions
Cl^-, BR^-, I^-	Not appreciably sorbed

under alkaline conditions using permanganate, the oxidation state of the cyanide ion is raised as it combines with an atom of oxygen to form cyanate. This reaction can be expressed as follows:

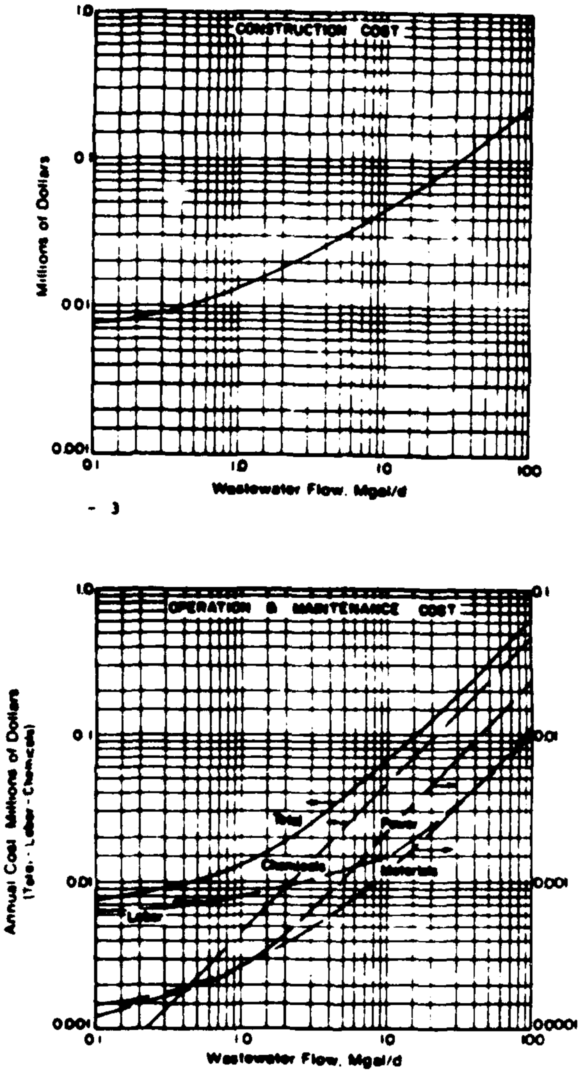
$$2\ NaCN + 2KMnO_4 + KOH \rightarrow 2\ K_2MNO_4 + NaCNO + H_2O$$

Common commercially available oxidants include potassium permanganate, hydrogen peroxide, *calcium or sodium hypochlorite, and chlorine gas.*

Chemical oxidation is used primarily for detoxification of cyanide and for treatment of dilute waste streams containing oxidizable organics. Among the organics for which oxidative treatment has been reported are aldehyde, mercaptans, phenols, benzidine, unsaturated acids, and certain pesticides (Kiang and Metry 1982).

Chemical oxidation can be an effective way of pretreating wastes prior to biological treatment; compounds that are refractory to biological treatment can be partially oxidized making them more amenable to biological oxidations.

One of the major limitations with chemical oxidation is that the oxidation reactions frequently are not complete (reactions do not proceed to CO_2 and H_2O). Incomplete oxidation may be due to oxidant concentration, pH, oxidation potential of the oxidant, or formation of a stable intermediate (Kiang and Metry 1982). The danger of incomplete oxidation is that more toxic oxidation products could be formed. Chemical oxidation is not well suited to high-strength complex waste streams. The most powerful oxidants are relatively nonselective and any oxidizable organics in the waste stream will be



*Costs can be updated to $1985 using ENR Construction Cost Indices for 1982 and 1985 (multiply value shown on this figure by 1.303)

Figure 4.24. Costs of chemical storage, chemical feeding, and chemical mixing

treated. For highly concentrated waste streams, this will result in the need to add large concentrations of oxidizing agents in order to treat target compounds. Some oxidant such as potassium permanganate can be decomposed in the presence of high concentrations of alcohols and organic solvents (Kiang and Metry 1982).

Equipment requirements for chemical oxidation are simple and include contact vessels with agitators to provide suitable contact of the oxidant with the waste, storage vessels, and chemical metering equipment. Some instrumentation is required to determine pH and the degree of completion of the oxidation reaction. Some oxidizing reagents react violently in the presence of significant quantities of readily oxidizable materials. Therefore reagents must be added in small quantities to avoid momentary excesses.

Oxidation reactions can be carried out using simple, readily available equipment; only storage vessels, metering equipment, and contact vessels with agitators are required. However, implementation is complicated because every oxidation/reduction reaction system must be designed for the specific application. Laboratory- and/or pilot-scale tests are essential to determine the appropriate chemical feed rates and reactor retention times in accordance with reaction kinetics. Oxidation and reduction has not been widely used in treating contaminants from dredged material disposal sites.

A major consideration in electing to utilize oxidation technology is that the treatment chemicals are invariably hazardous, and great care must be taken in their handling. In particular, the handling of many oxidizing agents is potentially hazardous, and suppliers' instructions should be carefully followed.

In some cases, undesirable byproducts may be formed as a result of oxidation. For example, addition of chlorine can result in formation of bio-resistant end products that can be odorous and more toxic than the original compound. The possibility of this undesirable side reaction needs to be considered when using chlorine for oxidation of wastewaters (Conway and Ross 1980).

Capital costs for chemical oxidation include costs for chemical storage, chemical feeding and chemical mixing. These costs can be approximated using Fig. 4.24.

Ion Exchange. Ion exchange is a process whereby the toxic ions are removed from the aqueous phase by being exchanged with relatively harmless ions held by the ion exchange material. Modern ion exchange resins are primarily synthetic organic materials containing ionic functional groups to which exchangeable ions are attached. These synthetic resins are structurally stable (that is, can tolerate a range of temperature and pH conditions), exhibit a high exchange capacity, and can be tailored to show selectivity towards specific ions. Exchangers with negatively-charged sites are cation exchangers because they take up positively charged ions. Anion exchangers have positively charged sites and, consequently, take up negative ions. The exchange reaction is reversible and concentration dependent, and it is possible to regenerate the exchange resins fo reuse. Sorptive (macroporous) resins are also available for removal of organics and the removal mechanism is one of sorption rather than ion exchange (Ghassemi et al. 1981).

Ion exchange is used to remove a broad range of ionic species from water including:

a. All metallic elements when present as soluble species, either anionic or cationic.

b. Inorganic anions such as halides, sulfates, nitrates, cyanides, etc.

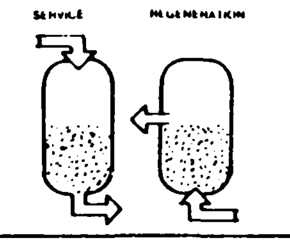
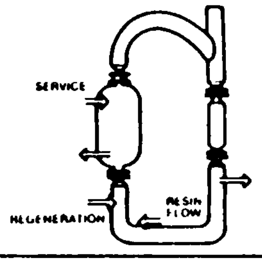
c. Organic acids such as carboxylics, sulfonics, and some phenols, at a pH sufficiently alkaline to give the ions.

d. Organic amines when the solution acidity is sufficiently acid to form the corresponding acid salt (De Renzo 1978).

Sorptive resins can remove a wide range of polar and non-polar organics.

A practical upper concentration limit for ion exchange is about 2,500 to 4,000 mg/ℓ. A higher concentration results in rapid exhaustion of the resin and inordinately high regeneration costs. Suspended solids in the feed stream should be less than 50 mg/ℓ to prevent plugging the resins, and waste streams must be free of oxidants (De Renzo 1978).

Specific ion exchange and sorptive resin systems must be designed on a case-by-case basis. It is useful to note that although there are three major operating models (fixed-bed cocurrent, fixed-bed countercurrent, and continuous countercurrent), fixed bed countercurrent systems are most widely used. Figure 4.25 illustrates the fixed bed countercurrent and continuous countercurrent systems. The continuous countercurrent system is suitable for high flows. Complete removal of cations and anions (demineralization) can be accomplished by using the hydrogen form of a cation exchange resin and the hydroxide form of an anion exchange resin. For removal of organics as well as inorganics, a combination adsorptive/demineralization system can be used. In this system, lead beds would carry sorptive resins that would act as organic scavengers, and the end beds would contain anion and cation exchange resins. By carrying different types of adsorptive resins (e.g., polar and nonpolar), a broad spectrum of organics could be removed (Ghassemi et al. 1981).

Types	Countercurrent Fixed Bed  	Continuous Countercurrent 
Description of Process	Regeneration flows opposite in direction to influent. Backwash (in regeneration) does not occur on every cycle to preserve resin stage heights. Resin bed is locked in place during regeneration	Multi stage countercurrent movement of resin in closed loop providing simultaneous treatment, regeneration, backwash and rinse. Operation is only interrupted for momentary resin pulse
Indications for Use	Handles high loads at moderate thruput or low loads at high thruput (GPM x TDS or GPM x PPM removal = 40,000 or more). Where effluent quality must be relatively constant, regeneration cost is relatively critical, disposal of single batch waste volume no problem	Highloads with high thruputs (GPM x TDS or GPM x PPM removal = 40,000 or more). Where constant effluent quality is essential, regeneration costs critical, total waste volume requires small, concentrated stream to be controllable. Where loss of product thru dilution and waste must be minimized. Where available floor space is limited
Advantages	Moderate capital cost. Can be operated with periodic attention. Moderate regeneration cost. Lesser volume of waste due to less frequent backwash. Consistent effluent quality	Lowest regeneration cost. Lowest resin inventory. Consistent effluent quality. Highest thruput to floor space. Large capacity units factory preassembled. Concentrated low volume waste stream. Can handle strong chemical solutions and slurry. Fully automatic operation
Disadvantages	Increased controls and instrumentation, higher cost. Requires mechanism to lock resin bed. Large single batches of waste disposal. Moderate water consmption thru dilution and waste. Requires substantial floor space	Requires automatic controls and instrumentation, higher capital cost. More headroom required

Source: Chemical Seperations Corporation

Figure 4.25. Typical ion exchange installations

Ion exchange is a well-established technology for removal of heavy metals and hazardous anions from dilute solutions. Ion exchange can be expected to perform well for these applications when fed wastes of variable composition, provided the system's effluent is continually monitored to determine when resin bed exhaustion has occurred. However, as mentioned previously, the reliability of ion exchange is markedly affected by the presence of suspended solids. Use of sorptive resins is relatively new and reliability under various conditions is not as well known.

Ion exchange systems are commercially available from a number of vendors. The units are relatively compact and are not energy intensive. Start-up or shut-down can be accomplished easily and quickly (Ghassemi et al. 1981).

These features allow for convenient use of ion exchange and sorptive resin systems in mobile treatment systems.

Although exchange columns can be operated manually or automatically, manual operation is better suited for disposal site applications because of the diversity of wastes encountered; with manual operation, the operator can decide when to stop the service cycle and begin the backwash cycle. However, this requires use of a skilled operator familiar with the process (Ghassemi et al. 1981).

Use of several exchange columns at a site can provide considerable flexibility. As described previously, various resin types can be used to remove anions, cations, and organics. Various columns can be arranged in series to increase service-life between regeneration of the lead bed or in parallel for maximum hydraulic capacity. The piping arrangement would allow for one or more beds to be taken out for regeneration while the remaining columns would remain in service (Ghassemi et al. 1981).

Consideration must be given to disposal of contaminated ion exchange regeneration solution. In addition to proper disposal, another important operational consideration is the selection of regeneration chemicals. Caution must be exercised in making this selection to ensure the compatibility of the regenerating chemical with the waste being treated. For example, the use of nitric acid to regenerate an ion exchange column containing ammonium ions results in the formation of ammonium nitrate, a potentially explosive compound.

Costs for various sizes of ion exchange units are presented in Table 4.19. The construction costs assume fabricated steel contact vessels with baked phenolic linings, a resin depth of 6 ft, housing for the columns, and all piping and backwash facilities.

Operation and maintenance costs include electricity for backwashing (after 150 bed volumes have been treated) and periodic repair and replacement costs. Costs for regenerant chemicals are not included because they vary depending on the types and concentrations of target chemicals to be removed from the wastewater.

Level III Treatment

Carbon Adsorption. Carbon adsorption removes contaminants from water by contacting the stream with a solid activated-carbon adsorbent in granular (most common) or powdered form. Organic compounds and some inorganic species

Table 4.19

General Cost Data for Various Sizes of Exchange Units*

Plant Capacity, gpm	Construction Cost, $*	Operation and Maintenance Costs $/year**
50	84,105	14,530
195	116,200	21,260
305	134,770	24,280
438	154,000	27,590
597	180,270	31,531

* Source: Adapted from Hansen, Gumerman, and Culp (1979).

** Updated from 1979 to 1984 dollars using third quarter Marshall and Swift Index.

become bound to the surface of the carbon particles (adsorption) and are subsequently removed along with the adsorbent. Carbon adsorption is normally used to remove organic contaminants that are resistant to biological treatment; however, in some cases has been used to replace biological treatment processes.

Several commercial carbons are available. The products differ in physical properties such as pore size, surface area, and adsorption characteristics. Some commercial carbons are listed in Table 4.20. Carbon selection requires laboratory testing of carbon-adsorption capacities for the specific waste stream to be treated. Both equilibrium adsorption isotherms and carbon column breakthrough curves should be determined.

Carbon columns can be used in either upflow or downflow configuration and can be arranged in either series or parallel operation as shown in Fig. 4.26. Table 4.21 describes attributes for the various arrangements. Downflow is generally an inefficient use of activated carbon and will require frequent backwashing. Upflow beds usually operate in expanded bed mode requiring no backwashing, but may require pressure pumping and will cost more than downflow beds. Field loading rates vary from 2 to 10 gpm per square foot of bed cross section. Bed depths range from 4 ft to 20 ft. In a pulsed bed system, a layer of exhausted carbon is withdrawn from the bottom of the carbon bed with a regenerated layer being added to the top of the bed.

Table 4.20

Properties of Several Commercially Available Carbons*

Physical Properties**	ICI America Hydrodarco 3000	Calgon Filtrasorb 300 (8x30)	Westvaco Nuchar WV-L (8x30)	Witco 517 (12x30)
Surface area, m^2/gm (BET)	600-500	950-1050	1000	1050
Apparent density, gm/cc	0.43	0.48	0.48	0.48
Density, backwashed and drained, lb/cu ft	22	26	26	30
Real density, gm/cc	2.0	2.1	2.1	2.1
Particle density, gm/cc	1.4-1.5	1.3-1.4	1.4	0.92
Effective size, mm	0.8-0.9	0.8-0.9	0.85-1.05	0.89
Uniformity coefficient	1.7	1.9 or less	1.8 or less	1.44
Pore volume, cc/gm	0.95	0.85	0.85	0.60
Mean particle diameter, mm	1.6	1.5-1.7	1.5-1.7	1.2
Specifications				
Sieve size (U.S. std. series)- maximum %				
Larger than No 8	8	8	8	c
Larger than No. 12	†	†	†	5
Smaller than No. 30	5	5	5	5
Smaller than No. 40	†	†	†	†
Iodine no.	650	900	950	1000
Abrasion no., minimum	††	70	70	85
Ash (%)	††	8	7.5	0.5
Moisture as packed, max. %	††	2	2	1

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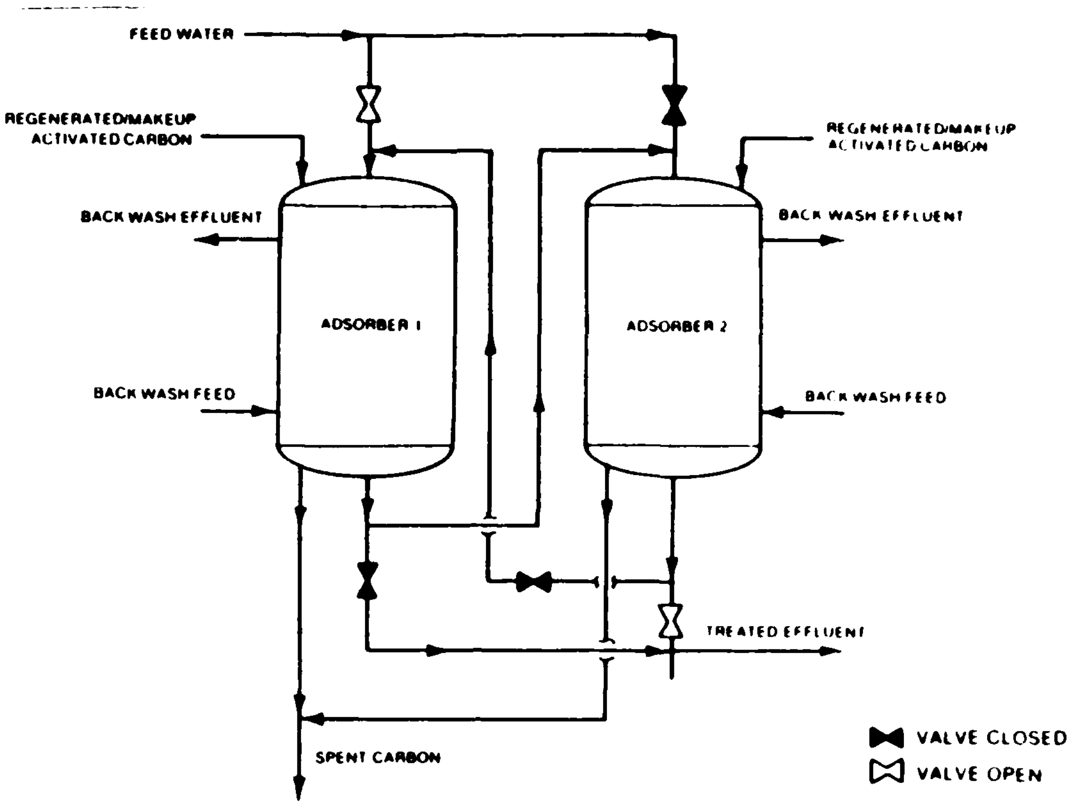
* Source: ADL (1976).

** Other sizes of carbon are available on request from the manufacturers.

† Not applicable to this size carbon.

†† No available data from the manufacturer.



Source: USEPA, 1973a

Figure 4.26. Granular activated-carbon system configuration

Powdered carbon is fed to a treatment system using chemical feed equipment. The spent carbon may either be wasted or recovered and regenerated. Carbon requirements range from 250 to 350 lb of carbon per million gallons of water treated. It is conceivable that powdered carbon could be added to the secondary settling basin with chemical addition during the chemical clarification process. The carbon would adsorb organics and trace metals and could be pumped back to the plain sedimentation basin along with the rest of the flocculated solids.

The choice of system configuration for both granular and powdered carbon depends on many factors. Table 4.22 presents a summary of the primary determinants. The flow direction depends on the specific application. Downflow systems can accommodate higher suspended concentrations (i.e., 65 to 70 mg/ℓ) if the liquid viscosity is similar to that of water. Solids are filtered out

Table 4.21

Attributes of Contacting Systems*

Methods	Application Conditions	Comments
Single or parallel adsorbers	Pollutant breakthrough curve Carbon recharge interval is long Volume flow is high Influent is viscous	Typical flows are 1 to 4 gpm/ft^2 Parallel system is usually selected if pressure drop problems are expected for the system Moderate adsorbent expense
Adsorbers in series	Pollutant breakthrough curve is gradual Uninterrupted operation is necessary Relatively low effluent concentration is required Carbon recharge interval is short	Typical flows are 3 to 7 gpm/ft^2 High adsorbent expense
Expanded upflow adsorber(s)	For high flows and high suspended solids concentrations	Typical flows are 5 to 9 gpm/ft^2 Suspended solids are passed through the column and not separated
Moving bed	For systems requiring efficient use of carbon (i.e., carbon-adsorption capacity is exhausted before removal from column).	Influent must contain less than 10 mg/ℓ TSS and not be biologically active. Either parameter will cause a pressure drop in the system and necessitate removal of carbon prior exhaustion of its absorption capacity

(Continued)

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* Source: ADL (1976).

Table 4.21 (Concluded)

Methods	Application Conditions	Comments
Powdered carbon with subsequent clarifier and/or filter	Carbon usage higher than for series of fixed-bed adsorbers	No restrictions on suspended solids or oil and grease in influent
	Influent concentration of pollutants should be relatively constant to avoid frequent sampling and adjustment of carbon dosage	Capital equipment costs relatively low
		Simple to operate
Powdered activated-carbon with activated sludge	For activated sludge systems receiving toxic or shock organic loadings	Protects the biological system from toxic organics and shock loadings. Generally improves effluent quality

Table 4.22

Factors Affecting Equilibrium Adsorbability*

- Compound adsorbability favored by:
  - Increasing carbon chain length**
  - Increasing aromaticity
  - Decreasing polarity
  - Decreasing branching
  - Decreasing solubility
  - Decreasing degree of dissociation
- Functionality
  - Relative adsorbability: acids > aldehydes > esters > ketones > alcohols > glycols when number of carbon atoms is <4
- pH effects
  - Undissociated species are more easily adsorbed
    - low pH favors adsorption of acids (e.g., volatile acids, phenol)†
    - high pH favors adsorption of bases (e.g., amines)
  - Other compounds: adsorption can be favored by higher pH
    - Postulated general effect:
      - Partial neutralization of surface acidity reduces hydrogen-bonding of surface groups eliminating steric blockage of micropores
- Temperature
  - Increased temperatures can increase rate of adsorption due to viscosity and diffusivity effects
  - Exothermic adsorption reactions are favored by decreasing temperatures, usually a minor effect on equilibrium level

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* Source: Conway and Ross (1980).

** When the rate is controlled by intraparticle transport, decreasing molecular size would result in faster rate, all else being equal.

† This often is the most significant pH effect, so adsorption generally is increased with decreasing pH.

and the column requires periodic backwashing. Upflow systems can handle more viscous liquids and require less bed washing. The most commonly used contact method is a flow through column system.

Carbon adsorption technology is applicable to dissolved organics, generally. Many organics can be reduced to the 1 to 10 μg/ℓ level. Results of an EPA study showed that 51 of 60 toxic organic compounds could be removed (USEPA 1980). Conventional water quality parameters (BOD, COD, TOC) are also reduced by carbon adsorption; the performance level is dependent on the specific waste stream characteristics. Although there is no theoretical technical upper limit for the concentration of adsorbable organics in the waste stream, economics in conventional systems generally dictate a practical limit of about 1 percent.

If carbon usage rates exceed 1,000 lb per day, regeneration of carbon is generally feasible. Regeneration of spent carbon may be accomplished by a variety of means, the most common involving thermal destruction of the adsorbed organics in a multiple hearth furnace. About 5 to 10 percent of the carbon is lost in this regeneration process (and most other processes) due to the creation of fines from the mechanical handling of the carbon. Other regeneration processes include thermal treatment with steam, extraction of adsorbed organics with solvents (including acids, bases, and super critical fluids), and biological degradation of the adsorbed material.

Activated carbon is a well developed technology which is widely used in the treatment of hazardous waste streams. It is especially well suited for removal of mixed organics from aqueous wastes. Table 4.23 provides an indication of the treatability of organics commonly found in groundwater.

As carbon adsorption is essentially an electrical interaction phenomenon, the polarity of the waste compounds will largely determine the effectiveness of the adsorption process. Highly polar molecules cannot be effectively removed by carbon adsorption. Another factor to consider in determining the likely effectiveness of carbon adsorption is aqueous solubility. The more hydrophobic (insoluble) a molecule is, the more readily the compound is adsorbed. Low solubility humic and fulvic acids that may be present in the groundwater can sorb to the activated carbon more readily than most waste contaminants and result in rapid carbon exhaustion.

In addition, some metals and inorganic species have shown excellent to good adsorption potential, including antimony, arsenic, bismuth, chromium, tin, silver, mercury, cobalt, zirconium, chlorine, bromine, and iodine.

Carbon adsorption is frequently used following biological treatment and/or granular media filtration in order to reduce the organic and suspended solids load on the carbon columns or to remove refractory organics that cannot be biodegraded. Air stripping may also be applied prior to carbon adsorption in order to remove a portion of the volatile contaminants, thereby reducing the organic load to the column. These pretreatment steps all minimize carbon regeneration costs.

The highest concentration of solute in the influent stream that has been treated on a continuous basis is 10,000 ppm total organic carbon (TOC), and a 1 percent solution is currently considered as the upper limit (De Renzo 1978). Pretreatment is required for oil and grease and suspended solids.

Table 4.23

Results of Carbon Adsorption on Various Contaminants*

Organic Compounds in Groundwater	Number of Occurrences	Influent Concentration Range/ℓ**	Carbon Effluent Concentration Achieved/ℓ**
Carbon tetrachloride	4	130 μg/ℓ-10 mg/ℓ	<1 μg/ℓ
Chloroform	5	20 μg/ℓ-3.4 mg/ℓ	<1 μg/ℓ
DDD	1	1 μg/ℓ	<.05 g/ℓ
DDE	1	1 μg/ℓ	<0.05 μg/ℓ
DDT	1	4 μg/ℓ	<0.05 μg/ℓ
CIS-1,2-dichloroethylene	8	5 μg/ℓ-4 mg/ℓ	<1 μg/ℓ
Dichloropentadiene	1	450 μg/ℓ	<10 μg/ℓ
Disopropyl ether	2	20-34 μg/ℓ	<1 μg/ℓ
Tertiary methyl-butylether	1	33 μg/ℓ	<5.0 μg/ℓ
Diisopropyl methyl phosphonate	1	1,250 μg/ℓ	<50 μg/ℓ
1,3-dichloropropene	1	10 μg/ℓ	<1 μg/ℓ
Dichlorethyl ether	1	1.1 mg/ℓ	<1 μg/ℓ
Dichloroisopropylether	1	0.8 mg/ℓ	<1 μg/ℓ
Benzene	2	0.4-11 mg/ℓ	<1 μg/ℓ
Acetone	1	10-100 μg/ℓ	<10 mg/ℓ
Ethyl acrylate	1	200 mg/ℓ	<1 mg/ℓ
Trichlorotrifloroethane	1	6 mg/ℓ	<10 μg/ℓ
Methylene chloride	2	1-21 mg/ℓ	<100 μg/ℓ
Phenol	2	63 mg/ℓ	<1 μg/ℓ
Orthochlorophenol	1	100 mg/ℓ	<1 μg/ℓ
Tetrachloroethylene	10	5 μg/ℓ-70 mg/ℓ	<1 μg/ℓ
Trichloroethylene	15	5 μg-16 mg/ℓ	<1 μg/ℓ
1,1,1-trichloroethane	6	60 μg/ℓ-25 mg/ℓ	<1 μg/ℓ
Vinylidiene chloride	2	5 μg/ℓ-4 mg/ℓ	<1 μg/ℓ
Toluene	1	5-7 mg/ℓ	<10 μg/ℓ
Xylene	3	0.2-10 mg/ℓ	<101 μg/ℓ

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* Source: O'Brien and Fisher (1983).

** Analyses conducted by Calgon Carbon Corporation conformed to published USEPA protocol methods. Tests in the field were conducted using available analytical methods.

Concentrations of oil and grease in the influent should be limited to 10 ppm. Suspended solids should be less than 50 ppm for upflow systems, while downflow systems can handle much higher solids loadings.

The phenomenon of adsorption is extremely complex and not mathematically predictable. To accurately predict performance, longevity, and operating economics, field pilot plant studies are necessary.

In order to conduct an initial estimate of carbon column sizing, the following data need to be established during pilot plant testing:

a. Hydraulic retention time (hours).
b. Flow (gallons/minute).
c. Hydraulic capacity of the carbon (gallons waste/pound carbon).
d. Collected volume of treated waste at breakthrough (gallons).
e. Carbon density (pounds carbon/cubic foot).

In the above list, the term "breakthrough" refers to the moment when the concentration of solute being treated first starts to rise in the carbon unit effluent. The term "exhaustion" refers to the moment when the concentration of solute being treated is the same in both effluent and influent.

Activated carbon is an effective and reliable means of removing low solubility organics. It is suitable for treating a wide range of organics over a broad concentration range. It is not particularly sensitive to changes in concentrations or flow rate and, unlike biological treatment, is not adversely affected by toxics. However, it is quite sensitive to suspended solids and oil and grease concentrations.

Activated carbon is easily implemented into more complex treatment systems. The process is well suited to mobile treatment systems as well as to onsite construction. Space requirements are small; start-up and shut-down are rapid; and there are numerous contractors who are experienced in operating mobile units.

Use of several carbon-adsorption columns at a site can provide considerable flexibility. Various columns can be arranged in series to increase service life between regeneration of the lead bed or in parallel for maximum hydraulic capacity. The piping arrangement would allow for one or more beds to be regenerated while the other columns remain in service.

The most obvious maintenance consideration associated with activated-carbon treatment is the regeneration of spent carbon for reuse. Regeneration must be performed for each column at the conclusion of its bed-life so the spent carbon may be restored as close as possible to its original condition for reuse; otherwise, the carbon must be disposed of. Other operation and maintenance requirements of activated-carbon technology are minimal if appropriate automatic controls have been installed.

It is recommended that the thermal destruction properties of waste chemicals be determined prior to selection of activated-carbon treatment technology, since any chemicals sorbed to activated carbon must eventually be destroyed in a carbon regeneration furnace. Therefore, of crucial importance to the selection of activated carbon treatment is whether the sorbed contaminants can be effectively destroyed in the regeneration furnace; otherwise, upon introduction to the furnace, they will become air pollutants.

The biggest limitation of the activated-carbon process is the high capital and operating cost. As described previously, the operating costs can be substantially reduced by pretreatment of the waste using biological treatment or air stripping.

The cost of activated-carbon units depends on the size of the contact unit, which is influenced by the concentrations of the target and nontarget organic compounds in the contaminated stream and the desired level or target compounds in the effluent. Table 4.24 presents construction, operation, and maintenance costs for cylindrical pressurized, downflow steel contactors based on a nominal detention time of 17.5 minutes and a carbon loading rate of 5 gpm/ft^2. The construction costs include housing, concrete foundation, and all the necessary pipes, valves, and nozzles for operating the unit plus the initial change of carbon. The operation and maintenance cost include the electricity and assume carbon replacement once a year. However, systems for unloading spent carbon and loading fresh carbon are not included.

There are a number of manufacturers such as Calgon Carbon Corporation who market mobile activated carbon treatment systems. For example, Calgon Carbon Corporation has a trailer-mounted carbon-adsorption treatment unit that can be shipped to a treatment location within 24 to 48 hr. The system can be configured with either single or multiple pre-piped adsorber vessels. It can handle flow of up to 200 gpm.

Carbon-adsorption system performance is sensitive to the composition of the influent and flow variations. Because a system design based on good data can perform poorly if influent conditions change, systems are generally oversized. For fixed-bed granular carbon systems, special attention must be given to the materials of construction (to prevent corrosion and mechanical failure) and to the materials handling equipment (pipes, pumps, valves, controls) for the transfer of carbon to and from various tanks and/or regeneration units.

Care must be taken to ensure that the adsorption capacity of the carbon is not reduced either by chemicals, resins, or fine precipitates in the influent or by the continued presence of similar chemicals in the residual water (after draining) if the carbon is thermally regenerated. In the latter case, any material (e.g., inorganic salts, some resins) that is not volatilized or

Table 4.24

General Cost Data for Various Sizes of Activated-Carbon Contact Units*

Capacity gpm	Column Diameter ft	Column Length ft	Housing Area ft^2	Construction Costs, $**	O&M Costs $/yr**
1.7	0.67	5	60	12,320	1,690
17	2	5	150	23,776	2,315
70	4	5	300	42,425	4,800
175	6.5	5	375	64,000	8,110
350	9	5	450	93,822	12,540

* Source: Adapted from Hansen, Gumerman, and Culp (1979).

** Updated from 1979 to 1984 dollars using third-quarter Marshall and Swift Equipment Index.

combusted during regeneration will remain in the pores of the carbon resulting in an irreversible loss of adsorption capacity.

In all cases, it is prudent to consider the possibility of biological activity on the carbon. Such activity can help (via pollutant biodegradation) or hinder (via clogging and/or odor generation) the process. Suspended solids and oil/grease can interfere with carbon adsorption treatment. Influent concentrations of these pollutants should not exceed 50 and 10 ppm, respectively (Arthur D. Little, Inc. 1976).

Treatment of highly saline waters has the potential of resulting in insoluble salt formation during carbon regeneration. Rinsing spent carbon with fresh water prior to regeneration should prevent this potential problem. Site-specific design studies will indicate if carbon regeneration is appropriate and if freshwater washing is needed.

Biological Treatment. The function of biological treatment is to remove organic matter from the contaminated liquid stream through microbial degradation. The most prevalent form of biological treatment is aerobic, i.e., in the presence of oxygen. A number of biological treatment processes exist that may be applicable to treatment of aqueous wastes from hazardous waste sites, including conventional activated sludge; various modifications of the activated sludge process including pure oxygen activated sludge, extended aeration, and contact stabilization; and fixed-film systems, which include rotating biological discs and trickling filters.

In the conventional activated sludge process, aqueous waste flows into an aeration basin where it is aerated for several hours. During this time, a suspended active microbial population (maintained by recycling sludge) aerobically degrades organic matter in the stream along with producing new cells. A simplified equation for this process is shown below:

$$\text{Organics} + O_2 \longrightarrow CO_2 + H_2O + \text{new cells}$$

The new cells produced during aeration form a sludge, which is settled out in a clarifier. A portion of the settled sludge is recycled to the aeration basin to maintain the microbial population while the remaining sludge is wasted; i.e., it undergoes volume reduction and disposal. Clarified water flows to disposal or further processing.

In the pure oxygen activated sludge process, oxygen or oxygen-enriched air is used instead of air to increase the transfer of oxygen. Extended aeration involves longer detention times than conventional activated sludge and relies on a higher population of microorganisms to degrade wastes. Contact stabilization involves only short contact of the aqueous wastes and suspended microbial solids, with subsequent settling of sludge and treatment of the sludge to remove sorbed organics. Fixed-film systems involve contact of the aqueous waste stream with microorganisms attached to some inert medium such as rock or specially designed plastic material. The original trickling filter consisted of a bed of rocks over which the contaminated water was sprayed. The microbes forming a slime layer on the rocks would metabolize the organics, while oxygen was provided as air moved countercurrent from the water flow (Canter and Knox 1985).

Biological towers are a modification of the trickling filter. The medium (e.g., polyvinyl chloride (PVC), polyethylene, polystyrene, or redwood) is stacked into towers, which typically reach 16 to 20 ft. The contaminated water is sprayed across the top, and, as the water moves downward, air is pulled upward through the tower. A slime layer of microorganisms forms on the media and removes the organic contaminants as the water flows over the slime layer.

A rotating biological contactor (RBC) consists of a series of rotating discs connected by a shaft and set in a basin or trough. The contaminated water passes through the basin where the microorganisms, attached to the discs, metabolize the organics present in the water. Approximately 40 percent of the disc's surface area is submerged. This allows the slime layer to alternately come in contact with the contaminated water and the air where oxygen is provided to the microorganisms (Canter and Knox 1985).

There is considerable flexibility in biological treatment because of the variety of available processes and adaptability of the microorganisms themselves. Many organic chemicals are considered biodegradable, although the relative ease of biodegradation varies widely. Several generalizations can be safe with regard to the ease of treatability of organics by aerobic biological treatment:

a. Unsubstituted nonaromatics or cyclic hydrocarbons are preferred over unsubstituted aromatics

b. Materials with unsaturated bonds such as alkenes are preferred over materials with saturated bonds

c. Soluble organics are usually more readily degraded than insoluble materials. Biological treatment is more efficient in removing dissolved or colloidal materials, which are more readily attacked by enzymes. This is not the case, however, for fixed-film treatment systems, which preferentially treat suspended matter

d. The presence of functional groups affects biodegradability. Alcohols, aldehydes, acids, esters, amides, and amino acids are more degradable than corresponding alkanes, olefins, ketones, dicarboxylic acids, nitriles, and chloroalkanes

e. Halogen-substituted compounds are the most refractory to biodegradation; chlorinated alphatics are generally more refractory than the corresponding aromatics, although the number of halogens and their position is also significant in determining degradation.

f. Nitro-substituted compounds are also difficult to degrade although they are generally less refractory than the halogen-substituted compounds.

Although there are a number of compounds that are considered to be relatively resistant to biological treatment, it is recommended in practice that the treatability of waste be determined through laboratory biochemical oxygen demand (BOD) tests on a case-by-case basis.

Despite the fact that industrial type wastes may be refractory to biological treatment, microorganisms can be acclimated to degrade many compounds that are initially refractory. Similarly, while heavy metals are inhibitory to biological treatment, the biomass can also be acclimated, within limits, to tolerate elevated concentrations of metals.

In terms of the variety of biological treatment processes available, Table 4.25 presents the applications and limitations of each. The completely-mixed activated sludge process is the most widely used for treatment of aqueous wastes with relatively high organic loads. However, the high purity oxygen system has advantages for hazardous waste site remediation.

In addition, a number of other parameters may influence the performance of the biological treatment system, such as concentration of suspended solids, oil and grease, organic load variations, and temperature. Table 4.26 lists parameters that may limit system performance, limiting concentrations, and the type of pretreatment steps required prior to biological treatment.

Design of the activated sludge or fixed-film systems for a particular application can be achieved best by first representing the system as a mathematical model, and then determining the necessary coefficients by running laboratory or pilot tests.

The following models have been found to be reliable for designing biological treatment systems for waste streams containing priority pollutants (Cantor and Knox 1985).

Activated sludge:

$$V = \frac{FS_i/X}{\left(\frac{U_{max}\,S_i}{S_i - S_e}\right) - K_B}$$

Biological tower and rotating biological contactor:

$$A = \frac{FS_i}{\left(\frac{U_{max}\,S_i}{S_i - S_e}\right) - K_B}$$

Table 4.25

Summary of Applications/Limitations for Biological Treatment Processes

Process	Applications/Limitations
Conventional	Applicable to low-strength wastes; subject to shock loads
Completely-mixed conventional	Resistant to shock loads
Extended aeration	Requires low organic load and long detention times; low volume of sludge; available as package plant
Contact stabilization	Not suitable for soluble BOD
Pure oxygen	Suitable for high-strength wastes; low sludge volume; reduced aeration tank volume
Trickling filters	More effective for removal of colloidal and suspended BOD; used primarily as a roughing filter
Rotating biological disc	Can handle large flow variations and high organic shock loads; modular construction provides flexibility to meet increased or decreased treatment needs.

where

V = volume of aeration tank, ft^3

F = flow rate, ft^3/day

X = mixed liquor volatile solids, mg/ℓ

S_i = influent BOD, COD, TOC, or specific organics, mg/ℓ

S_e = effluent BOD, COD, TOC, or specific organics, mg/ℓ

U_{max} and K_B = biokinetic constants, day^{-1}

A = surface area of biological tower or rotating biological contactor, ft^2

The biokinetic constants are determined by conducting laboratory or pilot plant studies. After the biokinetic constants are determined, the required volume of aeration tank or the required surface area for a biological tower or rotating biological contactor can be determined for any biological tower or

Table 4.26

Concentration of Contaminants that Make Pretreatment Desirable*

Pollutant or System Condition	Limiting Concentration	Kind of Pretreatment
Suspended solids	>50-125 mg/ℓ flotation, lagooning	Sedimentation
Oil or grease	>35-50 mg/ℓ	Skimming tank or separator
Toxic ions		Precipitation or ion exchange
Pb	≤0.1 mg/ℓ	
Cu+Ni+CN	≤1 mg/ℓ	
Cr^{+6}+Zn	≤3 mg/ℓ	
Cr	≤10 mg/ℓ	
pH	<6, >9	Neutralization
Alkalinity	0.5 lb alkalinity as $CaCO_3$/lb BOD removed	Neutralization for excessive alkalinity
Acidity	Free mineral acidity	Neutralization
Organic load variation	>2:1-4:1	Equalization
Sulfides	>100 mg/ℓ	Precipitation or stripping with recovery
Phenols	>70-300 mg/ℓ	Extraction, adsorption, internal dilution
Ammonia	>1.6 g/ℓ	Dilution, ion exchange, pH adjustment and stripping
Dissolved salts	>10-16 g/ℓ	Dilution, ion exchange
Temperature	13-38°C in reactor	Cooling, steam addition

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* Source: Conway and Ross (1980).

concentration of BOD, COD, TOC, or specific organic, and a required effluent concentration of BOD, COD, TOC, or specific organic.

Biological treatment has not been used for removal of contaminants from liquid waste streams at dredged material disposal sites. However, the process is well established for treating a wide variety of organic contaminants. Kincannon and Stover as reported by Canter and Knox (1985) have demonstrated the effectiveness of activated sludge for treating priority pollutants. The results shown in Table 4.27 indicate that activated sludge was effective for all groups of contaminants tested except for halogenated hydrocarbons.

Although biological treatment can effectively treat a wide range of organics, it has several drawbacks for disposal site applications. The reliability of the process can be adversely affected by shock loads of toxics. Start-up time can be slow if the organisms need to be acclimated to the wastes, and the detention time can be long for complex wastes. However, the existence of cultures which have been previously adapted to the wastes can dramatically decrease start-up and detention time.

There are a number of contractors who have used biological treatment as part of a mobile treatment system for cleanup of hazardous waste disposal sites. The high purity oxygen treatment process is well suited for mobile treatment applications because the high oxygen efficiency enables use of smaller reactors, shorter detention time, and reduced power consumptions relative to other activated sludge processes. A hazard associated with the high purity oxygen process is that the presence of low flash-point compounds can present a potential fire hazard. However, the system is equipped with hydrocarbon analyzers and control systems that deactivate the system when dangerously high concentrations of volatiles are detected (Ghassemi, Yu, and Quinlivan 1981). Loss of volatile organics from other biological treatment processes can also pose some localized air pollution and a health hazard to field personnel.

Rotating biological contactors also have advantages for disposal site operations. The units are compact; they can handle large flow variations and high organic shock loads; and they do not require use of aeration equipment.

Sludge produced in biological waste treatment may be a hazardous waste due to the sorption and concentration of toxic and hazardous compounds present in the wastewater. If the sludge is hazardous, it must be disposed in an

Table 4.27

Removal Mechanisms of Toxic Organics*

Compound	Percent Treatment Achieved		
	Stripping	Sorption	Biological
Nitrogen compounds			
Acrylonitrile			99.9
Phenols			
Phenol			99.9
2,4-DNP			99.3
2,4-DCP			95.2
PCP		0.58	97.3
Aromatics			
1,2-DCB	21.7		78.2
1,3-DCB			
Nitrobenzene			97.8
Benzene	2.0		97.9
Toluene	5.1	0.02	94.9
Ethylbenzene	5.2	0.19	94.6
Halogenated hydrocarbons			
Methylene chloride	8.0	91.7	
1,2-DCE	99.5	0.50	
1,1,1-TCE	93.5		
1,2DCP	99.9		
TCE	65.1	0.83	33.8
Chloroform	19.0	1.19	78.8
Carbon tetrachloride	33.0	1.38	64.9
Oxygenated compounds			
Acroleiln			99.9
Polynuclear aromatics			
Phenanthene			98.2
Napthalene			98.6
Phthalates			
Bis(2-Ethylhexyl)			76.9
Other			
Ethyl Acetate	1.0		98.8

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* Source: Canter and Knox (1985), as cited from Kincannon and Stover, updated.

approved manner. If the sludge is not hazardous, disposal should conform with State sludge disposal guidelines.

Costs for various sizes of activated sludge units are presented in Table 4.28. The costs for these units assumed a detention time of 3 hr and use of carbon steel basins, air supply equipment, piping, and a blower building. Influent and recycle pumps were not included. The basins were sized for 50-percent sludge recycle flow. The influent biological oxygen demand (BOD) was assumed to be no greater than 130 ppm, and the effluent BOD was assumed to be 40 ppm. The operation and maintenance costs assumed that the hydraulic head loss through the aeration tank was negligible. Sludge wasting and pumping energy were not included.

Union Carbide manufactures a high purity oxygen activated sludge system that is suitable for mobile system applications. The mobile UNOX systems have hydraulic capacity of 5 to 40 gpm, are contained within 40-ft van dimensions, and include an external clarifier. The oxygen required is also supplied by Union Carbide. The customer is expected to provide installation labor, operating manpower, analytical support, and utilities. A typical installation requires three to four days (Ghassemi et al. 1981).

The mobile UNOX system can be either rented or purchased from the Union Carbide Corporation. The estimated rental costs are as follows:

a. $6,540 for the checkout and refurbishment of equipment to make it operational.
b. $550/day for onsite service including engineering consultation on program planning and execution.
c. $9/day rental of equipment.
d. Transportation charges to get the equipment from the manufacturer to the site of operation and back again.

The purchase price for the UNOX mobile unit is between $260,000 and $330,000 (Ghassemi et al. 1981, updated using 1984 third-quarter Marshall Swift Index).

Stripping. Stripping removes volatile contaminants from an aqueous waste stream by passing air or steam through the wastes. With air, the volatile gases are transferred to the air streams for discharge to the atmosphere or for further treatment such as carbon absorption or thermal oxidation. With steam, the process is a steam distillation process with the volatile contaminants ending up in the distillate for treatment. Typical system

Table 4.28

General Cost Data for Various Sizes of Activated Sludge Treatment Units*

Capacity, gpm	Construction Costs, $**	O&M Costs, $/year**
70	78,500	4,300
140	85,600	6,400
350	107,000	10,000
694	160,000	15,700

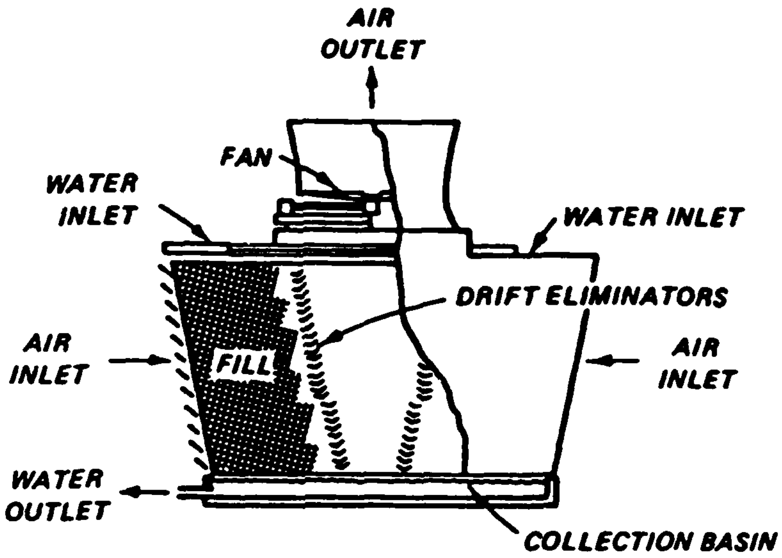
* Source: Adapted from USEPA (1980).

** Updated from 1978 to 1984 dollars using third-quarter Marshall and Swift Equipment Index.

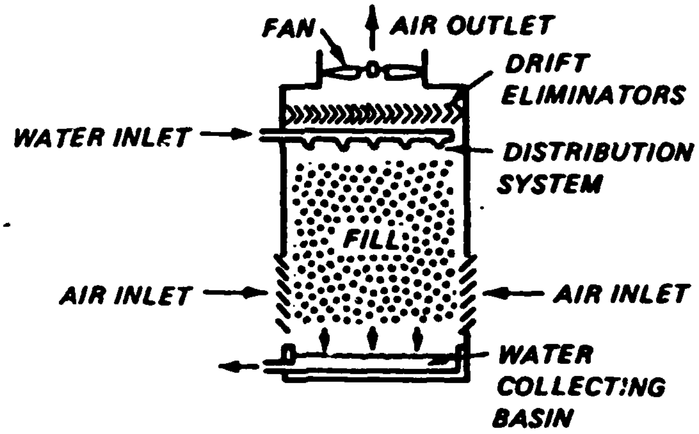
configurations are shown in Fig. 4.27. Because of economic considerations, air stripping will be stressed during this discussion.

Air stripping is frequently accomplished in a packed tower equipped with an air blower. The packed tower works on the principle of countercurrent flow. The water stream flows down through the packing while the air flows upward and is exhausted through the top. Volatile, soluble components have an affinity for the gas phase and tend to leave the aqueous stream for the gas phase. In the cross-flow tower, water flows down through the packing as in the countercurrent packed column; however, the air is pulled across the water flow path by a fan. The coke tray aerator is a simple low-maintenance process requiring no blower. The water being treated is allowed to trickle through several layers of trays. This produces a large surface area for gas transfer. Diffused aeration stripping and induced draft stripping use aeration basins similar to standard wastewater treatment aeration basins. Water flows through the basin from top to bottom or from one side to another with the air dispersed through diffusers at the bottom of the basin. The air-to-water ratio is significantly lower than in either the packed column or the cross-flow tower (Canter and Knox 1985).

Air stripping is used to remove volatile organics from aqueous wastestreams. Generally components with Henry's law constants greater than 0.003 can be effectively removed by air stripping (Conway and Ross 1980). This includes such components as 1,1,1-trichloroethane, trichloroethylene, chlorobenzene, vinyl chloride, and dichloroethylene. The feed stream must be low in suspended solids and may require pH adjustment of hydrogen sulfide,



CROSS-FLOW TOWER



COUNTERCURRENT TOWER

Figure 4.27. Typical stripping column configurations

phenol, ammonia, and other organic acids or bases to reduce solubility and improve transfer to the gas phase. Stripping is often only partially effective and must be followed by another process such as biological treatment or carbon absorption. Combined use of air stripping and activated carbon can be an effective way of removing contaminants from groundwater. The air stripper removes the more volatile compounds not removed by activated carbon and reduces the organic load on the carbon, thus reducing the frequency (and expense) of carbon regeneration.

The countercurrent packed tower has been the most widely used equipment configuration for air stripping. The reasons for this are (Canter and Knox 1985):

a. It provides the most liquid interfacial area.

b. High air-to water volume ratios are possible due to low air pressure drop through the tower.

c. Emission of stripped organics to the atmosphere may be environmentally unacceptable; however, a countercurrent tower is relatively small and can be readily connected to vapor recovery equipment.

The major disadvantage of the packed column is the high energy cost.

The design of a packed tower air stripper generally involves a determination of the cross-sectional area of the column, which is determined from physical properties of the air flowing through the column, the characteristics of the packing and the air-to-water flow ratio.

A key factor is the establishment of an acceptable air velocity. A general rule of thumb used for establishing the air velocity is that an acceptable air velocity is 60 percent of the air velocity at flooding. Flooding is the condition in which the air velocity is so high that it holds up the water in the column to the point where the water becomes the continuous phase rather than the air. If the air-to-water ratio is held constant, the air velocity determines the flooding condition. For a selected air-to-water ratio, the cross-sectional area is determined by dividing the air flow rate by the air velocity. The selection of the design air-to-water ratio must be based upon experience or pilot-scale treatability studies. Treatability studies are particularly important for developing design information for contaminated ground water (Canter and Knox 1985).

The height of column packing may be determined by the following equation (Canter and Knox, 1985):

$$Z = \frac{\ln \left[\frac{(X_2 - Y_1/H)}{(X_1 - Y_1/H)} (1-A) + A \right] L}{K_L a \; C(1-A) \; (1-X) \; M}$$

where Z = height of packing, ft

L = water velocity, lb-mole/hr/ft^2

X_2 = influent concentration of pollutant in ground water, mole fraction

X_1 = effluent concentration of pollution in ground water, mole fraction

K_La = mass transfer coefficient, gal/hr

C = molar density of water = 3.47 lb-mole/ft^3

H = Henry's law constant, mole fraction in air per mole fraction in water

G = air velocity, lb-mole/hr/ft^2

A = L/HG

(1-X)M = average of one minus the equilibrium water concentration through the column

Y_1 = influent concentration of pollutant in air, mole fraction

In most cases, the following assumptions can be made:

(1) $Y_1 = 0$, there should be no pollutants in the influent air.

(2) (1-X)M = 1, the influent concentrations should be too small when converted to mole fraction to shift this term significantly from 1.0.

The packing column height can then be determined by the simplified equation:

$$Z = \frac{\ln\left[\frac{X_2}{X_1}(1-A) + A\right] L}{K_La\ C\ (1-A)}$$

The mass transfer coefficient K_La is determined from pilot-scale treatability studies and is a function of type of compound being removed, air-to-water ratio, groundwater temperature, type of packing, and tower geometry (Canter and Knox 1985).

Calgon Carbon Corporation maintains a computer model that determines the appropriate tower diameters, packing heights, air/water ratios, and tower packing for a particular application (Calgon Carbon Corp. 1983). This model facilitates rapid mobilization of the packed tower equipment to a site.

Both versions of stripping are capable of high removal efficiencies. Air stripping of ammonia from wastewaters has exceeded 90 percent for influent ammonia concentrations of less than 100 ppm (Arthur D. Little, Inc. 1976), and 99+ percent has been achieved for removal of trichloroethylene from ground water. Steam stripping can be applied to:

a. Volatile organic compounds (phenol, vinyl, chloride, etc.).
b. Water-immiscible compounds (chlorinated hydrocarbons, etc.).
c. Ammonia.
d. Hydrogen sulfide.

Removal efficiencies of volatile organic compounds from wastewaters ranging from 10 to 99 percent have been reported (USEPA 1980).

In recent years, air stripping has gained increasing use for the effective removal of volatile organics from aqueous wastestreams. It has been used most cost effectively for treatment of low concentrations of volatiles or as a pretreatment step prior to activated carbon. Calgon manufacturers a treatment system that combines air stripping and activated carbon.

The equipment for air stripping is relatively simple; start-up and shutdown can be accomplished quickly; and the modular design of packed towers makes air stripping well suited for hazardous waste site applications.

An important factor in the consideration of whether to utilize air stripping technology for the removal of volatile contaminants is the air pollution implications of air stripping. The gas stream generated during treatment may require collection and subsequent treatment or incineration.

Packed tower air strippers have higher removal efficiencies than induced-draft systems, are lower in capital cost, and require less energy to operate than a packed-tower system. Table 4.29 describes the installed cost of an induced-draft stripper manufactured and marketed by the Calgon Carbon Corporation. As shown in Table 4.30, the installed cost of an induced-draft stripper, capable of treating 700 gpm and removing 75 percent of the TCE contamination, is about 31 percent ($19,000 vs. $61,300) of the cost of a packed-tower system, which also uses an additional $5,100 per year in electrical energy for operation of the blower.

In a typical treatment system, repumping of the treated water would be required. Adding the cost of a sump, flow control, and a pump, the overall project cost for the induced-draft system would be about one-half the cost of the packed-tower system (Calgon Carbon Corp., undated).

Table 4.29

Air Stripping Cost Estimates (Basis: 700 gpm; 1000 micrograms/liter TCE)*

	Induced-Draft Stripper (75% Removal)**	Packed-Tower 5-ft Diameter (95% Removal)†
Air Stripping Equipment	$15,000	$42,300
Stripper Assembly and Installation	4,000	19,000
Equipment Sub-total	$19,000	$61,300
Recharge Pump; Assembly and Controls	$16,000	$16,000
Foundation/Sump‡	18,000	23,700
Equipment Freight	2,000	5,000
Project Management	10,000	20,000
Project Contingency	7,000	20,000
Total	$72,000	$146,000

* Source: O'Brien and Stenzel (undated).

** Calgon Model No. 909B (8'0" x 9'1" x 9'0").

† Tower is made of fiberglass reinforced plastic and contains 15 ft of 2-in. diameter polypropylene pall ring packing. Cost includes tower, packing, packing support, demister, 4,000 cfm fan with 10 hp motor, damper, piping valves, and ductwork.

‡ Sump 5' x 5' x 8' below grade concrete.

Level IV Treatment

Level IV treatment processes are employed in those cases where nutrient removal is required. Nutrients include ammonia nitrogen and phosphates. Removal processes include both biological and physical-chemical processes. Common processes used for nutrient removal include air stripping, ion exchange, activated sludge, and chemical precipitation. Each of these has been discussed in detail in previous sections.

Level V

There are a number of processes that can be applied to the treatment of brackish and highly saline waters. These processes include, but are not limited to, distillation or evaporation, electrodialysis, ion exchange, and reverse osmosis. In the case of nearshore and upland treatment, these processes would only be used to achieve the highest quality of water. Because of the high initial investment and intensive energy and operation requirements, dissolved solids removal is rarely used except in production of potable drinking water or high quality water for industrial operations. There have been no known applications of dissolved solids removal associated with any dredging operation.

Distillation. Distillation or evaporation of saline water to produce fresh water goes back to antiquity. In distillation or evaporation processes, pore water vapor is created by heating saline water. The vapor is separated from the saline water and is condensed to form pure water.

There are three principal types of distillation processes currently being used on new construction:

a. Long-tube vertical (LTV).

b. Multistage flash (MSF).

c. Vapor compression (VC).

In LTV distillation, the water to be vaporized flows by gravity down the inside of a long vertical tube, while steam or hot vapor supplies heat on the outside.

In MSF distillation, the water is heated under pressure in tubes and then allowed to expand suddenly or flash into a chamber. As some of the water evaporates or flashes, the remaining water cools slightly and then flows into another chamber at lower pressure where it flashes again. The flashed vapor condenses on the outside of the tubes in each chamber through which cooler water is flowing and picking up heat. The condensed pure water then drips into collecting pans and is pumped to service.

In VC distillation, pure water vapor, which has been evaporated at a tube surface or in a flash chamber, is mechanically compressed (usually by a centrifugal or axial flow gas compressor) to raise its temperature and pressure for use in vaporizing more water. VC cycles must utilize mechanical or electrical energy or work rather than heat as the primary energy input for distillation.

These distillation processes can be combined, and there are many individual modifications, depending upon the amount, type, and cost of available steam, power, water, and other basic factors.

Distillation can result in 99+ percent removal of contaminants. Distillation plants having capacities up to several million gallons per day are in operation at a number of locations throughout the world and have proven their reliability.

Distillation plants require substantial amounts of thermal energy or electrical power. Accordingly, the cost and availability of energy are important factors in both the design and economic feasibility of distillation plants.

Close attention to water chemistry is essential to maintain the vital heat transfer surfaces of distillation equipment at peak efficiency. The chemistry and biochemistry of seawater vary substantially at different locations, and expert advice should be sought on the optimum chemical and mechanical treatments and operating conditions to avoid excessive corrosion, hard-scale formation, or marine fouling.

Electrodialysis. Electrodialysis (ED) is a widely used process for the treatment of brackish or highly mineralized waters. In ED, salts and minerals are removed from a stream of saline water through special plastic membranes by the action of a direct electrical current. The salts and minerals pass through the membranes in the form of positively and negatively charged ions. The water from which these ions have been removed flows between the membranes and is collected as a partially demineralized product via manifolds cut through the membranes. The salts and minerals removed from the product stream pass through the membranes into another stream of water that continuously washes the other side of each membrane and emerges through manifolds as a more concentrated waste stream. ED can operate at low pressures (approximately 50 psi).

ED plants having capacities up to about 1 million gallons per day are in operation at a number of locations throughout the world and have proven their reliability to produce fresh water for utility use. Removal of inorganics is very high (90+ percent).

ED plants require clear waters free from iron, manganese, turbidity, and organic matter for optimum operations. Accordingly, pretreatment of water by conventional means is always required prior to ED plants operating on surface water. ED plants will generally require from 10 to 30 percent of the feed water to carry off the concentrated salts and minerals removed.

Reverse Osmosis. Osmosis is the spontaneous flow of solvent (e.g., water) from a dilute solution through a semipermeable membrane (impurities or solute permeates at a much slower rate) to a more concentrated solution. Reverse osmosis is the application of sufficient pressure to the concentrated solution to overcome the osmotic pressure and force the net flow of water through the membrane toward the dilute phase. This allows the concentration of solute (impurities) to be built up in a circulating system on one side of the membrane while relatively pure water is transported through the membrane. Ions and small molecules in true solution can be separated from water by this technique.

The basic components of a reverse osmosis unit are the membrane, a membrane support structure, a containing vessel, and a high pressure pump. The membrane and membrane support structure are the most critical elements.

Reverse osmosis (RO) is used to reduce the concentrations of dissolved solids, both organic and inorganic. In treatment of contaminated streams, use of reverse osmosis would be primarily limited to polishing low-flow streams containing highly toxic contaminants. In general, good removal can be expected for high molecular weight organics and charged anions and cations. Multivalent ions are treated more effectively than are univalent ions. Recent advances in membrane technology have made it possible to remove such low molecular weight organics as alcohols, ketones, amines, and aldehydes (Gooding 1985). Table 4.30 shows removal results obtained during testing of a mobile RO unit using two favorable membrane materials (Whittaker 1984).

RO units are subject to chemical attack, fouling, and plugging. Pretreatment requirements can be extensive. Wastewater must be pretreated to remove oxidizing materials such as iron and manganese salts, to filter out particulates, to adjust pH to a range of 4.0 to 7.5, and to remove oil, grease, and other film forms (De Renzo 1978). The growth of slimy biomass on the membrane surface or the presence of organic macromolecules may also foul the membrane. This organic fouling can be minimized by prechlorination, addition of biocides, and/or pretreatment with activated carbon (Ghassemi et al. 1981).

The most critical design consideration applicable to reverse osmosis technology is the design of the semipermeable membrane. In addition to allowing the achievement of the required degree of separation at an economic flux

Table 4.30

Reverse Osmosis Removal Efficiencies*

			Percent Removed in Permeate	
Chemical	Feed Concentration (ppb)	Percent Concentrated in Concentrate	Polyether-polysulphone membrane	Polyester/amide polysulphone membrane
Dichloromethane	406	203	58	52
Acetone	110	355	84	76
1,1-Dichloroethene	34	795	99	95
Tetrahydrofuran	17,890	467	98	89
Diethyl ether	210	439	97	89
Chloroform	270**	567	98	92
1,2-Dichlorethane	99	415	92	85
1,1,1-Trichloroethane	659	651	99.8	97
Trichloroethene	24**	346	99	92
Benzene	539	491	99	99
Bromoform	12**	633	99.1	98
Hexane	10**	704	99.8	97

* Source: Whittaker (1984) as reported in USEPA (1985).

** No standard available; concentration estimated.

level under ideal conditions, the membrane must be incorporated in an operating system that satisfies these practical requirements (Conway and Ross 1980):

a. Minimum concentration polarization, i.e., ratio of impurity.
b. High packing density, i.e., membrane surface area per unit volume of the pressure module.
c. Ability to handle any particulate impurities (by proliferation, if necessary).
d. Adequate support for the membrane and other physical features such as effectiveness of seals, ease of membrane replacement, and ease of cleaning.

Membranes are usually fabricated in flat sheets or tubular forms and are assembled into modules. The most common materials used are cellulose acetate and other polymers such as polyamides and polyether-polysulphone. There are three basic module designs: tubular, hollow fiber, and spiral wound. These are illustrated in Fig. 4.28. Each type of membrane module has its own advantages and limitations.

The tubular module provides the largest flow channel and allows for turbulent fluid flow regime; thus, it is least susceptible to plugging caused by suspended solids and has the highest flux. However, because of its small area/volume ratio, the total product recovered per module is small. The cost of a tubular module is approximately five times that for the other modules for an equivalent rate of water recovery, and the total space requirement is about three to five times that for the spiral wound system (Ghassemi et al. 1981).

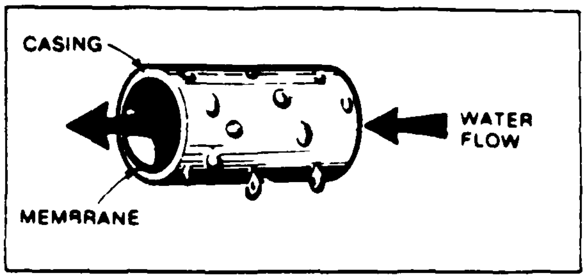
A hollow-fiber membrane is constructed of polyamide polymers and cellulose triacetate by Dupont and Dow, respectively. The polyamide membrane permits a wider operating pH range than cellulose acetate, which is commonly used for the construction of spiral wound and tubular membranes. The flow channel and the flux are about an order of magnitude lower than the other configurations. This small flux, however, is compensated for by the large surface area/volume ratio, with the total product water per module being close to that obtainable with spiral wound modules. However, because of the small size of the channels (about 0.004 in.) and the laminar fluid flow regime within the channels, this module is susceptible to plugging and may require extensive pretreatment to protect the membrane (Ghassemi et al. 1981).

The spiral-wound module consists of an envelope of flat sheet membranes rolled around a permeate collector tube. This configuration provides for a higher flux and greater resistance to fouling than the hollow fiber modules; it is also less expensive and occupies less space than a tubular module (Ghassemi et al. 1981).

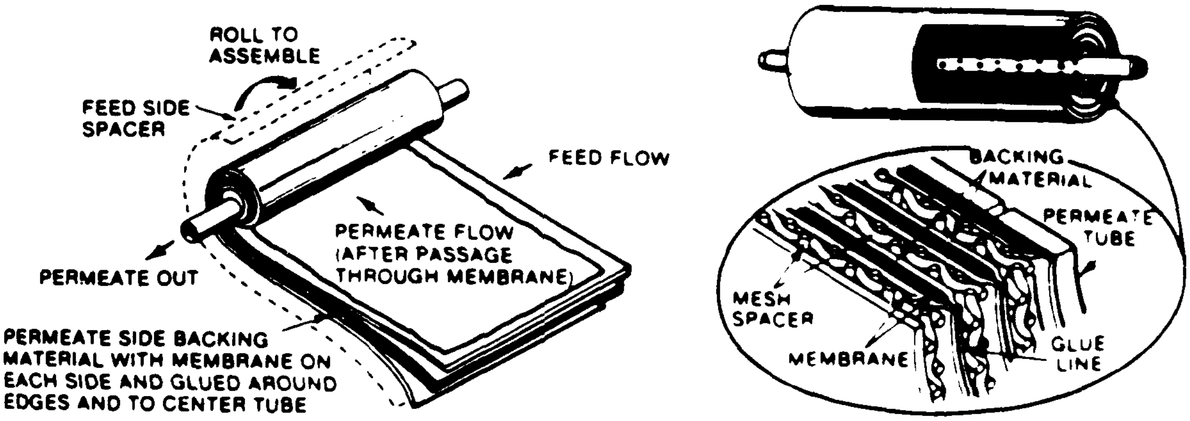
Reverse osmosis is an effective treatment technology for removal of dissolved solids presuming appropriate pretreatment has been performed for suspended solids removal, pH adjustments, and removal of oxidizers, oil, and grease. Because the process is so susceptible to fouling and plugging, on-line monitors may be required to monitor pH, suspended solids, etc. on a continuous basis. Reverse osmosis has not been widely used for treatment of hazardous wastes.

Reverse osmosis will not reliably treat wastes with a high organic content, as the membrane may dissolve in the waste. Lower levels of organic

A. TUBULAR MEMBRANE



b. SPIRAL-WOUND MODULE



c. HOLLOW-FIBER MODULE

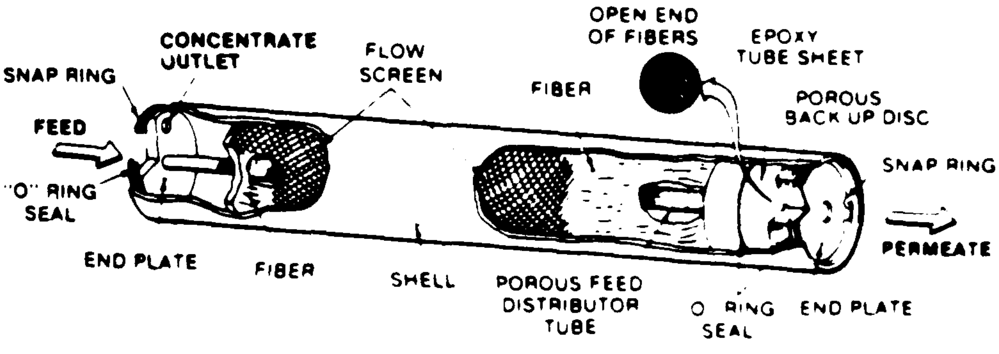


Figure 4.28. Reverse osmosis membrane designs

compounds may also be detrimental to the unit's reliability, as biological growth may form on a membrane fed an influent containing biodegradable organics.

The fact that RO units can be operated in series or in parallel provides some flexibility in dealing with increased flow rates or concentration of dissolved species.

Memtek Corporation of Ontario, Canada, has developed a mobile reverse osmosis unit for Environment Canada. The unit, which is capable of handling low flows of about 10 gpm, is currently being tested for various types of spills (Whittaker 1984).

The volume of the reject generated by reverse osmosis is about 10 to 25 percent of the feed volume. Provisions must be made to treat this potentially hazardous waste.

Costs for various sizes of reverse osmosis units are presented in Table 4.31. The construction costs include housing, tanks, piping, membranes, flow meters, cartridge filters, acid and polyphosphate feed equipment, and cleanup equipment. These costs were based on influent total dissolved solids concentrations of less than 10,000 ppm.

Table 4.31

General Cost Data for Various Sizes of Reverse Osmosis Units*

Plant Capacity, gpm	Construction Costs, $**	O&M Costs $/year**
1.74	17,070	7,580
7	33,280	12,070
70	171,820	40,829
700	1,014,600	249,930

* Source: Adapted from Hansen, Gumerman, and Culp (1979).

** Updated from 1979 to 1984 dollars using third-quarter Marshall and Swift Index.

The operation and maintenance costs include electricity for the high pressure feed pumps (400 psi operating pressure), building utilities, routine periodic repair, routine cleaning, and membrane replacement every 3 years. Operation and maintenance costs do not include costs for pretreatment chemicals due to extreme usage rate variability between plants.

Level VI Treatment

Level V treatment processes are employed in those cases where disinfection of the liquid streams is required. Disinfection is the selective destruction of pathogenic organisms and is generally considered as one of the most important processes in wastewater treatment. This practice used in wastewater treatment has resulted in the virtual disappearance of waterborne diseases. Disinfection may be accomplished through the use of chemical agents, physical agents, mechanical means, and radiation. The most commonly used disinfectant is chlorine; however, other halogens, ozone, and ultraviolet radiation have been used. Only disinfection using chlorine gas and ozonation are considered in this report.

Chlorination. The addition of chlorine (chlorination) is by far the most widely used method of wastewater disinfection. Only recently has chlorine become suspect because of its environmental impact. However, engineers have continued to design and specify chlorination systems as the primary means of wastewater disinfection because of technical familiarity, reliability, and cost considerations. The rate of disinfection by chlorine depends on several factors, including chlorine dosage, contact time, presence of organic matter, pH, and temperature. The recommended chlorine dosage for disinfection is that which produces a chlorine residual of 0.5 to 1 mg/ℓ after a specified contact time, usually 15 minutes at peak flows and 30 minutes at average flows. Typical chlorine dosages recommended for disinfection and odor control are presented in Table 4.32.

Chlorine is an extremely volatile, toxic, and hazardous material. Safety in handling cannot be overemphasized. Concentrations of chlorine in the air above 15 ppm by volume irritate the mucous membranes, the respiratory system, and the skin (WPCF 1976). Death may result in about 30 minutes in concentrations of 40 to 60 ppm. The WPCF (1976) and White (1972) provide a detailed discussion of chlorine handling safety and are recommended reading for anyone designing a liquid-gas chlorination system.

In recent years, the environmental effects of chlorination have been questioned. Chlorine has major environmental impact on the receiving stream. Chlorine residuals may be toxic to certain aquatic species at very low concentrations. Chlorinated effluents also have been reported to form halogenated organic compounds that are suspected of being toxic to both aquatic life and man. Chlorination results in the formation of chloramines when ammonia is

Table 4.32

Typical Chlorine Dosages for Disinfection and Odor Control

Type of Water*	Dosage mg/ℓ
Untreated domestic wastewater	6 to 25
Primary sedimentation	5 to 20
Chemical precipitation	2 to 6
Trickling filter plant	3 to 15
Activated sludge plant	2 to 8
Multimedia filter (following activated sludge plant)	1 to 5

* There is no reported experience on the chlorination of effluent from dredged material disposal areas.

present in the water. High levels of chloramines may be lethal to aquatic life. The reaction between chlorine and organics found in the site waters could produce carcinogenic compounds. Because of these concerns, attention should be given to the use of dechlorination or other alternatives for disinfection.

Three types of chlorine disinfection systems are available for application at disposal areas: liquid-gas systems, hypochlorination systems, and tablet dissolution systems.

Liquid-gas chlorination systems consist of two subsystems, the chlorine-injection subsystem and the contact tank. The major components of a chlorine-injection system for a low-flow installation include two 150-lb liquid chlorine cylinders, two cylinder valves, one chlorinator, an ejector, vacuum tubing, and pump with associated electrical service. A scale for weighing the cylinders and climate-controlled housing are also required for a successful installation. White (1972) provides a detailed discussion of liquid-gas chlorine system requirements. Figure 4.29 illustrates a typical chlorine gas feeding installation.

The physical process of injecting the chlorine is rather simple. Chlorine gas is extracted from the cylinder by vacuum whenever the pump is operating. The flow of chlorine is metered through the chlorinator, mixed into solution at the ejector, and mixed with the total wasteflow by use of a

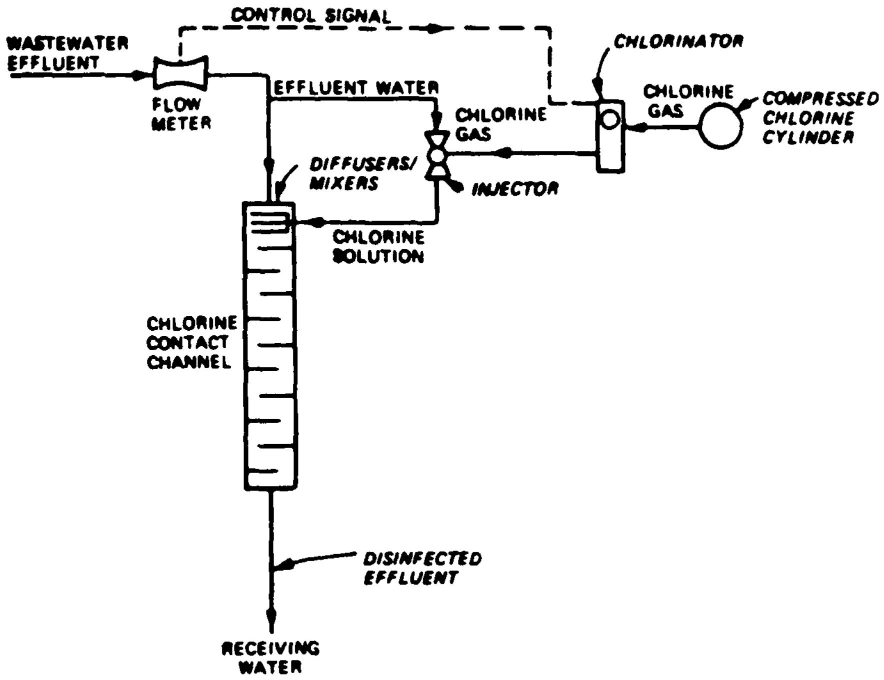


Figure 4.29. Typical chlorine gas feeding system

diffuser at the influent end of the chlorine contact tank. Built-in check valves prevent the chlorine gas from escaping whenever the circulation pump is not running.

Chlorinators commonly on the market today have maximum capacities of 1, 2, 3, 4, 10, 20, 50, or 100 lb of chlorine per 24-hr period. The maximum feed capacities can generally be valved down by a factor of 20. The maximum allowable gas withdrawal rate from a 150-lb cylinder is 40 lb/day (White 1972). Where large quantities are required, a chlorine evaporator or cylinder manifold system should be considered. White (1972) recommends the use of 1-ton cylinders whenever the application rate is expected to be more than 50 lb/day.

The chlorine application capacity required for a disposal site is a function of design flow and expected dosage rate. For example, the dosage for secondary effluent at a wastewater treatment facility is anticipated to range between 1 and 15 mg/ℓ (WPCF 1976). Assuming a design flow rate of 20,000 gal/day, the daily application rate would range between 0.17 and

2.5 lb. Selection of a 4-lb/day chlorinator gives an adjustable application range between 0.2 and 4 lb/day.

Chlorine gas feeding systems are technically feasible for disposal sites and can achieve required disinfection results. There are many manufacturers that specialize in this equipment and supply parts and service. The equipment is reliable and not overly complex. Automatic switchover devices are available to ensure continuous chlorine gas feed. Booster pumps and ejectors may be submerged or dry mounted. System housing may be custom designed, although complete prefabricated installations are available.

The most difficult aspect of chlorination system design is the provision of adequate control of the chlorine application rate. The ideal control system incorporates the integration of a flow signal from a flow meter and a chlorine residual signal from a chlorine residual analyzer to determine the appropriate application rate. Smaller plants are designed so that control of chlorination is either manual or semiautomated. Three control techniques are commonly utilized in small plants: manual control, flow control, or timer control.

Manual control is accomplished by using a constant feed rate, regardless of wastewater flow or characteristics. With manual control, it is common practice to maintain a high feed rate to ensure compliance with bacteriological standards. This practice usually results in unacceptably high chlorine residuals, which is in conflict with present concerns regarding the toxic and carcinogenic characteristics of chlorinated organics.

Flow-control systems utilize a proportional signal from a flow meter to pace the rate of chlorine application. Although chlorine residual is not monitored, the application rate is maintained proportional to flow.

Timer control is slightly better than the manual method but has many of the same shortcomings.

In addition to the control of the chlorine application rate, proper design of the chlorine contact tank is very important. Rapid mixing of the chlorine and design of the chlorine contact chamber is required to provide effective dispersion of the chlorine and long detention times with limited short circuiting. A minimum contact time of 15 minutes at peak hourly flow is generally required. The WPCF (1976) recommends that contact chamber length-to-width ratios should be greater than 40:1.

Because liquid-gas chlorination systems require specialized housing facilities and safety precautions, hypochlorination systems may be a more practical disinfection alternative. Hypochlorination refers to the use of solid or liquid hypochlorite compounds as the disinfecting agent. Hypochlorites are available as calcium hypochlorites (70 percent chlorine) in powder or tablet form and as sodium hypochlorite (15 percent chlorine commercial strength, 5 percent domestic strength) in liquid form. Sodium hypochlorite is preferred over calcium hypochlorite because of the latter's higher cost, sludge forming characteristics, and hazardous nature. Five-percent sodium hypochlorite is the most commonly used and is equivalent to ordinary household bleach.

Hypochlorination systems also consist of two subsystems, the hypochlorite feed system and the contact tank. The major components of the hypochlorination system include the chlorine solution storage tank, hypochlorinator (chemical feed pump), chlorine injector, chlorine solution diffuser, and associated piping and control systems. Figure 4.30 is a schematic representation of a typical hypochlorination system. Weather protection for the equipment is required; however, the specialized safety equipment required for liquid-gas systems is somewhat reduced.

Sodium hypochlorite may be delivered in 5 gal or larger carboys or in tank trucks of 2,000- to 5,000-gal capacity. Storage vessels may be constructed of polyethene or hypochlorite-resistant fiberglass resin. Because sodium hypochlorite deteriorates with time, most manufacturers recommend a maximum shelf life of 60 to 90 days. Storage vessels should be protected from light and heat, both of which accelerate the deterioration of the solution. Sodium hypochlorite is strongly alkaline and, therefore, requires care in handling. White (1972) and WPCF (1976) provide detailed criteria for handling systems.

Hypochlorination is a proven and reliable disinfection method. Equipment is simple and easier to operate than liquid-gas systems. Although the actual mechanisms for bacteria and virus kill are not known, it is postulated that they are the same as for gas or liquid chlorine. Design concepts for the solution-injection system and contact tank are identical to those developed for liquid-gas systems.

Hypochlorination disinfection methods produce the same environmental impacts as liquid-gas systems. Effluents with residual chlorine are toxic to

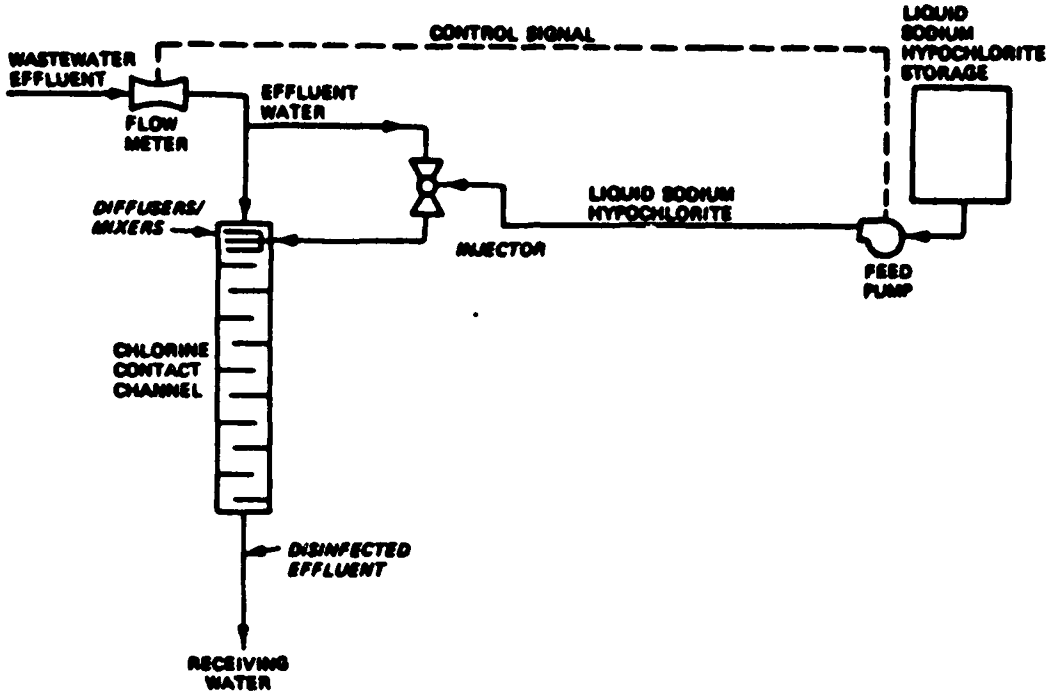


Figure 4.30. Schematic of a typical hypochlorination system

aquatic organisms and form chlorinated organic compounds. The main advantage in using hypochlorination instead of a liquid-gas system is that it is generally considered to be much safer. Although sodium hypochlorite is a hazardous and corrosive material, it is not under pressure and not as violently reactive as liquified elemental chlorine.

The selection of a hypochlorite or liquid-gas system is primarily a function of chlorine requirements. Larger systems generally use liquid-gas systems or generate the hypochlorite onsite. Smaller systems may economically employ either liquid-gas or hypochlorite systems. Liquid-gas systems require a larger capital investment; however, chemical costs are reduced. Hypochlorination systems are less capital intensive; however, chemical costs are higher.

A relatively new chlorination concept applicable to small systems is the solid tablet chlorinator system. Calcium hypochlorite (70-percent chlorine) formed into a solid tablet is usually the disinfecting agent used in these systems. The tablets are contained in feed tubes, and as the wastewater flows through the tubes, chlorine is released into the wastewater by the dissolving action of the water in contact with the tablets.

Chlorine dosage in tablet-dissolution systems is accomplished by selecting an appropriate number of feed tubes and controlling the level of water flowing over the tablets. The feed tubes are vertical, and the tablets are stacked to drop as the lower tablets dissolve. An adjustable outlet weir controls the level of water in contact with the tablets. As the incoming water flow rate increases, the weir level in the unit rises, immersing a greater number of tablets. In a similar fashion, as the flow decreases, fewer tablets are in contact with the water.

The major component of the tablet-dissolution system is the feed tube assembly installed in a housing unit. The unit can be installed in-line just preceding the chlorine contact tank. The tablet-dissolution system has no moving parts and requires no electrical supply. A chlorine contact tank is required and is designed to the same standards as used in liquid-gas or hypochlorination systems.

The requirement to provide effective disinfection for small water flows at low cost has resulted in an increased interest in the use of tablet-dissolution systems. The effectiveness may be comparable to liquid-gas or hypochlorination systems, relying on the same mechanisms for bacteria and viral kill. Although the tablet-dissolution systems are considered to be virtually self operating, system shortcomings have been reported. Field methods are normally employed to determine appropriate system operating parameters. Incorrect amounts of delivered chlorine may be due to selection of the incorrect number of feed tubes, poor water-tablet contact, jamming tablets, inconsistent chlorine content in the tablets, hydraulic overload, or clogged weirs.

The environmental impact associated with tablet dissolution systems is similar to liquid-gas and hypochlorination systems. Effluents with residual chlorine are toxic to aquatic life and may form chlorinated organic compounds. Materials handling procedures associated with tablet dissolution systems are much simpler than either liquid-gas or hypochlorination systems. The calcium hypochlorite tablets are safe to handle, store, and utilize. Tablets should be handled with rubber gloves and stored in a cool, dry area.

Ozonation. In ozonation, contact with ozone, a powerful oxidizing agent, breaks down many refractory organic compounds not treatable with biological treatment techniques. Ozone, produced in a separate generator, is introduced to a contactor where it mixes with the wastes and reacts with oxidizable species present.

Ozone dose rate is usually expressed as either parts per million ozone or pounds of ozone per pound of stream contaminants treated. Typical dose rates are 10 to 40 ppm for the former and 1.5 to 3.0 lb/lb of contaminant removed for the latter (Arthur D. Little, Inc. 1976). Retention time ranges from 10 minutes to 1 hr in several stages.

Typically, the very high ozone-to-water ratios are encountered in potable water facilities where the influent contaminant concentrations are in the parts per billion range and the effluent concentrations are nondetectable.

Ozonation is applicable only to dilute wastes, typically containing less than 1 percent oxidizable materials. The destructive power to refractory compounds may be enhanced by combining ozonation with ultraviolet radiation (Prengle et al. 1975). Ozonation is effective with:

a. Chlorinated hydrocarbons.
b. Alcohols.
c. Chlorinated aromatics.
d. Pesticides.
e. Cyanides.

Large contactors are required because reaction rates are mass transfer limited; ozone has only limited solubility in water. Contactor depth is typically on the order of 5 m (16 ft) to ensure adequate mixing and reaction time. Ultraviolet lamps, if used, are operated within the contactor vessel.

Ozone is corrosive, requiring special construction materials. Suitable materials include:

a. Stainless steel.
b. Unplasticized PVC.
c. Aluminum.
d. Teflon (registered trademark).
e. Chromium-plated brass or bronze.

Ozone is acutely toxic; personnel safety is therefore a major concern. Modern systems are completely automated. An ozone monitor measures ozone levels in the gaseous effluent and reduces the ozonator voltage or frequency if gaseous levels exceed a pre-set limit (usually 0.05 ppm). An ambient air monitor sounds an alarm and shuts off the ozonator in the event of leaks of ozonized air. An off-gas ozone destruction unit is also generally used in modern systems.

Treatment of Residual Solids

The final contaminated media that must be considered are the residual materials from processes used to treat site effluent, runoff, and leachate. Most of the liquid treatment processes discussed above do not destroy contaminants, they simply concentrate them by removal from the site effluent, runoff, or leachate water. These concentrated contaminants, often contained in a process sludge, regenerant fluid, residual solid, or reject stream, must be disposed of in an appropriate facility.

Practical concerns are expended activated carbon and any sludges from biological treatment or chemical precipitation processes. Other processes producing residual materials are believed to have little practical application at dredged material disposal sites. In addition, the production of residual materials are expected to be minimal except during active disposal operations.

If the residual materials are sufficiently contaminated to be classified as dangerous (DW) or extremely hazardous (EHW) wastes, they must be handled and disposed in accordance with state and Federal regulations. Offsite disposal of such materials is the preferred option since permitting requirements for onsite disposal of such material are expected to be extensive.

Reuse of Contaminated Dredge Material

Reuse has been proposed as a potential alternative for long term management of contaminated dredged material. The reuse alternative incorporates four possible scenarios:

a. Temporary storage of lightly contaminated dredged material at the primary site and later removal to another site for long-term disposal.

b. Dewatering and immediate transport of lightly contaminated dredged material to long-term disposal sites or some beneficial use.

c. Temporary storage of moderately or highly contaminated materials followed by treatment and removal to a long-term disposal site or other beneficial use.

d. Immediate treatment of moderately or highly contaminated materials at an intermodal transfer point followed by transport to an appropriate long-term disposal site or some beneficial use.

Reuse of contaminated dredged material serves at least two beneficial functions: continued use of confined sites located close to dredging areas and creation of a potential construction material resource. The concept of a reuse alternative may also incorporate beneficial uses of materials such as sand and gravel reclaimed by classification/separation processes. Treatment and materials classification processes were discussed previously in Part IV.

The development and evaluation of reuse alternatives is extremely site specific and will depend on several factors:

a. Physical and chemical characteristics of the material to be dredged.

b. Availability of temporary storage and/or treatment sites.

c. Identification of long-term disposal sites or suitable beneficial uses.

Reuse alternatives can be developed and evaluated within the overall alternative selection strategy presented in Part IX of this report.

PART V: CONTAMINANT CONTROL AND TREATMENT FOR NEARSHORE SITES

Background

Nearshore disposal sites are confined disposal facilities located within the areas of influence of normal tidal fluctuations. Dredged material is added to the diked area until the final elevation is above the high tide elevation. Nearshore sites are normally used in conjunction with hydraulic dredges but can accommodate dredged material from mechanical dredges directly, bottom-dump barges, and direct disposal from trucks or railcars. Sites in Puget Sound most frequently involve diking of old harbor waterways that are no longer used. Nearshore excavation is possible, but normally is too expensive for consideration (Phillips et al. 1985).

Three distinct physicochemical environments exist at a nearshore site after filling (Lee et al. 1985):

Upland -dry unsaturated layer
Intermediate--partially or intermittently saturated layer
Flooded--totally saturated layer

When material is initially placed in the site, it will all be flooded or saturated. After the site is filled, the dredged material above high tide will become upland, the bottom will be saturated, and the layer in between will alternately be saturated and unsaturated as the tide ebbs and floods (Fig. 5.1). It is the movement of moisture or leachate/seepage in and out of this intermediate layer that may dictate the need for controls and/or monitoring.

Control of volatile and sediment-bound contaminants is basically the same for nearshore as for upland sites. For soluble contaminants, the concerns are similar, but fewer opportunities are available for soluble contaminant control at nearshore sites. In the short term, control and treatment of the contaminant-laden effluent from either hydraulic or mechanical dredging is possible. Once filled, the upper layer of sediment will dewater and oxidize. The bottom sediment layer will continue to be saturated as a result of precipitation and marine water intrusion and will remain anaerobic. Soluble

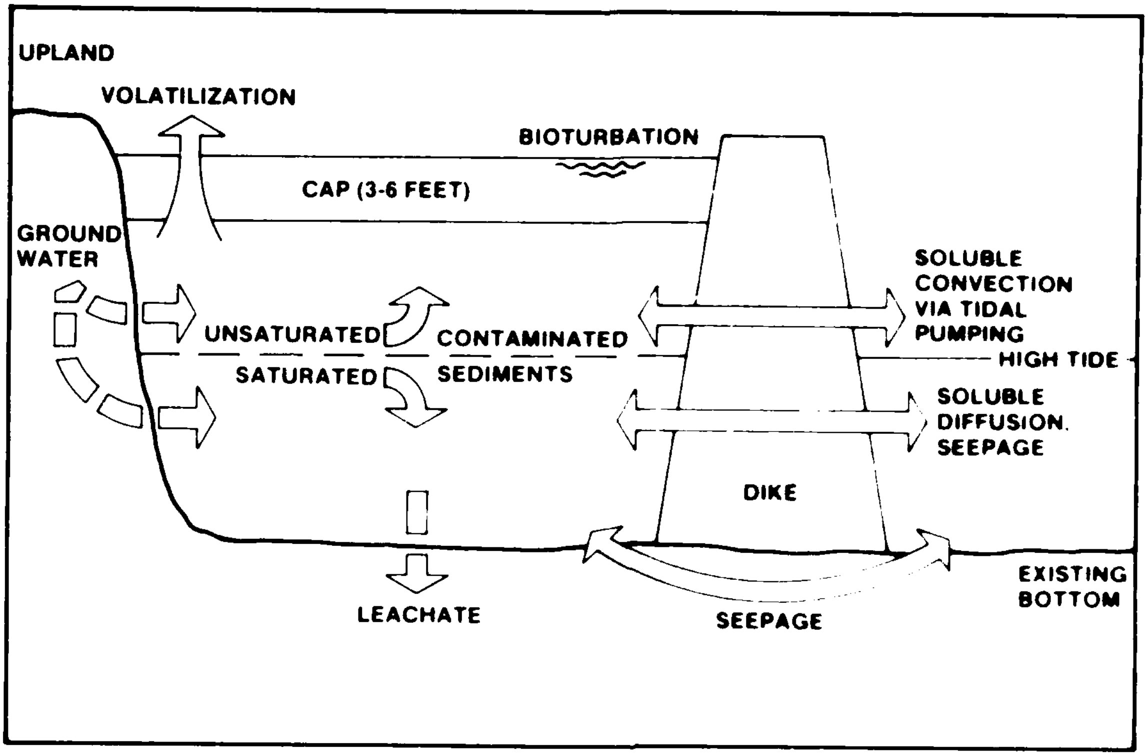


Figure 5.1. Nearshore disposal

contaminants may be released from the intermediate layer through diffusion and convection through the dikes of the disposal area as a result of tidal pumping and seepage. The drained upper sediment layer may carry soluble contaminants released as a result of the changed physicochemical environment into the lower saturated sediments. As the upper layer of material becomes more upland, long-term releases of contaminants due to changes in the physical and chemical equilibrium are similar to what would occur in a completely dewatered upland site (Phillips et al. 1985). Because of the effects of tidal flux on site water, control of these long-term releases is substantially more difficult at a nearshore than at an upland location. One alternative to prevent problems caused by the upland-type layer is to use cleaner sediment as a cap and place the more contaminated sediment in the flooded layer where most contaminants will remain attached to the sediment and immobilized.

In many areas the influence of tidal fluctuations through the dikes on the liquid elevation within the site is minor, and tidal pumping of the intermediate dredged material layer may have negligible effects on contaminant migration. For these areas contaminated materials may be placed in ar uncontrolled nearshore site. Acceptability of this alternative depends on the nature of the contaminant and the risk associated with migration of the contaminants. Hotchkiss (1985) reported on the Pier 90/91 disposal site in Puget Sound. This nearshore disposal site was approved by the regulatory agencies based on the minimum amount of contaminant release predicted. However, approval was granted on the premise that waters around the site will be monitored, and, if the environment appears threatened, control measures will be implemented.

This part of the report will review additional considerations and limitation for control measures at nearshore sites. Detail descriptions and design considerations for control or treatment technologies are essentially the same for nearshore as for upland sites and were presented in Part IV.

Site Control Measures

Site control measures include surface water controls, covers, liners, groundwater controls, leachate collection systems, and site security. Surface water controls, covers, and site security are applicable to nearshore sites and would be recommended to minimize the volume of leachate passing through the dry unsaturated layer and to avoid receptor contact at the surface. Liners are more difficult to construct in a nearshore situation. Laying the liner below water is not standard technology and special construction techniques would be required to line the dikes to withstand the opposing pressures of liquid within the site and tidal effects outside the dikes. This technology has been demonstrated by the Dutch (d'Angremond et al. [illegible]). Groundwater pumping is inappropriate for nearshore sites. The tidal inflows of marine water would negate any benefits of groundwater [illegible]. If it is necessary to isolate a nearshore site from tidal influence, [illegible] sheet piling may be considered.

Leachate collection would experience similar problems with [illegible] inflow of tidal flows. A [illegible] collection of leachate from the [illegible] intermediate layer. This system would [illegible] elevation above the intermediate layer overlaid with a layer of pervious material and leachate collection system.

Solids Removal Process

The same solids removal processes for containment area effluent during active dredging are applicable to nearshore sites as well as upland sites.

Site Water Treatment

Treatment of site water (i.e., supernatant, leachate, or surface runoff) by traditional liquid treatment processes could be used at nearshore sites. Water in nearshore sites would also be expected to have higher salinities than upland sites, causing difficulties for treatment processes designed to remove dissolved inorganics.

Solids and Residuals Treatment

Technologies for solids and residuals treatment at nearshores areas are basically the same as for upland sites. Stabilization of solids in the flooded and intermediate layers of a nearshore site is a promising opportunity for control at a nearshore site.

PART VI: CONTAMINANT CONTROL/TREATMENT FOR RESTRICTED OPEN-WATER DISPOSAL

Background

Restricted open-water disposal as used here simply suggests that some one or more controls beyond those normally applied in conventional projects are required to address either known risks or uncertainties associated with disposal of contaminated sediments. Controls may range from an intensive long-term monitoring program with remedial action plan to a fully engineered and constructed aquatic disposal site. Most positive control measures are based on the concept of isolating the contaminants from the water column or benthic environment. Recently, concepts based on either the separation of contaminants from the dredged material slurry or chemically stabilizing the contaminants in the dredged material have also been proposed. The remainder of this section provides a basic overview of the disposal process and the objectives of control measures. Subsequent sections discuss the use of site characteristics as a control available as part of the basic planning of an open-water project followed by descriptions of more intensive engineered controls and site design concepts.

Description of the Disposal Process

Dredged material may be transported to and placed at a disposal site in a variety of conditions and by a number of techniques. However, for practical purposes, it may be assumed that either barges/scows, hopper dredges, or a continuous pipeline will be used. The following is a brief overview of the physical processes that take place during disposal and the influence of different types of equipment on them.

The mechanics of placing material at an open water site by instantaneous discharge from a barge or hopper have been described and/or modelled by a number of investigators (Clark et al. 1971, Koh and Chang 1973, Gordon 1974, Brandsma and Divoky 1976, Johnson and Holliday 1978, Bokuniewicz et al. 1978, and others). These descriptions typically divide the behavior of the material into 3 or 4 distinct transport phases or stages generally paralleling the physical forces or processes that dominate during each period. The most common terminology in use today for these stages is convective descent, dynamic collapse, and long-term or passive diffusion. Figure 6.1 illustrates these basic stages.

When dredged material is released from the barge it descends through the water column as a dense fluid-like jet. Within this well defined jet there may also be solid blocks or clods of very dense, cohesive material. Sustar and Wakeman (1977), and Bokuniewicz and Gordon (1980) describe the factors affecting this descent. Both conclude that the proportion of material that forms into clods in the total discharge depends primarily on the mechanical properties of the sediment (especially moisture content and liquid limit) and how those properties have been influenced during the dredging operation. During the descent, large volumes of site water are entrained in the jet and as a result of several factors, including turbulent shear, some material is separated from the jet and remains in the upper portion of the water column. To complete the stages of the disposal process, the descending jet and its core of cohesive material then collapses, usually as a result of impact on the

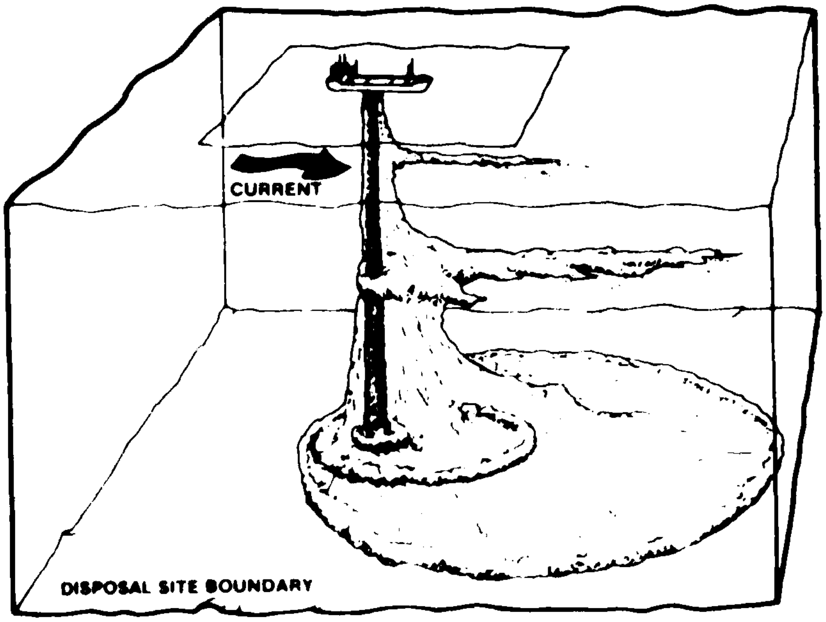


Figure 6.1. Bottom dump-disposal of dredged material

bottom or (more rarely and at deeper sites) when it encounters a stratification of the water column with equal ambient density. In the latter period of the collapse, that portion of the discharge that is not deposited when it impacts will move radially outward initially as a density/momentum-driven surge until sufficient energy is dissipated and material begins to rapidly settle on the bottom. At this time diffusive processes dominate and any material remaining from the surge will be mixed, diluted, and continue to settle, although more slowly.

Objectives of Controls

Restrictions on disposal can be thought of as directed toward either short- or long-term processes. Techniques, equipment, or designs to control the physical behavior of the dredged material during descent, impact, and surge are short-term restrictions. Objectives would focus on placing the material accurately in a discrete area with controlled spreading and little turbidity in the upper water column. Long-term objectives principally involve stability of the material after placement. Emphasis should be on controls or restrictions that reduce exposure to erosive currents, even encourage accretion and natural armoring, and that minimize opportunities for contaminant release. Restrictions can also be thought of in the context of potential impact areas, especially benthic impacts versus water column impacts. The specification of combined objectives then clarifies the intent of a restriction and allows it to be addressed more effectively. For example, the use of a conduit or downpipe principally controls the short-term water column impacts while the addition of capping material extends the restriction on water column impact to a longer term.

Site Characteristics as a Control Technology

A level of increased control or restriction can be achieved during disposal simply by taking advantage of the best features of the site, by considering natural mixing processes, and by using conventional techniques and equipment to their best potential.

Site Selection and Designation

At least six considerations can be identified that are important in evaluating the engineering acceptability of a proposed open water disposal site (Truitt 1986):

a. Currents (velocity and structure).

b. Average water depths.

c. Salinity/temperature stratifications.

d. Bathymetry (bottom contours).

e. Dispersion and mixing.

f. Navigation and positioning (location/distance, surface sea state, etc.).

As suggested above, probably the most important (physical) goal in selecting an open-water site for disposal of contaminated dredged material is long-term stability and the above characteristics do not typically reinforce each other toward that goal. Actually, in Puget Sound, many of these factors are in less conflict than in other areas because of the proximity of deep water to the dredging sites and the relatively sheltered conditions. Still, site selection normally involves a compromise or trade-off among the desirable criteria for each site characteristic. The influences of the more important site characteristics are discussed below.

Currents

Currents in Puget Sound are principally tidally dominated, but can also be influenced by river runoff and wind driven water movements. Bokuniewicz et al. (1978) monitored open water disposal operations at a site in Elliott Bay. Considerable detail is omitted here, but the currents in the Bay reported as part of that study were [illegible] ft/sec near the surface, [illegible] ft/sec at middepth; and, [illegible] ft/sec near the bottom. Directions [illegible] cases were variable. At least basic current information should be [illegible] of any prospective disposal site to identify site specific features, [illegible] value are sufficiently representative for its use [illegible]. Based on [illegible] the other site observations, Bokuniewicz concluded that the [illegible] [illegible] current [illegible] the receiving water [illegible] displace the [illegible] impact of the descending jet of material with the bottom (by a calculable amount). He stated that even strong currents observed at a Great Lakes site (three times those at Elliott Bay) need not be a serious impediment to accurate placement, nor do they result in significantly greater dispersion during placement. Further, currents do not appear to affect the surge phase of the disposal. Longer term effects of currents at the site may still need to be investigated, and little information is available on the transport of sediment from disposal mounds. For sediment generally classified as cohesive, the potential erodibility is far more dependent on the condition of the cohesive bonds than on the characteristics, especially size, of the individual particles. In addition, even when the cohesive strength has been reduced and such sediment is resuspended, the hydrodynamic behavior is complicated by the effects of flocculation. Biological activity is known to aggregate grains of sediment, resulting in a degree of "self-armoring" in relatively short periods. In sediment that contains a mixture of some sand-size material with the fine grained, winnowing can result in the surface layer having an average grain size much larger and less likely to transport than the underlying material.

Often, a consideration in site selection is an arbitrary water depth deep enough to place the dredged material below the action of storm winds and/or waves. Note that storm-induced movements are generally only of interest in the long-term stability of the site, and, therefore, we need consider only near-bottom currents. Wind-driven currents result from the transmission through the water column of frictional stresses on the sea surface. The magnitude of the stress and the resulting water velocity decrease with depth and are described by an exponentially decaying function (e.g., Ekman's solution). As an illustration of the magnitude of such currents, consider a sustained wind of [illegible] mph ([illegible] ft/sec) blowing over the sea surface. A reasonable estimate of the resulting surface current is [illegible] ft/sec ([illegible] wind speed) [illegible] degrees. At a depth of [illegible] ft, this is reduced to approximately [illegible] ft/sec and at [illegible] ft, [illegible] ft/sec. These magnitudes are [illegible] [illegible] [illegible] diameter, [illegible] [illegible] frequent [illegible]

Water Depth

Aside from the effect depth has on currents, there appears to be little additional short-term influence on disposal. Bokuniewicz observed the same general placement processes described above at sites with water depths ranging from approximately 50 to 220 ft. The very cohesive fraction of the material (clods or clumps) attain their terminal speed quickly and do not accelerate further with depth. In deeper water more entrainment occurs in the descent phase, and there is more dilution of the dredged material before it reaches the bottom. However, there is no increase in the jet impact speed, nor does the bottom surge spread at a faster rate. The initial thickness of the spreading surge above the bottom has been shown to be a function of water depth. Again, the total water depth at a site has more impact (usually favorable) in long-term time frames than on actual disposal processes. Operational problems may, however, be more severe at deeper sites because of anchorage difficulty and the resolution of monitoring procedures.

Density Stratification in Water Column

A sufficiently great density gradient in sufficiently deep water can result in arrest of the descending jet. The depth at which this occurs can be calculated. Bokuniewicz suggests that although highly stratified conditions may be encountered, it is most unlikely that water depths would be great enough at most sites to cause collapse in the upper water column. Johanson, Bowen, and Henry (1976), reporting on work discussed by Brooks (1973), present a simple empirical equation to estimate when a descending jet would penetrate a stratified layer. In addition to the relative differences in density, the depth to the interface (not total water depth) and the initial volume of the jet are the important terms. Several brief examples are summarized for a very severe pycnocline at various depths and initial volumes of released material. In order to create a situation in which the material would not penetrate through the pycnocline, the depth-to-interface had to exceed 100 ft and the volume had to be less than 250 cu yd.

Bathymetry

If the bottom in a disposal area is not horizontal, a component of the gravity force will influence the energy balance of the bottom surge. It is difficult to estimate the effects of slope alone, since bottom roughness plays an equally important role in mechanics of the spreading process. Gordon (1974) described the results of monitoring barged disposal operations at a level bottom site in Long Island Sound and concluded that 81 percent of the original volume of sediment released was deposited within a radius of 100 ft from impact and 99 percent was deposited within a radius of 400 ft. The Duwamish capping demonstration project monitored a disposal into an existing depression approximately 150 by 300 ft. Measurements of sediment in the water column at a distance of 100 ft from the center of impact showed that 93 percent of the original mass could be accounted for within this radius and confirmed the positive effect of using existing confining features at disposal sites.

In summary, the characteristics of the site tend to be more important in evaluating the long-term fate of the disposed material. The short-term effects are more influenced by factors such as the mechanical properties of the dredged material and the quantities/procedures at the time of release.

Dispersion and Mixing

The discharge of dredged material at an open-water disposal site can result in temporary increases in suspended solids levels and elevated concentrations of those chemical constituents present in the dredged material in a form available for release. Water quality standards or criteria were generally developed and are usually expressed as the concentration of a soluable constituent that will produce an undesirable effect if maintained for 95 hours or longer (Environmental Effects Laboratory 1976). However, a dredged material discharge is usually rapidly diluted following disposal; therefore, the dissolved constituent concentrations approximated by predictive testing such as the elutriate tests should also be reduced by some dilution factor to simulate as best as possible what will occur in the field. In addition, the expected dilution at the disposal site can be estimated by calculation of a mixing zone surrounding the release zone.

Applicable federal regulations (USEPA 1980, MacIntyre 1984) define the mixing zone of a discharge as a limited volume of water serving as a zone of initial dilution in the immediate vicinity of a discharge-point where receiving water quality may not meet quality standards or other requirements otherwise applicable to the receiving water. An interim method has been suggested to provide an estimate of the mixing zone size at an open-water site (Environmental Effects Laboratory 1976). This approximate method uses characteristic plume shapes and estimates of dispersion applicable in areas not influenced by boundaries. Although it is unlikely that the mixing characteristics at a proposed site would be the principal determining factor in selection, consideration of mixing zones can be used to optimize site location, sizing, or orientation. For example, an estimate of the surface area influenced by the mixing from a proposed discharge could suggest the most appropriate location within the site boundaries for the initial release point.

A discussion of mixing zone is also presented in the DMF (Lee et al. 1985, Peddicord et al. 1986).

Navigation and Positioning

Accurate navigation to an open-water site and precise positioning during material placement are obvious, yet frequently undefined, controls that can be applied to the disposal operation. The type of navigational and positioning equipment necessary will depend on the general location of the site. If the site is near enough to the shore, shore-based line-of-sight instruments can be used. At greater distances options include taut-moored buoys, various acoustical positioning devices, and computer-assisted real-time helmsman's aids. For point dumping, a minimum of a taut-moored buoy is necessary. In all cases, barges or scows should be required to come to a complete halt before release (static dump) and keep station to an accuracy on the order of 25 ft during release. Large operations may require several release points within the site with sequencing over a number of buoys or even anchored mooring points. On-site control of the operation is desirable where possible. The specification and effect of navigational controls vary greatly by project. Consider for example a designated site on the order of 5 acres in area and assumed to be circular in shape. The hopper dredge ESSAYONS has an overall length that would span from one side of the site to the other, making stationkeeping specifications meaningless.

Engineered Control Technologies

Submerged Discharge

The use of a submerged discharge or closed conduit of some type to place dredged material is a second level of restriction or control available. In general, a conduit is used primarily to ensure more accurate placement of the material and to reduce the exit velocity during formation of the surge phase. A conduit extending from the surface to the bottom will isolate the material from the water column during descent, reduce entrainment, and negate the effects of currents or stratifications. But, as discussed above, these factors have been shown in field investigations to be of secondary magnitude and can also be addressed or controlled by other means. The use of a conduit is a conservative measure that should be used to overcome placement problems or used in situations where the moisture content of the material is such that it would tend to flow on impact rather than mound.

A number of conduit technologies are available or have been suggested to place the dredged material through the water column.

Submerged Diffuser. A submerged diffuser (Fig. 6.2), originally designed as part of the Corps' DMRP, has been successfully field tested in the Netherlands at Rotterdam Harbor and as part of an equipment demonstration project at Calumet Harbor, IL. The diffuser minimizes upper water column impacts, and especially improves placement accuracy, and controls sediment spreading, reducing benthic impacts. By routing the slurry through a combined turning and radially divergent diffuser section, the discharge is released parallel to the bottom and at a lower velocity. The design of the section can be modified to suit project needs, but a typical design could reduce exit velocity by a factor of 8 to 16 without affecting the discharge flowrate. The diffuser

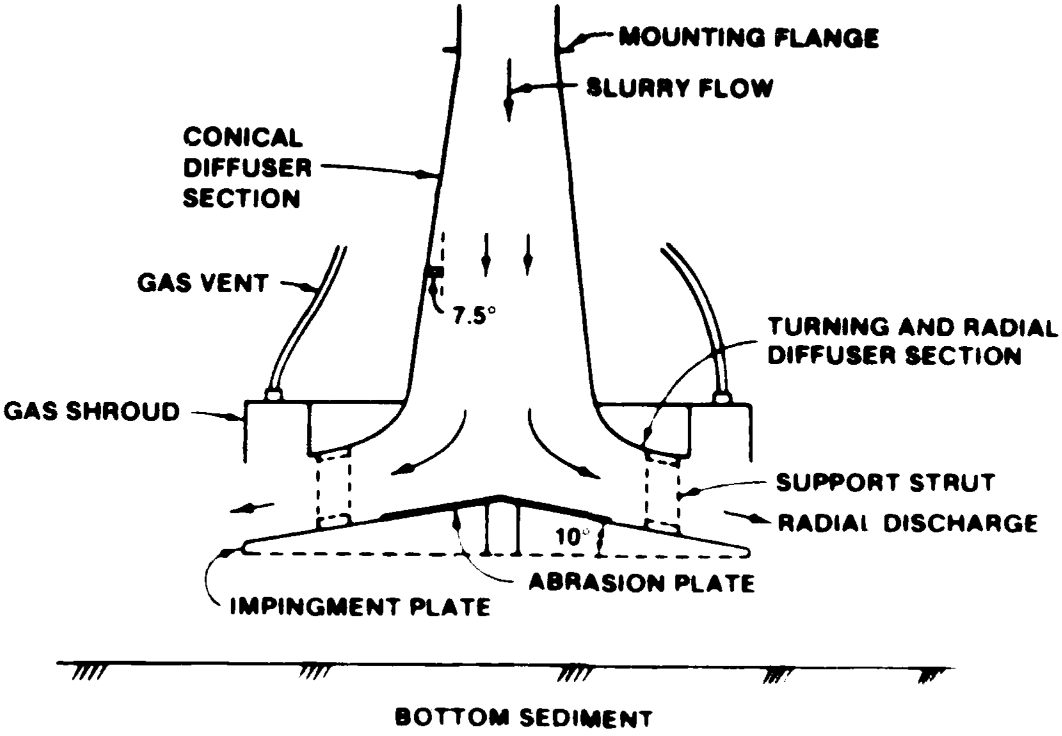


Figure 6.[illegible]. Submerged diffuser

could be employed as a direct connection to a pipeline disposal project or as a modification to hopper dredged or mechanically dredged material disposal techniques. For the latter cases, a re-slurrying pump-out capability [illegible] be required. The pipe connecting the surface support barge to the submerged diffuser head can be relatively small diameter [illegible] pipeline [illegible] can be semirigid, or can be flexible if the head is [illegible] by cable or other moorings.

Gravity-fed Downpipe (Tremie) [illegible]

Hopper Dredge Pumpdown. Some hopper dredges have pump-out capability by which material from the hoppers can be discharged like a conventional hydraulic pipeline dredge. In addition, some have further modifications that allow pumps to be reversed so that material can be pumped down through the dredge's extended dragarms. Because of the expansion at the draghead, the result is similar to use of a diffuser section.

Lateral Confinement at the Site

An increased degree of positive control over the movement of the material placed at a site can be achieved by using lateral barriers to confine the disposed material. Such confinement can be accomplished by using depressions or contour irregularities existing at a site, by excavating such depressions, or by construction of subaqueous dikes. Lateral confinement addresses the short-term benthic impact by ensuring accurate initial placement and attenuation of the spreading dredged material. It also addresses long-term benthic and water column impacts by providing an inherent degree of isolation from the aquatic environment, reducing the effects of convective currents, and increasing the ease and effectiveness of capping when used.

A phased demonstration project has been started in New York Harbor [illegible] the placement by hopper dredge of 160 loads of clean sediment to create a berm closing off the open end of an existing depression. Comparative bathymetry of the results of this first phase indicate that the berm construction was successful. Any of the conduit/diffuser technologies mentioned above [illegible] also be used to construct dikes or enhance existing bottom features.

Capping

Capping is simply the addition of a layer of some type of material over the mass of dredged sediment at the disposal site to effect isolation from the environment. The long-term impacts associated with soluble diffusion, convective transport, and bioturbation are reduced when a capping control measure is used. Physical stability of the disposal mass over time is also increased by capping, although short-term instability may be a concern if capping material [illegible] too rapidly over weak underlying dredged material.

Capping Materials. There has been a significant amount of research devoted to cover materials for burial of hazardous spills in lakes and waterways. This research, summarized by Hand et al. (1978), also applies to capping contaminated dredged material. Materials, both naturally occurring and manmade, that can be used to cover contaminated dredged material are divided into three categories: inert, chemically active, and sealing agents. Of these, only inert materials are likely to be successfully used in Puget Sound.

Inert materials include coarse- and fine-grained soils. Research is being performed at the WES to determine covering depths required to inhibit bioturbation of contaminated material and to retard leaching of contaminants into the water column. When soil is used as capping material, the cap should be thick enough to protect the underlying deposit from disturbances caused by storm-generated waves and by propeller wash from navigation traffic and to bury the contaminated sediments out of the reach of benthic organisms. The nature of the capping material will influence the depth and character of burrowing. Myers (1979) reported that a sand cap will attract suspension-feeding organisms that should not be expected to be deep burrowers while deep burrowing deposit feeders will colonize a fine-grained cap. Therefore, identification of site-specific biological populations (such as the deep-burrowing geoduck clam) is important in designing the cap thickness. Bokunieweiz (1981) reported that for disposal sites in relatively protected nearshore waters, a cap thickness of less than a metre should be sufficient, but site-specific studies should be done to evaluate biological populations and erosion potential.

Capping with chemically active materials involves the placement of a chemical compound over the contaminated dredged material that would react with [illegible] contaminants to neutralize or otherwise decrease toxicity. This strategy differs from the use of inert materials in that each contaminated dredged material must be dealt with on a case-by-case basis. Carbon compounds are a example of chemically active ingredients that can be added to a cap. [illegible] capping of dredged material, the active material should be combined [illegible] stabilizer to provide stability to the cap. Another approach [illegible] cover the active covering layer with an erosion-resistant inert [illegible] layer would also provide protection for the benthic organisms. While the inert covers have little [illegible] on the organisms, the chemical [illegible] sealing agents [illegible] some organisms. Also, greater accuracy [illegible] chemically active materials.

Sealing agents include grout, cements, and polymers. [illegible] feature of the grouts and cements is that, when placed [illegible] sediment, they will harden and form a crust, preventing [illegible] and resuspension of the contaminated material. A Japanese firm [illegible] has done work in dredged material stabilization and deep mixing of sediments using grouting compounds. Also, grouting is often used in the offshore [illegible] industry for stabilization of oil-producing facilities. The technology for using grout in the saltwater environment is well developed, and it could be adapted for use in capping contaminated dredged material. However, there are some disadvantages associated with the use of grout in capping dredged material. The thin layer of grout placed over the contaminated material cannot be considered as a permanent cap material. It should be used with a covering of inert material to provide additional stability and habitat for benthic organisms. There could also be problems with the grout cracking as the contaminated dredged material consolidates with time.

Polymer film systems have been the subject of a report by Widman and Epstein (1972). They proposed barge-mounted deployment systems for either hot or cold application of polymer film overlays. The application systems included those for placing coagulable polymers, hot-melt materials, and preformed commercially available films. The application system for the preformed overlay limited its application to water depths of 25 to 30 ft. Roe et al. (1970) reported on a chemical overlay system which included 2,000-sq ft per hour coverage and availability for water depths up to 120 ft. Concepts for the use of polymer film overlays for cover of contaminated dredged material were developed from early erosion-control efforts related to marine salvage work. None of the concepts have been field tested for dredged material. The major limitation to these concepts involves the design, construction, and cost of capital equipment required to place them.

Capping is currently being carried out in the Long Island Sound and New York Bight as a means of controlling the potential harm of contaminated or otherwise unacceptable sediment. In addition, capping was demonstrated in the Duwamish Waterway disposal project. All of these capping projects have used inert material to cover contaminated sediment. A significant amount of research has been performed on stability and biological activity of capping materials (Bokuniewicz et al. [illegible], Freeland et al. 1983, Morton [illegible] et al. [illegible], Brannon et al. [illegible]). Based on these past experiences, the possibility of using inert materials in Puget Sound is considered to be a reasonable treatment alternative for some of the contaminated sediment.

Stability of Capping Materials. Stability of the capping material is a major concern in the design of capping projects. Factors influencing cap erosion include (1) the particles (size, uniformity, shape, size distribution, texture, etc.); (2) the hydrodynamics of the system; (3) slope of the mound; and (4) the degree of cap material cohesiveness. Therefore, the prediction of erosion potential of a capping material should be made on the basis of site specific data. The inert materials used for capping can be classified as cohesive or noncohesive. For given erosive forces, movement of noncohesive particles depends on shape, size, and density of discrete particles and on the relative position of the particle with respect to surrounding particles. As previously discussed, the movement of cohesive particles depends on those factors cited above for noncohesive particles as well as on the strength of the cohesive bond between particles. Cohesive capping material excavated by mechanical dredges will be more resistant to erosion than those excavated by hydraulic dredges although more difficult to place.

A resulting problem with underwater capping is the potential for displacement of the contaminated mass by capping. Depending upon substrate firmness and density of the contaminated mass, the cap material may displace and redistribute the contaminated material, especially if the capping material is of a higher density or coarser size than the contaminated material. Determination of the potential for mass failure and dispersion would require testing with materials physically similar to those which will be placed underwater.

Conceptual Designs for Restricted Open-Water Disposal

Phillips et al. (1985) using the technologies discussed previously described five conceptual designs for restricted open-water disposal sites: deep-water mound, deep-water confined, shallow-water mound, shallow-water confined, and waterway confined. The general features of each concept are described below.

Deep-Water Mound

Deep-water mounding is the most simple design evaluated (Fig. 6.3). Deep water is any depth below the influence of storm waves, which will vary between sites. Theoretically, depths are unlimited, although in fact the ability to accurately place contaminated and capping materials establishes practical limits. Most deep-water sites would be between 60 and 500 ft deep. Dredged material is transported to the identified disposal site and placed on the bottom by bottom dump or vertical pipeline diffuser. No attempt is made to line the bottom; that is, separate the contaminated dredged material from the existing substrate or to confine the spread. However, the contaminated sediment should be concentrated as much as possible in one location, and partial containment may be possible by use of natural depressions. Once the contaminated material is placed, it is capped with clean coarse material placed by any of the methods previously described. Since the deep-water site was presumably selected for its low-energy environment, a relatively thin cap (3 ft) should be sufficient depending on the type of material used. As the contaminated material is mounded without confinement on the bottom, the major construction problem is to ensure that sufficient capping material is properly placed to completely cover the mounds to sufficient depth (properly designed for the hydrodynamic regime and bioturbation potential). So long as the cap remains in place, the major pathways of concern for contaminant loss are soluble diffusion and convection over time. Due to water depth, movement of ground water is expected to be substantially absent and contaminant movement through the ground consequently reduced.

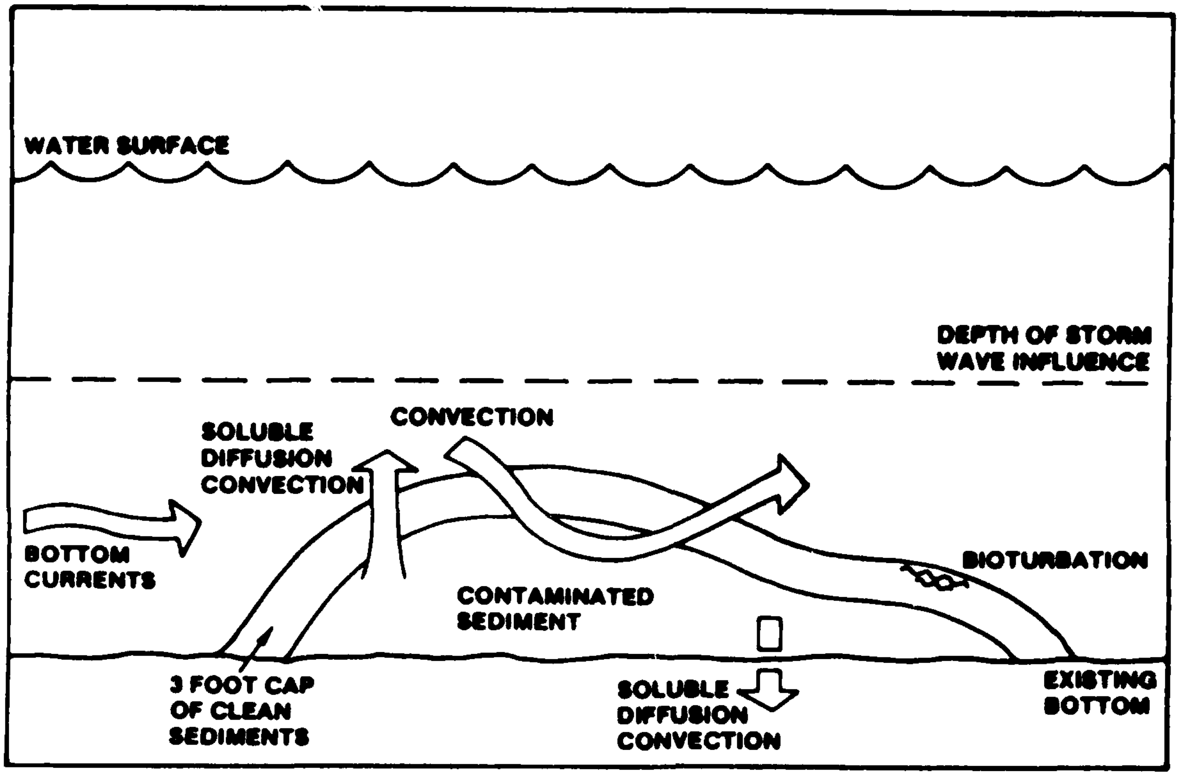


Figure 6.3. Concept for deep-water disposal mounds

Deep-Wate Confined

This design differs from deep-water mounding in that materials are placed in a natural or manmade depression in the sea floor to aid confinement (Fig. 6.4). Use of a vertical pipe allows construction of underwater diking to encircle the site or work in combination with existing natural features (e.g., rock outcrop). This design is more expensive than deep-water mounding due to site preparation, but may be easier to cap and the contaminated sediments are more isolated from the aquatic environment. Just as with the deep-water mound, the stable low-energy environment allows for a relatively thin cap. Pathways for contaminants to escape are essentially the same as for the deep-water mound.

Shallow Water Mound

The considerations for design and construction of shallow-water mounds are essentially the same as those of the deep-water mound. Conceptually, the

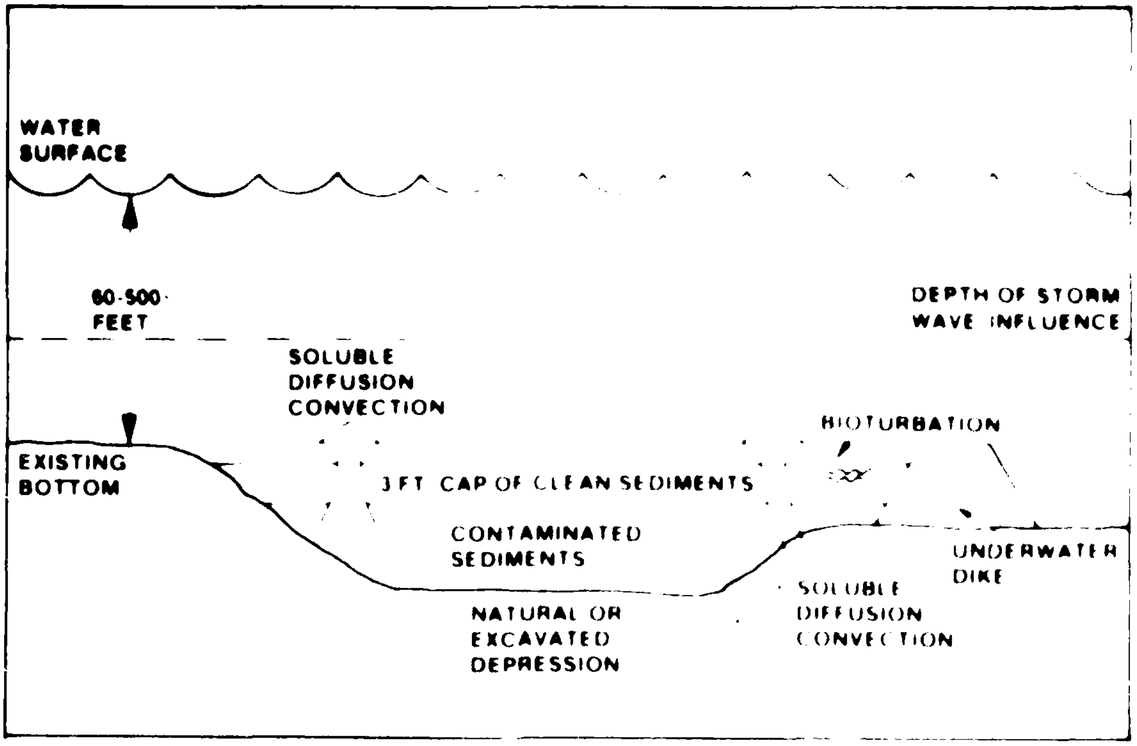


Figure 6.4. Concept for deep-water confined disposal

shallow-water mound should be easier to construct because of the lesser depths involved. Phillips et al. (1985) discounted the shallow-water mound as a reliable disposal alternative because of the high-energy environments characteristic of such sites. A thicker cap or armouring could be used to minimize these problems, however, the energy characteristics of potential disposal areas should be evaluated on a site specific basis.

Shallow-Water Confined

Shallow-water areas are those within the influence of storm waves but below intertidal elevations. Hence, final elevation of the cap would be within the -10 ft MLLW to -60 ft MLLW range. As with deep-water confined disposal, this design (Fig. 6.5) includes manmade containment structures or excavation, wholely or in combination with existing natural features, to hold the contaminated sediment. Because of higher energies found in shallow-water areas, a thicker cap is necessary (e.g., 6 ft rather than 3 ft) for this design. In addition, burial of the cap beneath a buffering layer of clean

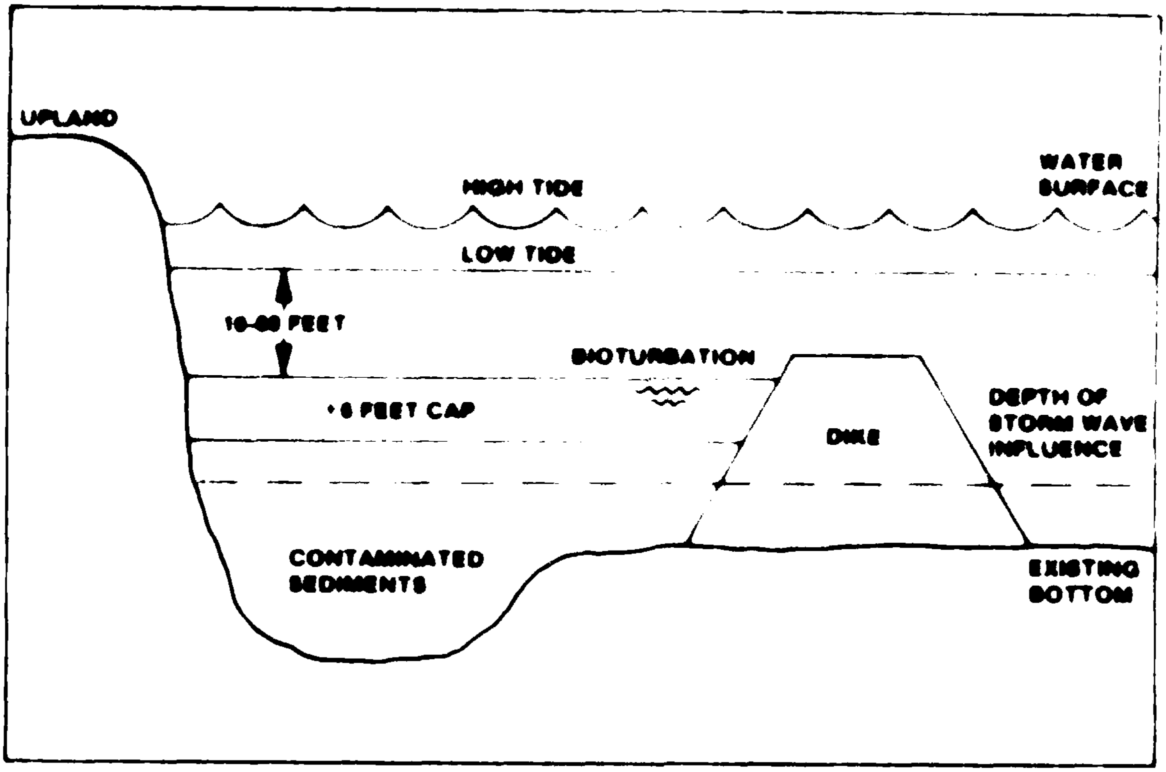


Figure 6.5. Concept for shallow-water confined disposal

sediment similar to the surrounding substrate may be appropriate in some instances to protect the integrity of the cap from erosion and bioturbation and to mitigate esthetic and resource impacts. Pathways for escape of contaminants are increased over deep-water designs by tidal or current induced convection of soluble fractions. Bioturbation and leaching into the underlying substrata are of more concern in the shallow-water environment than in deep water. Ground water infiltration from adjacent uplands may also be of concern. The increased cost of site preparation may be partially or completely offset by savings in transportation cost to a deep-water site.

Waterway Confined

Although this design (Fig. 6.6) is very similar to the option of burial of sediment in shallow-water areas, it differs in one very important respect. The shallow-water confined design can apply to many different geographic locations: open water, aquatic shelves near an urban shoreline, or relatively pristine environments. In these environments, agitation by currents, tides,

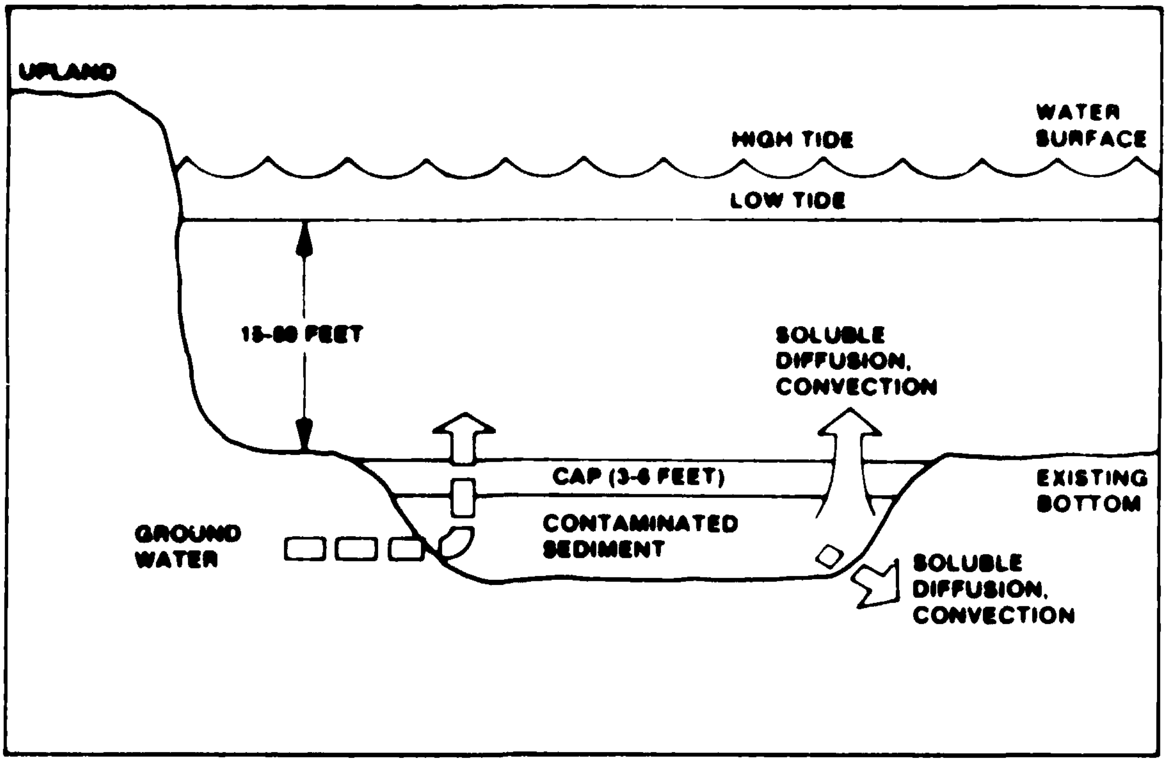


Figure 6.6. Concept for waterway confined disposal

and storms are factors that must be countered by the site design (i.e., a thicker cap, a buffer over the cap, frequent cap maintenance). In the waterway design, a confined pit is excavated deep within and into the bottom of an existing waterway. Preferably, the disposal site should be located in an area that will not be dredged. Otherwise, the disposal pit must be of sufficient depth to be well below anticipated dredging depths. Escape pathways are virtually identical to shallow-water confined disposal, though reduced in intensity to levels similar to the deep-water designs.

Dredged Material Treatment and Open Water Disposal

Restricted open water disposal is necessitated by the presence of contaminants associated with the sediment. On a mass basis, these contaminants are a very small fraction of the total amount of dredged material. Recently, concepts based on the treatment of the dredged material followed by either unrestricted open water disposal or open water disposal with less stringent restrictions than would be applied to the untreated dredged material have been proposed. These concepts generally fall into three categories: separation of the contaminants from the dredge material, immobilization of the contaminants in the dredged material, or contaminant destruction.

Contaminant Separation

Separation of contaminants from the dredged material is a method of reducing the amount of material that must be placed in restricted disposal sites. Typically, contaminant separation schemes result in a large volume of relatively uncontaminated dredged material and a smaller volume of highly contaminated material. Ideally, the large volume of relatively uncontaminated material is suitable for unconfined open water disposal. The smaller volume of highly contaminated material is subjected to further treatment or restricted disposal. Both physical and chemical separation technologies have been proposed.

Physical Separation. It is usually presumed that most contaminants are closely bound to the finer material found in sediments. As a result, separation of the classification of the sediment into fine and course fractions should result in a relatively uncontaminated course material and a more contaminated fine material. Physical separation and classification equipment have been described in Part IV.

Sediment classification schemes have been demonstrated on the laboratory and pilot scale (Tiederman and Reischman 1973, van der Burgt 1985) using hydrocyclones. However, this concept has not been used on a field scale project. Neither the technical or the economic feasibility of this concept have been evaluated in detail. Technical feasibility will depend on the grain size distribution of the sediment and thus is highly project specific. Designs for floating or shore based equipment required to fully implement this concept have not been developed and such equipment is not known to be available.

The cost of sediment classification schemes, implemented on the field scale has not been evaluated. The cost of the floating and shore based equipment is expected to be substantial; however, these costs will be mitigated by the anticipated reduction in disposal costs. The operation and maintenance cost of this concept is expected to substantially increase the cost of the dredging operation. Since the required equipment is highly dependent on project specific requirements, it is not possible to provide quantitative cost data for concept implementation.

Sediment classification is recommended as a potential demonstration project in Part VIII of this report. Such a project could provide meaningful information on technical effectiveness and economic viability of the concept.

Contaminant Extraction. A concept similar to contaminant separation is contaminant extraction. This concept, as applied to contaminated soils, is the subject of much ongoing research (EPA 1985). Various solvents are being tested as extractants. A brief review of the current status of this technology is contained in Part IV. Application of this concept to dredged material may have potential; however, use on a large scale is many years in the future. To date, no research has been performed on the extraction of contaminants from dredged material slurries. Equipment requirements and cost have not been evaluated; however, both are expected to be substantial.

Contaminant Immobilization

Contaminant immobilization technologies, as applied to contaminated soils, have been investigated (EPA 1985) and are reviewed briefly in Part IV. In general, these methods have not been applied to the immobilization of contaminants in dredge material slurries or solids. Chemical solidification/stabilization (S/S) of dredged material solids has been investigated on a laboratory scale and found to be technically feasible. S/S of dredged material slurries and solids have not been attempted on field scale projects. Concepts that couple S/S technology with near shore and upland disposal are presented in Part VIII as potential demonstration projects.

Contaminant immobilization coupled with unrestricted open water disposal has not been attempted. Most immobilization technologies are based on the premise that the stabilized material will be placed in a dry or substantially dry environment. Disposal in an open water environment has not been investigated. This concept may have merit; however, a substantial research and development investment will be required to demonstrate the technical effectiveness of the concept.

The floating and onshore equipment requirements and costs for this concept have not been developed. Both are expected to be substantial. The primary drawback to this technology are the large quantities of material that must be handled.

Contaminant Destruction

Contaminant destruction followed by unrestricted open water or conventional upland or near shore disposal of the residue is sometimes proposed as an appropriate method of contaminated dredged material disposal. These proposals are usually based on incineration technologies for contaminant destruction. Unfortunately, incineration has been shown to be extremely costly and economically infeasible for the vast majority of dredging projects. There may be special cases where this concept is applicable, i.e. small volumes of sediments with high concentrations of organics. Incineration technology is discussed in Part IV.

Summary

Although treatment of the contaminated dredged material followed by unrestricted open water disposal is an attractive concept, there have been no field scale demonstrations. Floating and shore based equipment is not readily available and the cost is uncertain. Part VIII discusses the possibility of projects to demonstrate some of the technologies required to implement this concept.

PART VII: TESTS FOR EVALUATION OF CONTAMINATED SEDIMENT AND FOR DESIGN OF CONTROL TECHNOLOGIES FOR CONTAMINATED DREDGED MATERIAL

This part of the report reviews the laboratory procedures or tests and protocols used to evaluate and characterize contaminated sediment and the disposal site, and the engineering or bench-scale tests that provide the data necessary to design the control technologies. A basic description of the tests are described along with references to standard laboratory procedures manuals where they are available. Procedures for selected tests that are specifically for dredged material and that are not widely published elsewhere are included in Appendix A.

Sediment Characterization

Chemical

An initial step in any dredging project is an inventory of the bulk sediment for contaminants expected to be present in the area. Characterizing the sediment can be a difficult task involving the following decisions (Plumb 1981):

- Selection of sampling locations.
- Selection of sampling equipment.
- Number of samples to collect.
- Type of tests to be performed on the samples.
- Specific chemical analyses to be performed.

Guidance for making these decisions for dredging projects is provided in "Procedures for Handling and Chemical Analysis of Sediment and Water Samples" (Plumb 1981).

Bulk analysis provides an estimate of the total concentration of a constituent in the sediment sample. The analytical result will combine the content of the various sediment phases (interstitial water phase, exchangeable phase, residual phase, etc.). From this value for a particular constituent, an estimate can be made of the total mass of a contaminant that will be handled by the dredging project. Bulk analysis is generally the easiest way to determine what, if any, contaminants that may require control or treatment are present. Bulk analysis will not predict migration potential, mobility, or

Biological evaluation [illegible] environmental effects [illegible] other tests, bulk analysis is the recommended starting [illegible] evaluation and should be performed before implementing [illegible] tests, a program that seeks to determine [illegible] environmental effects [illegible] [illegible] dredging and disposal.

Once samples are collected, a decision must be made regarding the individual chemical analyses to be determined. If historical data are available for the general area of the dredging project, they may indicate contaminants of concern. Other sources of data are pollutant discharge permits, self monitoring data, and general characteristics of point source discharges in the area and nonpoint source pollution data including land use, cultural practices, and use of agricultural chemicals. Appendix B lists pollutants regulated by the Clear Water Act and references standard analytical methods for performing the analyses.

Table 7.1 presents the detection limits for contaminants of potential concern in the Puget Sound (Tetra Tech 1983) that generally could be used in the chemical analyses of samples from the test protocols. Not all of these will be identified as contaminants of real concern in any specific sediment. All of the detection limits listed in Table 7.1 are for procedures found in Appendix B. These detection limits are based on relatively clean samples with few interferences. Most of the detection limits for metals may be achieved using an Atomic Absorption Spectrometer equipped with a heated graphite furnace or an inductively coupled plasma emission spectrometer. Detection limits for mercury are obtained using a cold vapor technique with the atomic absorption spectrometer. The detection limits for the organics (except pesticides and PCBs) are for GC/MS procedures using one litre of water or 50 g of solid material. The lower detection limits cited for pesticides and PCBs are based on GC procedures. Although all of these procedures have been in use for a number of years at laboratories analyzing environmental samples, most require analysts who are experienced in the methodology and who are acquainted with the interferences that can alter results. Lower levels of detection can be obtained through concentrating samples by a factor of ten. Further lowering of detection levels will require more sophistication in facilities and experienced analysts that will not be available at routine environmental testing laboratories and will be extremely laborious and expensive. For example, to

Table 7.1

Detection Limits for a Contaminants of Potential Concern in Puget Sound Bay*

Contaminants	Sediment mg/kg	Plant mg/kg	Animal mg/kg	Water µg/l
METALS				
Ag	0.1	0.1	0.1	0.6
As	0.1	0.05	0.1	1
Be	0.5	0.5	0.5	5
Cd	0.01	0.01	0.01	0.1
Cr	0.1	0.05	0.1	1
Cu	0.1	0.1	0.1	1
Hg	0.1	0.1	0.1	0.2
Ni	0.3	0.05	0.3	3
Pb	0.1	0.1	0.1	0.1
Sb	0.5	0.5	0.5	5
Se	0.2	0.05	0.2	2
Tl	0.1	0.1	0.1	1
Zn	0.1	0.1	0.1	1
Volatiles				
Benzene**	0.050	NA++	NA	10
Bromoform				
Carbon tetrachloride				
Chloroform				
Chloroethane+				
Chlorodibromomethane				
Dichloromethane				
Dichlorobromomethane				
Ethylbenzene**				
Formaldehyde+				
Tetrachloroethane**				
1,1,1-Trichloroethylene				
Toluene				
1,1-Dichloroethane				
1,1-Dichloroethylene+				
1,2-trans-Dichloroethylene+				
Xylene**				
BASE/NEUTRALS (except PCBs)				
Haloginated Compounds				
Hexachloroethane	0.2	[illegible]		
1,2-Dichlorobenzene	0.2	[illegible]		

(Continued)

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* Priority pollutants and other significant [illegible] ment Bay sediments, waters, or point sources.

** Reported in waters but not in sediments [illegible]

\+ Reported only in point sources.

++ NA - Not applicable.

AD-A184 930 GUIDELINES FOR SELECTING CONTROL AND TREATMENT OPTIONS 4/8
FOR CONTAMINATED DREDGED MATERIAL(U) ARMY ENGINEER
WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR..
UNCLASSIFIED M J CULLINANE ET AL. SEP 86 F/G 24/3 NL

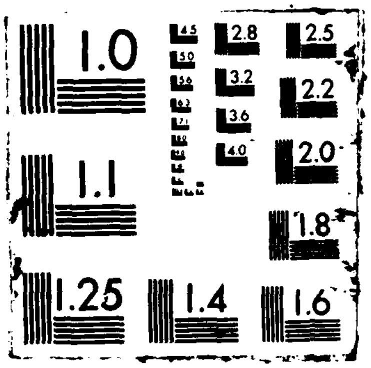
1.0
4.5
5.0
5.6
6.3
7.1
8.0
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

Table 7.1 (Continued)

Contaminants	Sediment mg/kg	Plant mg/kg	Animal mg/kg	Water µg/ℓ
BASE/NEUTRALS				
Haloginated Compounds (Continued)				
1,3-Dichlorobenzene	0.2	0.2	0.2	10
1,4-Dichlorobenzene	0.2	0.2	0.2	10
1,2,4-Trichlorobenzene				
2-Chloronaphthalene				
Hexachlorobenzene				
Hexachlorobutadiene				
Misc. chlorinated butadienes**				
Bis(2-chloroethyoxy) ether				
Bis(2-chloroethyoxy) methane				
Low MW Aromatics				
Azobenzene	0.2	0.2	0.2	10
Naphthalene				
2-methylnaphthalene**				
1-methylnaphthalene**				
2,6-dimethylnaphthalene**				
1,3-dimethylnaphthalene**				
2,3-dimethylnaphthalene**				
2,3,6-trimethylnaphthalene**				
2,3,5-trimethylnaphthalene**				
Acenaphthene				
Acenaphthalene				
Fluorene				
Biphenyl**				
Anthracene/phenanthrene				
1-methylphenanthrene**				
2-methylphenanthrene**				
High MW Aromatics				
Fluoranthene	0.2	0.2	0.2	10
Pyrene				
1-methylpyrene**				
Benzo(a)anthracene				
Chrysene/triphenylene				
Dibenzo(a,h)anthracene	0.5	0.5	0.5	25
Benzofluoranthenes	0.2	0.2	0.2	10
Benzo(e)pyrene**	0.2	0.2	0.2	10
Benzo(a)pyrene	0.2	0.2	0.2	10
Indeno(1,2,3-cd)pyrene	0.5	0.5	0.5	25
Benzo(g,h,i)perylene	0.5	0.5	0.5	25
Phthalate Esters				
Diethylphthalate	0.2	0.2	0.2	10

(Continued)

** Reported in waters but not in sediments (to date).

Table 7.1 (Concluded)

Contaminants	Sediment mg/kg	Plant mg/kg	Animal mg/kg	Water µg/ℓ
BASE/NEUTRALS				
Phthalate Esters (Continued)				
Bis(2-ethylhexyl)phthalate	0.2	0.2	0.2	10
Butylbenzylphthalate	0.2	0.2	0.2	10
Di-n-butylphthalate				
Di-me-phthalate				
Di-n-octylphthalate				
ACID EXTRACTABLES				
Cresol**	0.5	0.5	0.5	25
Phenol				
2-chlorophenol				
2,4-dichlorophenol+				
2,4,6-trichlorophenol				
Pentachlorophenol				
P-chloro-m-cresol				
4-nitrophenol				
PESTICIDES AND PCBs				
A-chlordane	1	0.001	0.001	0.001
Aldrin	0.2	0.0002	0.0002	0.010
α-Hexachlorocyclohexane (HCH)++				
β-HCH				
γ-HCH (lindane)				
4-4'-DDD				
4-4'-DDE				
4-4'-DDT				
PCB-1242	2	0.002	0.002	0.01
PCB-1248	2	0.002	0.002	0.01
PCB-1254	2	0.002	0.002	0.01
PCB-1260	4	0.004	0.004	0.02
MISCELLANEOUS SUBSTANCES				
Manganese (Mn)+	0.1	0.1	0.1	0.001
Molybdenum (Mo)+	0.1	0.0001	0.0001	0.001
A-endosulfan+	0.2	0.0002	0.0002	0.004
Cyanide+	1	1.0	1.0	1
Nitrosodiphenylamine	0.2	0.2	0.2	0.010

** Reported only in point sources.

\+ Reported in waters but not in sediments (to date).

++ Hexachlorocyclohexanc (HCH) is sometimes referred to elsewhere as BHC (benzene hexachloride), but this is a misnomer and is not used here.

lower detection limits for certain organic compounds may require 10 ℓ of test solution concentrated down to 1 ml prior to analysis.

EPA Standards and criteria for toxic or hazardous contaminants are presented in Appendix C. These criteria are not applicable to bulk sediment analyses, but are presented primarily to identify the priority contaminants that may be considered for analysis. The potential for environmental or human exposure depends on the amount of contaminant present, volatility, mobility in soil, solubility in water, and transformation potential. WES is developing testing protocols specifically designed to define the mobility of contaminants from dredged material. These protocols will be described later in this chapter.

Physical Analyses

Physical analyses of sediment are required to characterize dredged material behavior, including contaminant mobility, and to determine the requirement for control measures for the site, such as dikes, covers, surface water controls, and leachate collection systems.

Characterization of dredged material involves soil tests listed in Table 7.2 with the addition of several tests specifically selected to predict the behavior of dredged material and its associated contaminants. Figure 7.1 is a flow chart showing the testing program recommended by WES for determining the physical properties of sediment and dredged material samples. The tests identified in Fig. 7.1 are briefly discussed in the following paragraphs.

Visual Classification. Visual classification of sediment samples by an experienced professional is helpful in classifying the type of sediment and in planning subsequent soil tests. It is a recommended first step in a testing program.

Gradation. Gradation or grain size analyses should be performed on coarse-grained samples or on the coarse grained fraction of samples including coarse- and fine-grained material. Sediment samples used to simulate dredged material should be separated into coarse- and fine-grained material before proceeding with further tests since in a containment area the coarse material rapidly settles out of the dredge slurry at the end of the pipe. Sizing the containment area depends on behavior of the remaining fine-grained material. Grain-size analysis of coarse material is generally a sieve analysis; whereas fine-grained material is usually classified using a hydrometer analysis.

Table 7.2

Manual Designations of Selected Engineering Soil Tests*

Test	ASTM	AASHTO	USBR	USCE
Gradation (mechanical analysis)	D-422**	T-88	E-6	Appendix V
Water content	D-2216	--	E-9	Appendix I
Specific gravity	D-854	T-100	E-10	Appendix IV
Liquid limit	D-423	T-89	E-7	Appendix III
Plastic limit	D-424	T-90	E-7	Appendix III
Shrinkage limit	D-427	T-92	E-7	Appendix III
Relative density	D-2049	--	E-12	Appendix XII
Standard Proctor compaction	D-698	T-99	E-11	Appendix VI
Modified Proctor compaction	D-1557	T-180	--	Appendix VI
One-Dimensional Consolidation	D-2435	T-216	E-15	Appendix VIII
Permeability	D-2434	T-215	+	Appendix VII
Shrink/swell behavior	D-3877	--	--	Appendix VIII-A

* Adapted from McAneny et al. 1986

** Other specialized ASTM designations relate to gradation.

\+ E-12, E-14, E-15, E-18, E-19, E-36

Note: Manuals referred to in this table are the following:

ASTM: "Part 19: Soil and Rock; Building Stones," Annual Book of ASTM Standards, published annually by the American Society for Testing and Materials, Philadelphia, PA.

AASHTO: Standard Specifications for Transporation Materials and Methods of Sampling and Testing, published every four years by the American Association of State Highway and Transportation Officials, Washington, DC.

USBR: Earth Manual, 2nd edition (1974), published by the Bureau of Reclamation, U. S. Department of the Interior.

USCE: "Laboratory Soils Testing," Engineer Manual EM 1110-2-1906 (1970; revision issued 1980), published by the Office of the Chief of Engineers, U. S. Department of the Army.

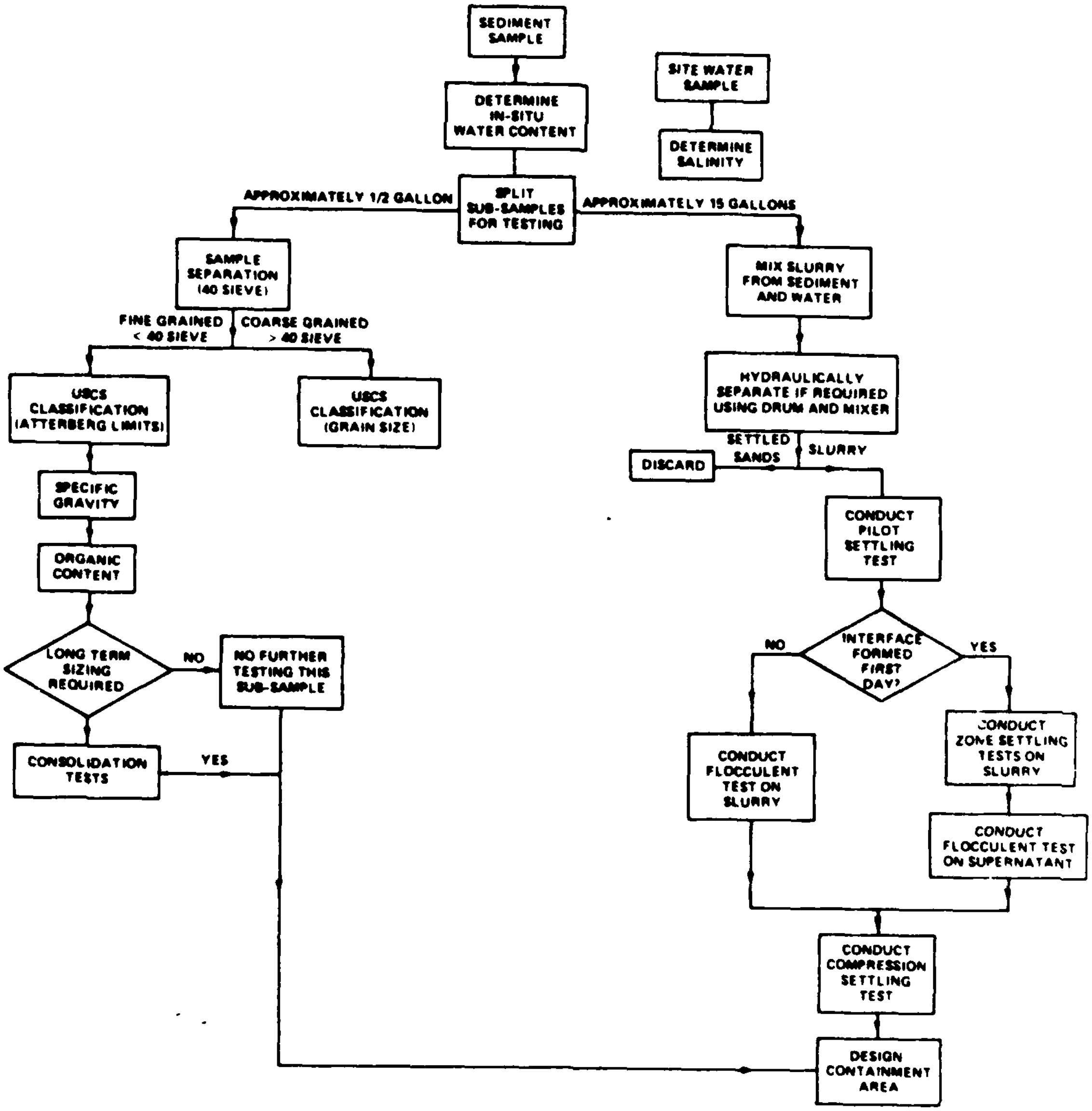

Figure 7.1. Flow chart depicting laboratory testing program for determining engineering properties of sediment samples (Montgomery 1978)

Plasticity Analyses. In order to evaluate the plasticity of fine-grained samples of sediment, the Atterberg liquid limit (LL) and plastic limit (PL) must be determined. The LL is that water content above which the material is said to be in a semiliquid state and below which the material is in a plastic state. Similarly, the water content that defines the lower limit of the plastic state and the upper limit of the semisolid state is termed the PL. The plasticity index (PI), defined as the numerical difference between the LL and the PL, is used to express the plasticity of the sediment. Plasticity analyses should be performed on the fine-grained fraction (<No. 40 sieve) of sediment samples. A detailed explanation of the LL and PL test procedures and apparatus can be found in Appendix III of EM 1110-2-1906 (OCE 1970).

Water Content. Water content is an important factor used in sizing dredged material containment areas and in performing other soils tests. Water content determinations should be made on representative sediment samples. In the case of mixtures of coarse- and fine-grained sediment samples, the water content of the sample should be determined prior to separation on the No. 40 sieve. The detailed test procedure for determining the water content is found in Appendix I of EM 1110-2-1906.

Specific Gravity. Values for specific gravity of solids for fine-grained sediment and dredged material are required for determining void ratios, conducting hydrometer analyses, and consolidation testing. Procedures for conducting the specific gravity test are given in Appendix IV of EM 1110-2-1906.

USCS Classification. When classifying sediment samples, the fine-grained portion which passes the No. 40 sieve should be classified separately from the coarse-grained portion retained on the No. 40 sieve, regardless of which fraction comprises the greatest percentage by weight. Additional information regarding the Unified Soils Classification System USCS classification may be found in WES Technical Memorandum No. 3-357.

Organic content. For classification purposes, the organic content generally need not be quantified, but rather a knowledge of whether significant organic matter is present is required. The following dry combustion test procedure is recommended to determine the organic content expressed as the percentage of weight lost on ignition:

1. Dry a 40-g sample at 105°C until there is no further weight loss (usually 4 to 6 hr).

2. Place it in a desiccator to cool for 15 min.

3. Weigh the sample and place it in the oven at 440°C for 4 hr.

4. Place it in the desiccator to cool for 15 min.

5. Weigh the sample and determine the organic content by dividing the weight lost by the sample while in the oven at 440°C by the total weight of the sample at the time it was placed in the oven.

Upland and Nearshore Site Characterization

Upland and nearshore site characterization is a critical element of evaluation of alternatives for disposal of contaminated dredged material. Collection of all data necessary to define the impact of an alternative on human health and the environment by defining pathways and receptors and proper design of the alternative are the objectives of site characterization. However, collection of a laundry list of items for every site would not be cost effective. Existing information and professional judgement must be used to select the specific pieces of information important to the project.

Investigations of upland and nearshore site characteristics may be categorized as geology, ground-water hydrology, surface-water hydrology, pedology, climatology, human populations, and ecology. Elements of each of these types of investigations have been discussed in USEPA (1985) and are reviewed in the following paragraphs.

Geologic Investigations

Geology of a disposal site is important because of its interrelationship to contaminant releases, water movement and contaminant transport, and ease of implementation of control/treatment alternatives.

Structures influencing ground-water flow may include folds, faults, joints, fractures, and interconnected voids. Stratigraphic information may be used to identify aquifers and confining formations so that the units most likely to transport contaminants can be delineated. Stratigraphic data and composition of the geologic units are useful in estimating effective porosity, permeability, and homogeneity, which cause flow within an aquifer. The geologic information that may be needed to evaluate the site hydrology and site engineering aspects is summarized in Table 7.3 (USEPA 1985).

Ground-water Investigations

Protection of ground water should be a primary goal of upland and nearshore disposal site selection. Characterization of contaminant transport in

Table 7.3

Summary of Important Geologic Information

Information Needed	Purpose or Rationale	Appropriate Collection Methods	
		Primary	Secondary*
Structural features:			
• Folds, faults	Determine natural flow barriers or controls	Existing geologic maps, field surveys	Remote sensing, aerial photography, geophysical techniques
• Joints, fractures, interconnected voids	Predict major boundaries, avenues of ground-water flow	Existing geologic profiles, pump tests	Borehole logging and mapping, geophysical techniques (limited)
Stratigraphic characteristics:			
• Thickness, aerial extent, correlation of units, extent (horizontal and vertical) of aquifers and confining units	Determine geometry of aquifers and confining layers, aquifer recharge and discharge	Existing geologic maps, observation wells	Borehole logging and mapping, geophysical techniques (limited)
• Mineral composition, permeability and porosity, grain-size distribution, in-situ density, moisture content	Determine ground-water quality, movement, occurrence, productivity	Laboratory analysis, existing geologic literature	Existing literature

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* May be appropriate if detailed information is required.

ground water requires determination of the hydrologic properties of the aquifer. These properties include direction and rate of ground-water flow. Flow varies according to aquifer type (confined, unconfined, or perched), hydrologic boundaries, leakage to or from other aquifers, and recharge or withdrawal from the aquifer (USEPA 1985).

Ground-water and geologic data not available in the literature almost always require direct observation through the installation of ground-water wells, aquifer tests to determine flow parameters such as permeability and hydraulic potential, and extensive sampling and analysis. Geophysical survey methods may be useful for determining geologic and geohydrologic conditions and for evaluating the direction and extent of contaminant plumes. Procedures for well installation, aquifer testing, and sampling of the ground-water regime are described in Ford et al. (1983). The types of hydrologic data that may be needed to characterize the movement of contaminants in ground water are presented in Table 7.4 (USEPA 1985).

Surface-water Investigations

If contaminants can be transported via surface-water runoff, then sampling to evaluate the types and levels of contaminants within this medium should be performed. Because the importance of this pathway depends greatly on weather conditions, data should be collected at specific known locations (or stations), under known meteorological conditions, and through periods representing natural cycles in ambient conditions (USEPA 1985). Established sampling and analytical procedures for surface-water field studies and water quality modeling may be found in a large number of texts and agency publications. Surface-water information that may be required for characterization of an upland or nearshore site is presented in Table 7.5.

Pedological Investigations

The amount of contaminated liquid that infiltrates into the ground depends on the ground cover, antecedent moisture, land use, and the surface soil type. The amount of contaminated liquid and the pathway it may take to enter an aquifer depend on the physical properties (e.g., permeability, porosity) of the subsurface geologic media and the near-surface characteristics (e.g., soil porosity and moisture content, slope, vegetative cover) (USEPA 1985). Surface characteristics of the disposal site may be predetermined by appropriately designing and installing a cover. However, dredged material properties and leachate prediction tests will be needed to complement

Table 7.4

Summary of Important Ground-Water Information*

Information Needed	Purpose or Rationale	Appropriate Collection Methods	
		Primary	Secondary**
Ground-water occurrence:			
• Aquifer boundaries and locations	Define flow limits and degree of aquifer confinement	Existing literature, Water Resource Atlases	Borehole logging, regional water-level measurements
• Aquifer ability to transmit water	Determine potential quantities and rates for treatment options	Pumping and injection tests of monitor wells	
Ground-water movement:			
• Direction of flow	Identify most likely pathways of contaminant migration	Existing hydrologic literature	Water-level measurements in monitor wells
• Rate of flow	Determine maximum potential migration rate and dispersion of contaminants	Existing hydrologic literature	Hydraulic gradient, permeability, and effective porosity from water-level contours, pump test results, and laboratory analyses

(Continued)

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* USEPA (1985).

** May be appropriate if detailed information is required or if it is the only method due to a paucity of published data.

Table 7.4 (Concluded)

Information Needed	Purpose or Rationale	Appropriate Collection Methods	
		Primary	Secondary**
Ground-water recharge/discharge:			
• Location of recharge/discharge areas	Determine interception points for withdrawal options or areas of capping	Existing site data, hydrologic literature, site inspection	Comparison of water levels in observation wells, piezometers, lakes, and streams
• Rate	Determine variability of loading to treatment options	Existing literature	Water-balance calculations aided by geology and soil data
Ground-water quality:			
• pH, total dissolved solids, salinity, specific contaminant concentrations	Determine exposure via ground water; define contaminant plume for evaluation of interception methods	Existing site data	Analysis of groundwater samples from observation wells, geophysics

Table 7.5

Summary of Important Surface-water Information*

Information Needed	Purpose or Rationale	Appropriate Collection Methods	
		Primary	Secondary**
Drainage patterns:			
● Overland flow, topography, channel flow pattern, tributary relationships	Determine if overland or channel flow can result in onsite or offsite flow and if pattern form contaminant pathways	Topographic maps, site inspection	Aerial mapping, ground survey
Surface-water bodies:			
● Flow, stream widths and depths, channel elevations, flooding tendencies	Determine volume and velocity, transport times, dilution potential, potential spread of contamination	Public agency data and atlases; catalogs, maps, and handbooks for background data	Aerial mapping, ground survey
● Structures	Effect of manmade structures on contaminant transport and mitigation	Public agency maps and records	
● Surface-water/groundwater relationships	Predict contaminant pathways between media	Public agency reports and surveys	Water-level measurements, modeling

(Continued)

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* USEPA (1985).

** May be appropriate if detailed information is required.

Table 7.5 (Concluded)

Information Needed	Purpose or Rationale	Appropriate Collection Methods	
		Primary	Secondary**
Surface-water quality:			
pH, temperature, total suspended solids, suspended sediment, salinity, specific contaminant concentrations	Provide capacity of water to carry contaminants and water/sediment partitioning	Public agency computerized data files, handbooks, open literature	Sampling and analysis

pedological data. Important pedological information is presented in Table 7.6.

Climatological Investigations

Local climatological data are important to defining releases of contaminants and to design control or treatment facilities. Rainfall volumes must be calculated for peak storms and for long term operations in order to design surface-water control facilities and to calculate a water balance identifying where the rainfall goes (e.g., surface water, percolation, etc.) and the volume that must be treated prior to release. Temperatures affect design parameters for some treatment processes, and winds can be important if volatile contaminants are a concern. Climatic data is generally available from the National Oceanic and Atmospheric Administration (NOAA). A summary of important climatological information is presented in Table 7.7.

Investigations of Effects on Public Health

Potential exposure of human populations to dredged material contaminants should be included when characterizing an upland or nearshore site. Exposure depends not only on the rate of contaminant release from the site, which is defined by the numerous tests discussed in this chapter, but also the numbers and locations of inhabitants in a given geographic area and the type and extent of human contact with the contaminated media (USEPA 1985). Typical information needed is as follows:

- Local use of surface water draining the site.
  - Drinking water
  - Recreation (swimming, fishing)

- Local use of ground water as a drinking water source.
  - Distance of wells from site
  - Expected direction of ground-water flow

- Human use of or access to the site and adjacent lands.
  - Recreation
  - Hunting
  - Residential
  - Commercial
  - Relationship between population locations and prevailing wind direction

More detailed guidance regarding potential health impacts are presented in EPA guidance documents (USEPA 1984).

Ecological Investigations

Biological and ecological information is collected for use in the endangerment and environmental assessments. The assessment may follow the

Table 7.6

Summary of Important Pedological Information*

Information Needed	Purpose or Rationale	Appropriate Collection Methods	
		Primary	Secondary**
Soil characteristics:			
● Type, holding capacity, temperature, biological activity, engineering properties	Estimate the effect of the properties on infiltration and retardation of leachates and the release of gaseous contaminants	Reports and maps by Federal and county agencies, Soil Conservation Service (SCS) publications	Borehole sampling, laboratory measurements (ASTM methods)
Unsaturated Zone Characteristics:			
● Permeability, variability, porosity, moisture content, chemical characteristics, extent of contamination	Estimate lechate transport through soil matrices	Existing literature	Borehole logs, geophysical surveys, sampling and analysis, lysimeters

(Continued)

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* USEPA (1985).

** May be appropriate if detailed information is required.

Table 7.6 (Concluded)

Information Needed	Purpose or Rationale	Appropriate Collection Methods	
		Primary	Secondary**
Soil chemistry characteristics:			
• Solubility, ion speciation, adsorption coefficients, leachability, exchange capacity, mineral partition coefficients, chemical and sorptive properties	Predict contaminant movement through soils and availability of contaminants to biological systems	Existing scientific literature	Chemical analysis, column experiments, leaching tests

Table 7.7

Summary of Important Climatological Information*

Information Needed	Purpose or Rationale	Appropriate Collection Methods	
		Primary	Secondary**
Local Climate: • Precipitation • Temperature • Evaporation • Wind speed and direction • Presence of inversion layers	Define recharge, aeolian erosion, evaporation potential, effect of weather patterns on alternatives, area of deposition of particles	National Climate Center (NCC) of National Oceanic Atmospheric Administration, local weather bureaus	Onsite measurements and observations
Weather extremes: • Storms • Floods • Winds	Determine effect of weather extremes on selection and timing of alternative actions, extremes of depositional areas	NCC, State emergency planning offices	

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* USEPA (1985).

** May be appropriate if detailed information is required.

guidelines of the National Environmental Policy Act of 1969, as amended; however, State guidelines may be more stringent and should also be consulted. The information should include identification of the site fauna and flora (especially endangered species and those consumed by humans or found in human foodchains), critical habitats, land use, water use, and the distribution of water wells (USEPA 1982b). A summary of important ecological information is provided in Table 7.8. The extent to which this information is necessary for a particular project is site specific and dependent of the nature of the contaminated dredged material.

Contaminant Release Studies for Upland and Nearshore Sites

Migration of contaminants from dredged material disposal operations cannot be predicted on the basis of bulk chemical analysis of sediment. Other testing protocols are required to quantify the contaminant release to the various migration pathways and potential receptors. The Corps of Engineers Dredged Material Research Program, Long Term Effects of Dredging Operations Program, and Dredging Operations Technical Support Program have pursued establishment of testing protocols to define the following:

- Release of contaminants in the effluent during disposal operations.
- Surface runoff of contaminants in either dissolved or suspended particulate following disposal.
- Leaching into ground water.
- Plant uptake directly from dredged material, followed by indirect animal uptake from feeding on vegetation.
- Animal uptake directly from dredged material.
- Gaseous or volatile emissions during and after placement of dredged material.

Results of these tests provide the basis for decision making on the need for restrictions in the "Management Strategy" (Francingues et al. 1985) and the "Decisionmaking Framework" (Lee et al. 1986). These documents briefly describe the proposed test protocols. A brief summary of the various tests is presented below and details where available are presented in Appendix A.

Table 7.8

Summary of Important Ecological Information*

Information Needed	Purpose or Rationale	Appropriate Collection Methods	
		Primary	Secondary**
Fauna and flora	Determine potentially affected ecosystems; determine presence of endangered species	Public records of area plants and animals survey, survey of plants and animals on or near site, survey of site/area photographs	Remote sensing, ground survey
Critical habitats	Determine areas on or near site to be protected during remediation	Public records of site environment	Ground survey
Land-use characteristics	Determine if terrestrial environment could result in human utilization, e.g., presence of game animals, agricultural land	Agricultural and development maps, site survey	Remote sensing, ground and aerial survey
Water-use characteristics	Determine if aquatic environment could result in human utilization of water, e.g., presence of game, fish, recreational waters	Water resource agency reports, site survey	
Biocontamination	Determine observable impact of contaminants on ecosystems		Sampling and analysis, remote sensing

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* USEPA (1985).

** May be appropriate if detailed information is required.

Effluent Quality

Water quality effects of upland disposal effluents (water discharged during active disposal operations) have been identified as one of the greatest deficiencies in knowledge of the environmental impact of dredged material disposal (Jones and Lee 1978). Dredged material placed in an upland disposal area undergoes sedimentation, while clarified supernatant waters are discharged from the site as effluent during active dredging operations. The effluent may contain levels of both dissolved and particulate-associated contaminants. A large portion of the total contaminant level is particulate associated.

The standard elutriate test is sometimes used to evaluate effluent water quality, but this test does not reflect the conditions existing in confined disposal sites that influence contaminant release. A modified elutriate test procedure, developed under the LEDO program (Palermo 1986), can be used to predict both the dissolved and particulate-associated concentrations of contaminants in upland disposal area effluents (water discharged during active disposal operations). The laboratory test simulates contaminant release under upland disposal conditions and reflects sedimentation behavior of dredged material, retention time of the containment, and chemical environment in ponded water during active disposal.

The modified elutriate test procedure is described in Appendix A. Sediment and dredging site water are mixed to a slurry concentration equal to the expected influent concentration under field conditions. The mixed slurry is aerated in a 4-ℓ cylinder for 1 hr to ensure oxidizing conditions will be present in the supernatant water. Following aeration, the slurry is allowed to settle under quiescent conditions for a period equal to the expected mean field retention time, up to a maximum of 24 hr. A sample is then extracted from the supernatant water and analyzed for total suspended solids and dissolved and total concentrations of contaminants of interest. The contaminant fractions of the total suspended solids may then be calculated. Column settling tests, similar to those used for design of disposal areas for effective settling (Palermo et al. 1978, and Palermo 1986), are used to define the concentration of suspended solids in the effluent for a given operational condition, i.e., ponded area, depth, and inflow rate. Using results from both of these analyses, a prediction of the total concentration of contaminants can be made. Detailed procedures are given in Palermo (1986).

The acceptability of the proposed upland disposal operation can be evaluated by comparing the predicted dissolved contaminant concentrations with applicable water quality standards while considering an appropriate mixing zone and the quality of the receiving water body. Where the primary administrative goal is maximum containment of contaminants, appropriate controls and restrictions may be required to first meet water quality criteria without a mixing zone or secondarily to ensure that an acceptable mixing zone is maintained.

Surface Runoff Quality

After dredged material has been placed in an upland disposal site and the dewatering process has been initiated, contaminant mobility in rainfall-induced runoff is considered in the overall environmental impact of the dredged material being placed in a confined disposal site. The quality of the runoff water can vary depending on the physicochemical process and the contaminants present in the dredged material. Drying and oxidation will promote aerobic microbiological activity, which more completely breaks down the organic component of the dredged material and oxidizes sulfide compounds to more soluble sulfate compounds. Concurrently reduced iron compounds will become oxidized and iron oxides will be formed that can act as metal scavengers to adsorb soluble metals and render them less soluble. The pH of the dredged material will be affected by the amount of acid-forming compounds present as well as the amount of basic compounds that can buffer acid formation. Generally, large amounts of sulfur, organic matter, and/or pyrite material will generate acid conditions. Basic components of dredged material such as calcium carbonate will tend to neutralize acidity produced. The resulting pH of the dredged material will depend on the relative amounts of acid formed and basic compounds present.

Runoff water quality will depend on the results of the above processes as the dredged material dries out. For example, should there be more acid formation than the amount of bases present to neutralize the acid, then the dredged material will become acidic in pH. Excessive amounts of pyrite when oxidized can reduce pH values from an initial pH 7 down to pH 3. Under these conditions surface runoff water quality can be acidic and could contain elevated concentrations of trace metals.

An appropriate test for evaluating surface runoff water quality must consider the effects of the drying process to adequately estimate and predict runoff water quality. At present there is no single simplified laboratory test to predict runoff water quality. Research was initiated in November 1984 to develop such a test. A laboratory test using a rainfall simulator has been developed and is being used to predict surface runoff water quality from dredged material as part of the CE/EPA FVP (Westerdahl and Skogerboe 1981, Lee and Skogerboe 1983a, Lee and Skogerboe 1983b). This test protocol involves taking a sediment sample from a waterway and placing it in a soil-bed lysimeter in its original wet reduced state. The sediment is allowed to dry out. At intervals during the drying process, rainfall events are applied to the lysimeter, and surface runoff water samples are collected and analyzed for selected water quality parameters. Rainfall simulations are repeated on the soil-bed lysimeter until the sediment has completely dried out. Results of the tests can be used to predict the surface runoff water quality that can be expected in a confined disposal site when the dredged material dries. From these results control measures can be formulated to treat surface runoff water if required to minimize the environmental impact to surrounding areas.

An example of the use of this test protocol was cited by Lee and Skogerboe (1983b). An estuarine dredged material highly contaminated with the metals Zn, Cu, Cd, Ni, and Cr was evaluated using this test procedure. An acid rainfall simulating typical rainfall quality at the upland disposal site was used. Test results indicated significant solubilization of these metals in surface runoff water after the dredged material had dried. The pH of the dredged material became acid because of limited base neutralizing compounds present and the acid rainfall applied. The oxidation of sulfide compounds and organic complexes apparently released metals into more soluble and mobile forms. Based on these test results, control measures were designed to neutralize acidity and remove these metals in surface runoff water.

Leachate Quality

Subsurface drainage from disposal sites in an upland environment may reach adjacent aquifers or may enter surface waters. Fine-grained dredged material tends to form its own disposal-area liner as particles settle with percolation drainage water, but the consolidation may require some time for self-sealing to develop. In addition, diffusion of contaminants through fine-grained materials will continue even after the self-sealing has stopped much of the water convection. It is surmised, but not demonstrated, that hydrophobic organic contaminants can ride piggy-back on naturally occurring dissolved organic carbon and thus can diffuse into ground water beneath a site. Further work is needed to substantiate this theory. Since most contaminants potentially present in dredged material are closely adsorbed to particles, primarily the dissolved fraction will be present in leachates. A potential for leachate impacts exists when a dredged material from a saltwater environment is placed in an upland site adjacent to freshwater aquifers or to surface waters. The site-specific nature of subsurface conditions is the major factor in determining possible impact (Chen et al. 1978).

An appropriate leachate quality testing protocol must predict which contaminants may be released in leachate and the relative degree of release. There is presently no routinely applied testing protocol to predict leachate quality from dredged material disposal sites. An evaluation of available leaching procedures is needed before a leaching test protocol for confined dredged material can be recommended. Although a wide variety of leaching or extraction tests have been proposed for hazardous waste (Lowenbach et al. 1977), none have been field verified for use to evaluate leaching of dredged material placed in upland disposal sites.

A review of the literature has indicated that theoretical models and data on the leaching potential of dredged material are needed in order to evaluate alternative strategies for the treatment and containment of contaminants in upland disposal sites. Theoretical developments that are needed involve pertinent transport rate equations that describe the leaching of chemicals from dewatered and consolidated dredged material. Data gaps include lack of sufficient information on: (a) bulk transport of contaminants by seepage; (b) contaminant leachability under various environmental conditions; and (c) long-term geochemical consequences that alter contaminant leachability. Leaching tests are recommended that can assist in the development of an appropriate predictive protocol for Commencement Bay sediment.

Development of leachate prediction models using mass-transport equations will require information on the relative significance of intra-particle diffusion, surface desorption, film diffusion, and other possible rate controlling mechanisms for contaminant leaching (e.g., irreversible chemical reactions). Serial batch leach tests (Houle and Long 1980) can indicate whether leaching of a sediment is an equilibrium- or kinetically-controlled process. Theoretical considerations indicate that, with proper interpretation, results from serial batch leach tests can yield coefficients suitable for modeling contaminant leaching in a confined disposal site. Predicative techniques, including serial batch leach tests, are presently being evaluated at the WES (Hill et al. 1984).

Column leach tests using specially constructed permeameters can provide information needed for modeling bulk transport of contaminants in an upland disposal site (Goerlitz 1984). The disposal site environment is simulated in a test permeameter by passing a reference liquid or site water through the dredged material. Comparison of batch leach test and permeameter leach test results can indicate the relative significance of bulk transport and diffusive transport within a volume of dredged material, and the relative importance of film effects and nonequilibrium processes on contaminant desorption mechanisms. The potential use of permeameters and batch leaching tests for predicting leachate quality in an upland disposal site is presently under investigation at the WES. Routine testing procedures cannot be recommended at this time.

Plant Uptake

After dredged material has been placed in either an intertidal, wetland, or an upland environment, plants can invade and colonize the site. In most cases, fine-grain dredged material contains large amounts of nitrogen and phosphorus, which promote vigorous plant growth. Elevations in confined disposal sites can range from wetland to upland terrestrial environments. In many cases, the dredged material was placed in upland disposal sites because contaminants were present in the dredged material. Consequently, there is potential for movement of contaminants from the dredged material into the environment through plants and then eventually into the food chain.

An appropriate test for evaluating plant uptake of contaminants from dredged material must consider the ultimate environment in which the dredged material is placed. The physicochemical processes become extremely important in determining the availability of contaminants for plant uptake.

There is a plant bioassay test protocol that was developed under the LEDO Program based on the results of the DMRP. This procedure has been applied to a number of contaminated dredged materials (both fresh water and estuarine). Results obtained from these plant bioassays have provided sufficient information to predict the potential for plant uptake of contaminants from dredged material (Folsom and Lee 1981, 1983; Lee et al. 1982; Folsom et al. 1981). The procedure is presently being field verified under the CE/EPA FVP and is being applied to a wide variety of contaminated materials such as sewage sludge amended soils in the US and metal mining waste contaminated soils in Wales, U. K.

The plant bioassay procedure requires taking a sample of sediment from a waterway and placing it either in a flooded wetland environment or an upland terrestrial environment in the laboratory. An index plant, *Spartina alterniflora* for estuarine sediments and *Cyperus esculentus* for freshwater sediments, is then grown in the sediment under conditions of both wetland and upland disposal environments. Plant growth, phytotoxicity, and bioaccumulation of contaminants are monitored during the growth period. Plants are harvested and analyzed for contaminants. The test results indicate the potential for plants to become contaminated when grown on the dredged material in either wetland or upland terrestrial environment. From the test results, appropriate management strategies can be formulated as to where to place a dredged material to minimize plant uptake or how to control and manage plant species on the site so that desirable plant species that do not take up and accumulate contaminants are allowed to colonize the site, while undesirable plant species are removed or eliminated.

There is another laboratory test being developed under the LEDO Program that utilizes the results of an organic solvent extraction method to chemically predict plant uptake of certain trace metals such as zinc, cadmium, nickel chromium, lead, and copper. This test procedure attempts to simulate the capacity of a plant root to extract metals from a dredged material. Field verification of this test protocol is being conducted under the CE/EPA FVP. This test procedure takes a sample of dredged material in the flooded reduced wetland condition and another sample that has been air dried for an upland condition. The samples are extracted for 24 hr in a modified DTPA extraction solution according to Lee et al. (1983). This solution is then filtered through a millipore filter and the filtrate is analyzed for soluble contaminants. This procedure has been successful in predicting plant leaf tissue contents of certain metals. There is no existing extraction procedure that predicts plant availability of organic contaminants.

Animal Uptake

Many animal species invade and colonize upland dredged material disposal sites. In some cases, prolific wildlife habitats have become established on these sites. These habitats are usually rich in waterfowl and often become the focus of public interest through local ornithologists, sportsmen, and the environmentally aware public. Concern has developed recently over the potential for invertebrate animals inhabiting terrestrial upland disposal sites to become contaminated and contribute to the contamination of food-webs associated with the site.

An appropriate test for evaluating animal uptake of contaminants from dredged material must consider the ultimate environment in which the dredged material is placed, the anticipated ecosystem developed, and the physicochemical processes governing the biological availability of contaminants for animal uptake.

There is a recommended test protocol being tested under the CE/EPA FVP that utilizes an earthworm as an index species to indicate toxicity and bioaccumulation of contaminants from dredged material. In this procedure, an earthworm is placed in sediment maintained in moist and semi-moist air-dried environments. The toxicity and bioaccumulation of contaminants are monitored over a 28-day period (Simmers et al. 1983; Marquenie and Simmers 1984). This procedure is a modification of a procedure developed by Dr. C. A. Edwards in England for determining the hazardous nature of manufactured chemicals to be sold in the European Economic Community. Test results to date indicate the terrestrial earthworm test procedure can indicate potential environmental effects of dredged material disposal in upland environments. The evaluative portion of the test is mainly tissue analysis rather than strictly mortality. While the test is being established, those treatments necessary to ensure survival for the test period (such as washing or dilution) suggest potential field site management strategies. The earthworm contaminant levels can also be related to the food web that could exist on the site after disposal. This type of test can be conducted simultaneously under optimum conditions in the laboratory and in the field at or near the proposed disposal site to further assess the extent of contaminant mobility. This test can identify bioavailable metals and organic contaminants in the material to be dredged.

Tests for Control/Treatment Technology Design for Upland and Nearshore Sites

The variations in dredged material characteristics, both physical and chemical, and the lack of documented field experiences with control or treatment technologies for contaminated dredged material dictate the need for laboratory, bench-scale, or perhaps pilot studies to determine design parameters for these technologies. This section of the report will discuss test procedures developed to date specifically for dredged material and available test procedures for solid and liquid treatment.

Settling Tests

Settling tests are an important element of confined disposal facility design where the dredged material slurry is dredged hydraulically or pumped into the facility from a barge or scow. The objective of running settling tests on sediment to be dredged or dredged material slurry is to define, on a batch basis, their settling behavior in a large-scale continuous flow dredged material containment area. The tests provide numerical design that can be projected to the size and design of the containment area to meet effluent suspended solids criteria and to provide adequate storage capacity for solids. WES recommends that the tests be performed in an 8-in. diameter, 6-ft deep plexiglass column. Appendix A presents the procedures and equipment for running the test on dredged materials.

Chemical Clarification

Chemical clarification may be required where gravity settling alone does not adequately remove suspended solids from a dredged material slurry. Jar tests, similar to those used in the water treatment industry, have been adapted for use in selecting flocculating agents and determining the required dosage for dredged material samples. The procedure has been reported by Schroeder (1983) and is presented in Appendix A. In addition to containment area effluent, chemical clarification may also be applicable to surface-water runoff.

Consolidation Tests

Determination of containment area long-term storage capacity requires estimates of settlement due to self-weight consolidation and due to consolidation of foundation soils. Consolidation test results must be obtained, including time-consolidation data, to estimate the average voids ratio at completion of 100 percent to primary consolidation. Consolidation tests for foundation soils should be performed as described in EM 1110-2-1906 (OCE 1970). Constant rate of strain tests or fixed-ring consolidometers should be used for consolidation testing of dredged material samples due to their fluid-like consistency. For dredged material, the major modifications to standard fixed-ring testing procedure involve the sample preparation and method of loading.

Liner Tests

Numerous tests are available to evaluate the strength, durability, permeability, and chemical compatibility of liner materials. These tests are discussed in detail in "Lining of Waste Impoundment and Disposal Facilities" (USEPA 1983). USEPA does not require that specific liner tests be performed. The primary site-specific tests for design are those that evaluate the compatibility of contaminants and liner materials. For synthetic materials USEPA (1983) discussed two tests: the immersion test and the pouch test. Brief descriptions of these two tests from USEPA (1983) are presented in the next two paragraphs.

Immersion Test. In this test, samples of the specific membrane liners are immersed in the waste and the effects of the immersion upon the weight and dimensions of the liner specimens and a selected number of physical properties are measured as a function of immersion time. By immersing the samples totally in the waste fluid, a somewhat accelerated test is generated. Further acceleration can be effected by increasing the temperature somewhat. However, the closer the temperature and exposure conditions are to actual service, the more reliable the results will be. Also, the longer the test can be run, the more reliable it will be. These types of tests should be initiated early in the design phase of the waste facility. An exposure period of twelve months is desirable. Samples can be withdrawn at one, two, four, etc., months to assess the effect as a function of time.

Pouch Test. This test was designed to measure the permeability of polymeric membrane liner materials to water and to dissolved constituents of the wastes. A sample of the waste is sealed in a small pouch fabricated of the liner material under test that is then placed in distilled or deionized water. Measurements are taken periodically to determine the extent of movement of water into the membrane and/or leakage of waste into the water. A concentration gradient is created by the deionized water on one side of the membrane and the waste on the other side. This test environment results in the movement by osmosis of water and ions and other dissolved constituents through the membrane due to the differences in concentrations on either side of the membrane. Changes in liner materials are observed and later physical properties are tested. At present, this test is limited to thermoplastic and crystalline membranes; however, it can be used to assess the compatibility of wastes with these materials.

Solidification/Stabilization Tests.

Design of solidification or stabilization technologies requires a laboratory procedure to determine the optimum mix of solidification agent(s) with the contaminated dredged material. The test must be able to account for the different physical and chemical characteristics of various sediments. Thus far there is no standard test established to accomplish this task. Various procedures have been used by different laboratories, but no single recommended test is available.

Tests for two separate design objectives might be considered. The material could be mixed to achieve a desired strength or to minimize contaminant release. For strength, a series of solidified samples using different concentrations of agent(s) may be prepared and subjected to a standard unconfined compressive strength test (ASTM C-109). For contaminant release, serial graded batch leaching tests may be performed on various product mixes to determine those with minimum contaminant release. An approach to a standard test method has been presented in the "Evaluation of Dredged Material Disposal Alternatives for U.S. Navy Homeport at Everett, Washington" (Palermo et al. 1986).

Problems arise from the cost effectiveness of increasing the amount of reagent to a maximum compressive strength or minimum contaminant release. Also, all contaminants are not affected equally by different mixes, so a priority order of contaminants of concern may be necessary. Optimization of reagent dose, strength, contaminant release, and cost is necessary to design the system. The type of batch leaching test and preparation of the sample prior to the batch leach test are unsettled questions for the laboratory procedures.

Wastewater Treatment Processes.

Many of the treatment processes for liquid and solid treatment technologies require bench-scale testing to establish design parameters, particularly for materials that have not been previously subjected to these technologies. Dredged material in the Puget Sound area will be saline, and the high dissolved solids concentrations may interfere with the performance of some technologies that have proven effectiveness in freshwater systems.

Protocols for these bench scale tests are generally not standard methods because of the wide range of applicability of these technologies in the public and the private or industrial sector. However, a number of standard reference textbooks are available that present bench-scale tests for most of the technologies discussed in Part IV. Table 7.9 lists the technologies and bench-scale methods referenced to several available texts or reports.

Open-water Site Characterization

Site Selection and Designation.

As discussed in Part VI, at least six considerations can be identified that are important in evaluating just the engineering acceptability of a proposed open water disposal site (Truitt 1986) bathymetry, average water depths, currents (velocity and structure), salinity/temperature stratifications, bottom sediments, and operational requirements.

Currents. Current velocities may be measured with various rotating element current meters. A typical current velocity meter is a Gurly Model 665 vertical axis cup-type impeller meter. This meter may be used in conjunction with a magsyne directional indicator to record current direction. Current velocity and direction should be measured at various depths to record current structure.

Water Depths. Water depths may be measured with lead lines or electronic fathometers. Various fathometer sonar devices are available to instantaneously record water depths.

Salinity. Salinity stratification may be measured by retrieving water samples at various depths and then measuring the salinity of the samples or by instantaneously measuring the salinity using submersible probes. Salinities may be determined using calibrated specific conductance instruments.

Water Column Density Stratification. The stratification in the water column may be determined by measuring salinities and temperatures at various depths. In this way a density gradient may be developed and the depth at which it occurs calculated. Suspended sediments at varying depths may also affect the density gradient and may be measured by determining the suspended solids in water samples.

Bathymetry. The bathymetry or bottom contours of a site may be determined using side scan sonar devices. Sub-bottom profilers may also be used to

Table 7.9

References to Laboratory Testing Procedures for Treatment Process Design

Unit Process	Reference*
Sedimentation	4,2
Screening	NA
Hydraulic classification	NA
Spiral classification	NA
Cyclones/hydrocyclones	NA
Solidification/stabilization	NA
Incineration	NA
Chemical clarification	3
Filtration	1,2,5
Chemical precipitation	2
Chemical reduction	NA
Chemical oxidation	NA
Ion exchange	2
Carbon adsorption	1,2
Biological treatment	1,2
Stripping	1
Chlorination	NA
Ozonation	NA
Distillation	NA
Electrodialysis	NA
Reverse osmosis	NA

* Testing procedure references:

1. Adams, Carl E., Jr., and Eckenfelder, W. Wesley, Jr. 1974. Process Design Techniques for Industrial Waste Treatment, EnviroPress, Nashville, TN.

2. Eckenfelder, W. W. and Ford, D. L. 1970. Water Pollution Control: Experimental Procedures for Process Design, Jenkins, Austin, TX.

3. Schroeder, Paul R. 1983. "Chemical Clarification Methods for Confined Dredged Material Disposal," Technical Report D-83-2, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

4. Palermo, Michael R., Montgomery, Raymond L., and Poindexter, Marian E. 1978. "Guidelines for Designing, Operating, and Managing Dredged Material Containment Areas," Technical Report DS-78-10, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

5. USEPA. 1982. "Design Manual: Dewatering Municipal Wastewater Sludges," Technology Transfer, EPA-625/1-82-014, USEPA, Center for Environmental Research Information, Cincinnati, OH.

determine the nature of the material below the bottom if excavation of a confined open water disposal site is being considered.

Bottom Sediments. A variety of samplers are available to sample bottom sediments. Corers and grab samplers are useful for sediment sampling. In general, equipment of simple construction is preferred due to ease of operation and maintenance plus lower expense.

Dispersion and Mixing. The elevated suspended solids levels and elevated chemical concentrations resulting from open water disposal of dredged material can be estimated by predictive testing. The discharge is usually rapidly diluted following disposal therefore the expected dilution should be estimated by calculation of a mixing zone surrounding the release zone and the resulting concentrations compared to water quality criteria or standards.

Contaminant Release Studies for Open-water Sites

Evaluation of General Aquatic Impacts

Highly contaminated dredged material placed in an aquatic environment has a conceptual potential for impacts due to release of contaminants into the water column during disposal, although this potential has rarely been realized in practice. Because dredged material placed in open-water sites remains anaerobic and near neutral in pH, contaminant mobility at the disposal site will be similar to that occurring at the dredging site. There is also a potential for physical effects on benthic organisms and for long-term toxicity and/or bioaccumulation of contaminants from the dredged material. These biological effects are best determined at present by site-specific bioassays. Potential impacts on health of operating crews would be a rare occurrence and beyond the scope of this document, but should be evaluated when considered appropriate.

Evaluation of Water Column Impacts

The standard elutriate test (EPA/CE 1977) is appropriate for evaluating the potential for dredged material disposal to impact the water column. Since this test includes contaminants in both the interstitial water and the loosely bound (easily exchangeable) fraction in the sediment, it approximates the fractions of chemical constituents that are potentially available for release to the water column when sediments are dredged and disposed through the water column. The standard elutriate is prepared by mixing the sediment and dredging site water in a volumetric sediment-to-water ratio of 1:4. Mixed with agitation and vigorous aeration for 30 min, it is then allowed to settle for 1 hr. The supernatant is then centrifuged and/or filtered to remove particulates prior to chemical analysis. This procedure is followed because the water-quality criteria apply only to dissolved contaminants and chemical analyses of an unfiltered water sample cannot identify the bioavailable fraction of sediment-sorbed contaminants. A detailed description of the procedure, including sample preparation, is provided in Appendix A.

Chemical evaluation. Water-column impacts of dredged material may be evaluated either as described in this paragraph or as specified in the following paragraph, depending on the situation. Where the initial evaluation identifies concern about the presence of specific contaminants that may be released in soluble form, the standard elutriate may be analyzed chemically and the results evaluated by comparison to water-quality criteria for those contaminants after allowance for mixing at the disposal site. This provides an indirect evaluation of potential biological impacts of the dissolved contaminants since the water-quality criteria were derived from bioassays of solutions of the various contaminants. Chemical analyses of the standard elutriate are quantitatively interpretable in terms of potential impact only for those contaminants for which specific water-quality criteria have been established.

Biological evaluation. If the water-quality criteria approach is not taken, the potential for water-column impacts must be evaluated by bioassays, with consideration given to mixing. An aquatic bioassay should also be used to determine the potential interactions among multiple contaminants. In this way elutriate bioassays can aid in evaluating the importance of dissolved chemical constituents released from the sediment during disposal operations. The standard elutriate is prepared just as for chemical use, but the filtrate is used as a bioassay test solution rather than for chemical analysis. A series of experimental treatments and controls are established using graded dilutions of the elutriate. The test organisms are added to the test chambers and exposed under standard conditions for a prescribed period of time. The surviving organisms are examined at appropriate intervals to determine if the test solution is producing an effect. Any bioassay protocol designed for use with solutions can be used by substituting the standard elutriate for the original solution. A useful general protocol is presented in EPA/CE (1977).

Mixing. All data from chemical analyses and bioassays of the standard elutriate must be interpreted in light of mixing. This is necessary since biological effects (which are the basis for water-quality criteria) are a function of biologically available contaminant concentration and exposure time of the organism. In the field both concentration and time of exposure to a particular concentration change continuously. Since both factors will influence the degree of biological impact, it is necessary to incorporate the mixing expected at the disposal site in the interpretation of both chemical and biological data. An example of a quantitative approach to a mixing zone is presented in the "Decisionmaking Framework" (Lee et al. 1985, Peddicord et al. 1986).

Benthic. It is generally felt that if a dredged material is going to have an environmental impact, the greater potential for impact lies with the deposited sediment at the disposal site. This is because it is not mixed and dispersed as rapidly or as greatly as the dissolved material; most contaminants remain associated with the particulates; and bottom-dwelling animals live and feed in and on the deposited material for extended periods. Therefore, the major evaluative efforts should be placed on the deposited material. No chemical procedures exist that will determine the environmental activity of any contaminants or combination of contaminants present in the solid phase of dredged material. Therefore, animals are used in a bioassay to provide a measurement of environmental activity of the chemicals found in the material.

Chemical analysis can, however, serve to identify contaminants of potential concern present in the sediment and their presence in high or low concentration. In the case of neutral organic chemicals that are persistent and common contaminants of sediments, chemical analyses can provide the information necessary for an estimation of the maximum levels that could be reached in the tissues of exposed organisms for which the sediments provide the only source of contamination (McFarland 1984, McFarland and Clark 1986). In summary potential impacts are best evaluated by a combined consideration of total or bulk chemical analyses of sediment and toxicity/bioaccumulation test(s) to determine their bioavailability.

Tests for Control/Treatment Technology Design for Open Water Sites

Capping Effectiveness

Laboratory studies to assess the medium-term (40 days) effectiveness of various cap materials in isolating a contaminated sediment from clams and polychaetes have been conducted in large (250 ℓ) flow-through reactor units. The ability of capping materials to chemically seal contaminated dredged material containing relatively mobile and oxygen-demanding constituents from overlying water has been determined in small (22.6 ℓ) reactor units. Both of these procedures are presented in detail in "Effectiveness of Capping in Isolating Contaminated Dredged Material from Biota and the Overlying Water" (Brannon et al. 1985).

Volume Determinations

Procedures for determining the volumes for restricted open water disposal sites are under investigation at the present time. Also models to predict the degree of sediment spread on the bottom and the portion of the total sediment disposed that will remain in the water column have been developed for a one dump scenario only (Holliday et al. 1978).

PART VIII: PROVEN OR DEMONSTRABLE TECHNOLOGIES

Background

The purpose of this part of the report is to review the technologies that have been previously presented and to select those technologies that could be recommended for actual implementation at the field level. The basis for this selection is previous field applications, adequate design information and performance data from similar applications of the technology, and reasonable cost effectiveness. To facilitate this evaluation, the technologies discussed in Parts II through VI are described by the following classifications:

a. Proven: Technologies that have been applied to the dredging industry or other industries for treatment or control of contaminated wastes or materials.

b. Field Demonstrated: Technologies that have been applied to a dredging operation, either on a pilot scale or full scale, for control or treatment of contaminated sediment.

c. Demonstrable: Technologies that could be considered for field demonstration in a dredging scenario on a pilot or full scale without the need for additional process development. (This does not alleviate the need for laboratory and engineering studies to design and implement the technology.)

d. Conceptual: Technologies that in theory would treat, control, or destroy dredged material contaminants, but are unlikely choices because of obvious intensive equipment requirements, operational problems, or unreasonable costs.

Most of the technologies that have been included in this report can be considered proven technologies for control or treatment of contaminated materials. Exceptions to this premise are some of the controls for restricted open-water disposal that are specifically intended for the dredging industry and have not been fully developed. Examples of unproven technologies are diffusers, downpipes, and capping technologies in the deep-water sites characteristic of Puget Sound. Conceptual technologies include most of the advanced liquid treatment processes and contaminant destruction for dredged material slurries or solids by incineration or other technologies. Table 8.1 lists the technologies and their respective classification. Note that proven

Table 8.1

Status of Application of Control/Treatment Technologies

Technology	Proven	Demonstrated	Demonstrable	Conceptual
Controls During Dredging				
Dredge selection	X	X		
Barriers	X	X		
Operational controls	X	X		
Controls During Transport				
Hopper dredges	X	X		
Specialized barges	X		X	
Pipeline controls	X		X	
Pump controls	X		X	
Route/navigation controls	X		X	
Loading/unloading controls	X		X	
Truck transport	X		X	
Rail transport	X		X	
Restricted Open-Water Disposal				
Submerged diffuser	X		X	
Gravity-fed downpipe	X		X	
Hopper dredge pump down				X
Solidification/stabilization				X
Capping	X		X	
Lateral confinement			X	X
Restricted Upland Disposal				
Covers	X		X	
Surface sediment stabilization	X		X	
Liners (synthetic)	X		X	
Liners (soil)	X		X	
Slurry walls	X		X	
Surface-water controls	X		X	
Subsurface drainage	X	X		
Ground-water pumping	X		X	
Sheet piling	X		X	
Site security	X		X	
Settling basins	X	X		
Stationary screens and sieves	X			X
Moving screens	X			X
Hydraulic classifiers	X			X
Spiral classifiers	X			X
Cyclones and hydrocyclones	X		X	
Solidification/stabilization	X		X	

(Continued)

Table 8.1 (Continued)

Technology	Proven	Demonstrated	Demonstrable	Conceptual
Rotary-kiln incineration	X			X
Multiple-hearth incineration	X			X
Fluidized-bed incineration	X			X
Extraction	X			X
Immobilization	X			X
Degradation	X			X
Attenuation	X			X
Chemically-assisted	X	X		
clarification	X	X		
Filtration	X		X	
Chemical precipitation	X			X
Carbon adsorption (metals)				X
Chemical reduction				X
Chemical oxidation				X
Ion exchange				
	X		X	
Carbon adsorption (organics)				X
Biological treatment				X
Stripping				
				X
Chlorination				X
Ozonation				
				X
Distillation				X
Electrodialysis				X
Reverse osmosis				
<u>Restricted Nearshore Disposal</u>				
	X		X	
Covers	X		X	
Surface-sediment stabilization	X		X	
Liners (synthetic)	X		X	
Liners (soil)	X		X	
Slurry walls	X	X		
Surface-water controls				X
Subsurface drainage				X
Ground-water pumping				
	X		X	
Sheet piling	X		X	
Site security				
	X	X		
Settling basins	X			X
Stationary screens and sieves	X			X
Moving screens	X			X

(Continued)

Table 8.1 (Concluded)

Technology	Proven	Demonstrated	Demonstrable	Conceptual
Hydraulic classifiers	X			X
Spiral classifiers				
Cyclones and Hydrocyclones	X		X	
Solidification/stabilization	X		X	
Rotary-kiln incineration	X			X
Multiple-hearth incineration	X			X
Fluidized-bed incineration	X			X
Extraction	X			X
Immobilization	X			X
Degradation	X			X
Attenuation	X			X
Chemically-assisted	X	X		
clarification	X	X		
Filtration	X		X	
Chemical precipitation	X		X	
Carbon adsorption (metals)	X			X
Chemical reduction	X			X
Chemical oxidation	X			X
Ion exchange				
	X		X	
Carbon adsorption (organics)	X			X
Biological treatment	X			X
Stripping				
	X			X
Chlorination	X			X
Ozonation				
	X			X
Distillation	X			X
Electrodialysis	X			X
Reverse osmosis				

technologies have a second classification additional to proven. Technologies that have been field demonstrated or are demonstrable are discussed further in the paragraphs below.

Field-Demonstrated Technologies

Controls During Dredging Operations

Technologies for control of sediment resuspension during dredging operations have been, for the most part, field demonstrated. The various types of dredges discussed in Part II have been employed in field applications either in the U.S. or in other countries such as Japan or The Netherlands. Reductions in sediment resuspension using innovative equipment, barriers, and operational controls have been demonstrated. While it is assumed that reductions in contaminants are proportional to reductions in suspended sediment, chemical contaminant data that indicate benefits of these controls in reducing contaminant release are limited.

During the period 15-30 October 1985, a demonstration of innovative dredging equipment and techniques took place in Calumet Harbor, IL. The study was a cooperative effort among USAE Division, North Central; USAE District, Chicago; and WES. Three principal objectives were addressed in the demonstration: evaluation of a matchbox suction dredge head; use of the submerged diffuser for placement of dredged material; and operation of a conventional cutter suction dredge over a range of operational parameters to investigate its resuspension characteristics. Considerable data collection took place on the operation of the equipment and suspended solids levels in the water column during the demonstration. Background information for the matchbox and cutterhead operation objectives is presented below based on field observations and without benefit of analysis of the data.

Matchbox Dredge Head. A matchbox head was fabricated and fitted to the ladder of the 12-in. hydraulic dredge "Dubuque" for the demonstration. It should be noted that the design and fabrication costs were necessary because direct scaling of existing heads/plans is not possible for a pure suction system. The cross-sectional areas of the faces that produce the material to the suction must be compatible with the specific dredge's capability to swing into the sediment and with its pumping ranges. The dredge was able to swing the matchbox through the Calumet sediment (organic sandy silt), and no significant operational problems were encountered. Digging depth at the site was 30 to 32 ft and disposal took place through a floating pipeline typically 400 to 800 ft long into an adjoining confined disposal facility. Slurry concentrations in the pipeline varied during a typical swing sequence, but at their peak were higher than the conventional cutter head in the same material. Different swing speeds were investigated to optimize the production. Discrete water samples for TSS analysis were taken from points on the ladder and at stations throughout the entire waterway. Results are not available, but no surface turbidity plume was visually noticeable during the operation.

Cutter Head Operation. Following the matchbox demonstration, the normal cutter head was re-fitted on the "Dubuque," and studies were focused on the effects on resuspension in the dredging area produced by variations in operation. Combinations of cutter rotation speed and swing speed were used over several days of dredging while water samples were taken from the waterways for TSS analysis.

Silt Curtains. Silt curtains have been used for a number of applications and can be considered to be field demonstrated. JBF (1978) performed analytical studies and field measurements on actual silt curtain operations. A silt curtain that is properly deployed and maintained provides a mechanism for controlling the dispersion of turbid water by diverting its flow under the curtain. The effectiveness of the silt curtain depends on the nature of the operation; the characteristics of the material in suspension; the type, condition, and deployment of the silt curtain; the configuration of the enclosure; and the hydrodynamic regime present at the site. Johanson (1976) reported that polymeric sheets strengthened with woven reinforcement have been used successfully in dredging operations as well as in other situations requiring containment of toxic materials.

Controls During Material Transport

Projects requiring special handling to prevent release of toxic substances during material transport have not been widely documented. Precautions have likely been considered as standard operation procedures when dealing with hazardous substances. Such controls are of a preventive nature, and their need surfaces when there is a failure within the transport system.

Control/Treatment for Restricted Open-Water Sites

Submerged diffusers have been successfully field tested in the Netherlands at Rotterdam Harbor and as part of a recent equipment demonstration project at Calumet Harbor. A brief description of the Calumet project is given below.

Calumet Submerged Diffuser. A radially divergent diffuser section was fabricated based on designs suggested in WES DMRP publications and was operated during the demonstration. Disposal using the diffuser took place into the CDF also, in order to ensure a controlled hydrodynamic environment for the study. A portion of the CDF having water depths on the order of 25 to 30 ft was used. The diffuser was suspended approximately 3 ft off the bottom by cable from a support barge placed in the CDF. The connection to the pipeline was made using seamless, flexible plastic dredge pipe. Clear water was initially pumped through the pipeline to establish background suspended solids levels in the CDF prior to actual dredging. TSS samples were taken from a point on the pipe directly (3 ft) above the diffuser and from a depth series approximately 25 ft away from the diffuser. Velocity meters were mounted directly in the exit path on the diffuser and at the station 25 ft away.

Data analysis for the Calumet study is in progress and firm conclusions are not available. However, the preliminary indications are that the diffuser performed as expected and exit velocities were on the order of 25 to 40 percent of the discharge pipeline velocity. Material exiting the diffuser appeared to remain confined to the bottom 3 to 4 ft of the water column. No increase in water velocity above this point was noted at the 25-ft station and water samples taken at the diffuser and in the mid to upper water column showed no visible turbidity.

Capping. Successful capping has been demonstrated in Long Island Sound and New York Bight as discussed in Part VI. The capping technology has received much attention and is reasonably well developed. However, how to place sediment and capping material in deep water has not been demonstrated.

Control/Treatment for Upland Sites

Field-demonstrated control or treatment technologies for upland sites have been associated primarily with design and operation of the confined disposal facility. Procedures developed during the DMRP are summarized in Technical Report DS 78-10, "Guidelines for Designing, Operating, and Managing Dredged Material Containment Areas--Synthesis Report" (Palermo et al. 1978). These guidelines summarize field studies that demonstrated storage and retention of dredged material solids in a diked containment area. These studies confirmed application of sedimentation technology to dredged material slurry.

Palermo (1984) showed that chemical quality of CDF effluent could be predicted by column settling tests and the modified elutriate test. Palermo et al. (1981) applied guidelines developed per containment area design to a management plan for Craney Island Disposal Area.

Another upland treatment technology that has been field demonstrated is chemical clarification. Jones et al. (1978) conducted pilot-plant tests to study the efficiency of polyelectrolyte coagulation of overflow from a dredged material CDF and evaluated pipeline injection of polymers into a full-scale hydraulic dredge pipeline. Results of the pilot-plant studies were favorable whereas pipeline injection was not effective. Schroeder (1983) used three field demonstrations to show the effectiveness of chemical clarification for removing suspended solids from CDF effluent. The field sites were all freshwater sites. Chemical clarification of saltwater sites is generally less advantageous because of the flocculating effect of dissolved ions in sea water.

Dewatering technology has been field demonstrated. DMRP results are summarized by Haliburton (1978). Filtering systems for dredged material containment facilities have been studied on a laboratory scale (Krizek et al. 1976). Vacuum filtration has also shown to be effective on a laboratory scale (Long et al. 1978).

Most field demonstrations for dredged material have focused on solids removal and dewatering. Studies to verify the effectiveness of these and other treatment technologies on contaminated sediment are generally not in the literature.

Control/Treatment for Nearshore Sites

Most of the technologies discussed above for upland sites are applicable to nearshore sites. Dewatering in a nearshore environment would be inappropriate or require different strategies than dewatering an upland site.

Field demonstration of placing contaminated sediment in a nearshore site is currently being evaluated in the Port of Seattle Terminal 91 Short Fill study. This study seeks to limit mobility of contaminants by maintaining the sediment in an anoxic saturated environment. The site is being monitored for detection of any contaminant release that occurs. If criteria are violated, an already developed remedial action plan will be implemented (Hotchkiss and Watson 1985).

Demonstrable Technologies

Controls During Dredging Operations

Technologies that are candidates for demonstration and evaluation in Puget Sound are innovative dredging systems. Use of the matchbox suction head and the closed-bucket clamshell should be high priority systems.

Controls During Transport

Unique technologies for safety during material transport are not available. However, other demonstration projects could include, as an objective, development of a contingency plan for remedial action should failure of the transport system occur.

Control/Treatment for Open-Water Sites

Potential demonstrations for restricted open-water disposal in Puget Sound should focus on the engineering problems associated with placing material in deep-water sites. Submerged diffusers and/or downpipes are technologies that, if successful, would benefit the PSDDA program. Another promising technology proposed for demonstration is stabilization/solidification of dredged material or physical separation of contaminants prior to open-water disposal.

Controls/Treatment for Upland Sites

Ludwig et al. (1985) proposed four strategies for implementation of solidification/stabilization technology to dredged material. Three of these deal with upland sites and the fourth with open-water sites. The three upland strategies that could be considered for demonstration in Puget Sound are described below:

STRATEGY A. Hydraulic Dredging with Disposal into a Confined Disposal Facility (CDF) (Figure 8.1).

- Excavate contaminated sludge with a hopper or pipeline dredge. An improved suction head design to limit draghead turbulence is used and no overflow is allowed if a hopper dredge is used.
- Utilize silt curtains to contain turbulence within the contaminated region.
- Employ pipeline injection of coagulant during discharge into the CDF.
- Hasten dewatering with wicks, trenching, and sand overburden.

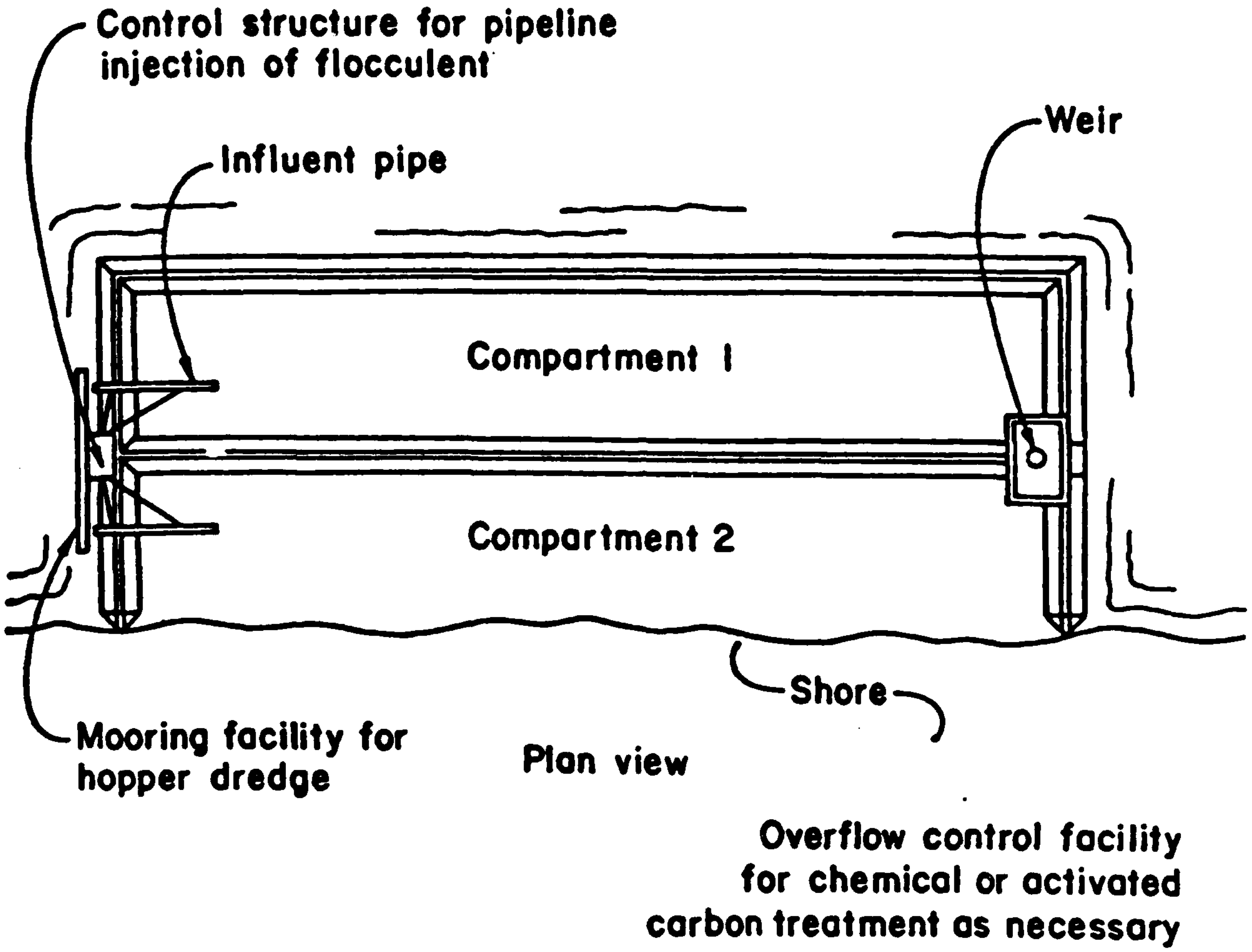

Figure 8.1. Conceptual sketch of confined disposal facility for physical solidification/consolidation of toxic dredged material (Ludwig et al. 1985)

- Control effluent overflow by chemical or activated carbon treatment.
- Cap as necessary.

STRATEGY B. Mechanical Dredging with Chemical Stabilization in a Confined Disposal Facility (Fig. 8.2).

- Clamshell dredge using silt curtains.
- Transport to prepared containment site via barge.
- Clamshell discharge into facility.
- Mix with cement in situ.
- Cover with clean material.

STRATEGY C. Upland Disposal

- Clamshell dredge into barge using silt curtains.
- Mix sludge and cement in barge enroute to discharge point (Fig. 8.3).
- Offload mixture onto dump trucks.
- Deposit in an upland disposal site as landfill.
- Cap with clean material.

Selected elements of these strategies may apply depending on the degree of contamination and environmental concerns.

Another technology that has been discussed but not actually implemented in the field is the layering concept for contaminated dredged material. This technology could be included as an element of an overall demonstration of management of an upland site to contain pollutants in a contaminated sediment. Other elements could include solids retention during filling, dewatering the contaminated dredged material, placement of layer(s) of clean material above and/or below the contaminated material, and a final cover that has an impermeable layer and a vegetative layer.

An operational technique recommended for demonstration is the use of hydrocyclones for classifying dredged material into coarse- and fine-grained fractions. The presumption is that the coarse material would be relatively uncontaminated and contaminants would be tied to the finer particles. By segregating the two fractions, control measures would be necessary for a smaller volume. Tiederman and Reischman (1973) performed a feasibility study of hydrocyclone systems for dredge operations and concluded that sand could be recovered from dredged material using a hydrocyclone. Dutch investigators (Van Der Burgt 1985) evaluated applicability of the hydrocyclone to

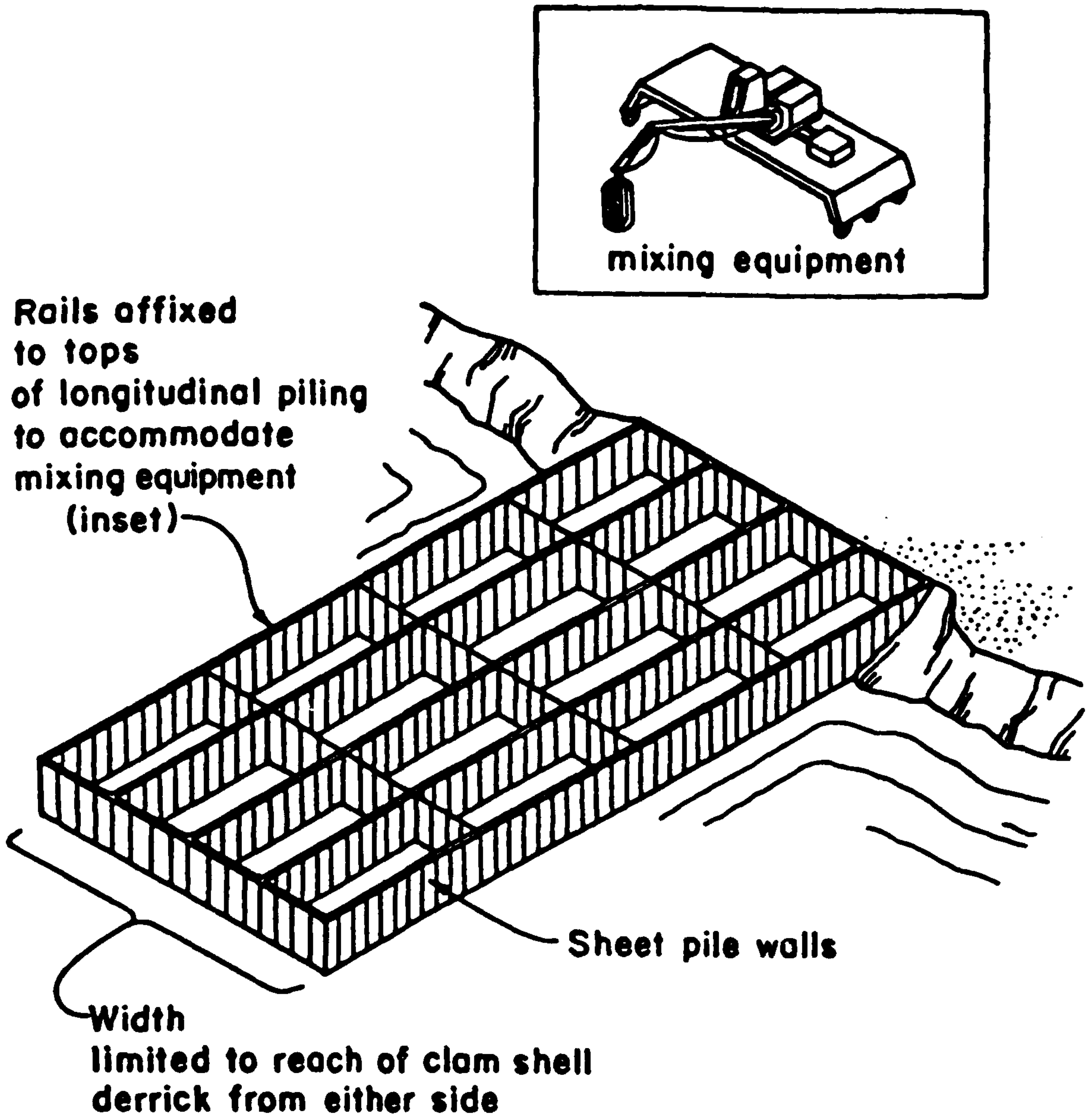

Figure 8.2. Conceptual sketch of confined containment facility for chemical solidification of toxic dredged material (Ludwig et al. 1985)

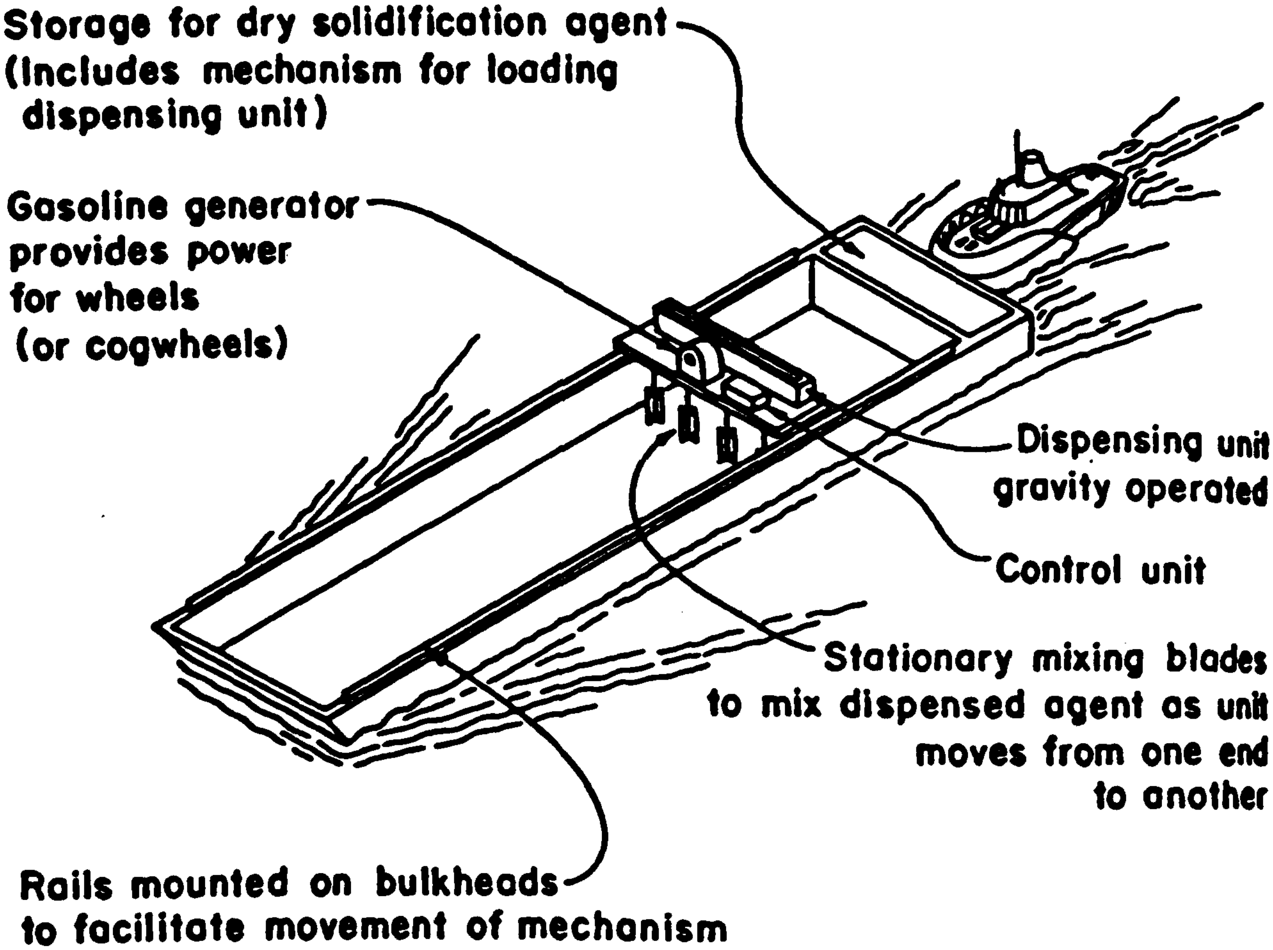

Figure 8.3. Conceptual sketch of barge fitted with mechanism for plant mixing of contaminated dredged material during transit (Ludwig et al. 1985)

contaminated sediments in the laboratory and proposed a field demonstration of a hydrocyclone in the near future.

PART IX: STRATEGY FOR SELECTION OF DREDGING/CONTROL/TREATMENT ALTERNATIVES

Background

Prior parts of this report have concentrated on the technical aspects of various control/treatment technologies that can be implemented to reduce or eliminate the release of contaminants during the three phases of a dredging project. This part describes a strategy (Dredged Material Alternative Selection Strategy or DMASS) for selecting appropriate control/treatment alternatives for site specific contaminant release problems. The DMASS is intended to provide a generic approach to the solution of the problem, yet provide as much detail as possible to guide decisionmakers through the process of formulating and choosing an appropriate dredging/transportation/disposal alternative. Since decisionmakers in different localities may stress different criteria and use different analyses, the strategy specifies where these local decisions should be made.

The DMASS is described in sequential order in the following sections, beginning with a general overview of the strategy followed by a description of the strategy, which comprises five subsections, each providing a detailed description of the sequence followed within each major phase of the DMASS process. Following the detailed description, an example application of the DMASS is presented. Prior to the detailed presentations, however, some additional background information concerning development of the DMASS is provided.

Integration with Previous Studies

Francingues et al. (1985) presented a general management strategy for the disposal of contaminated dredged material. The general management strategy, which is the basis for a logical assessment of contaminated dredged material and proper disposal techniques, is presented in Fig. 9.1. The flowchart has two major components: (1) evaluation of the dredged material to determine if restrictions are necessary and (2) determination of appropriate dredging/transportation/disposal options. Lee et al. (1985) and Peddicord et al. (1986) present a detailed decisionmaking framework (DMF) for determining the necessity of restrictions during dredging/transportation/disposal of dredged material. The DMASS expands the second part of the management strategy to provide detailed guidance on the evaluation of various dredging/transportation/disposal alternatives so that a logical selection can be made.

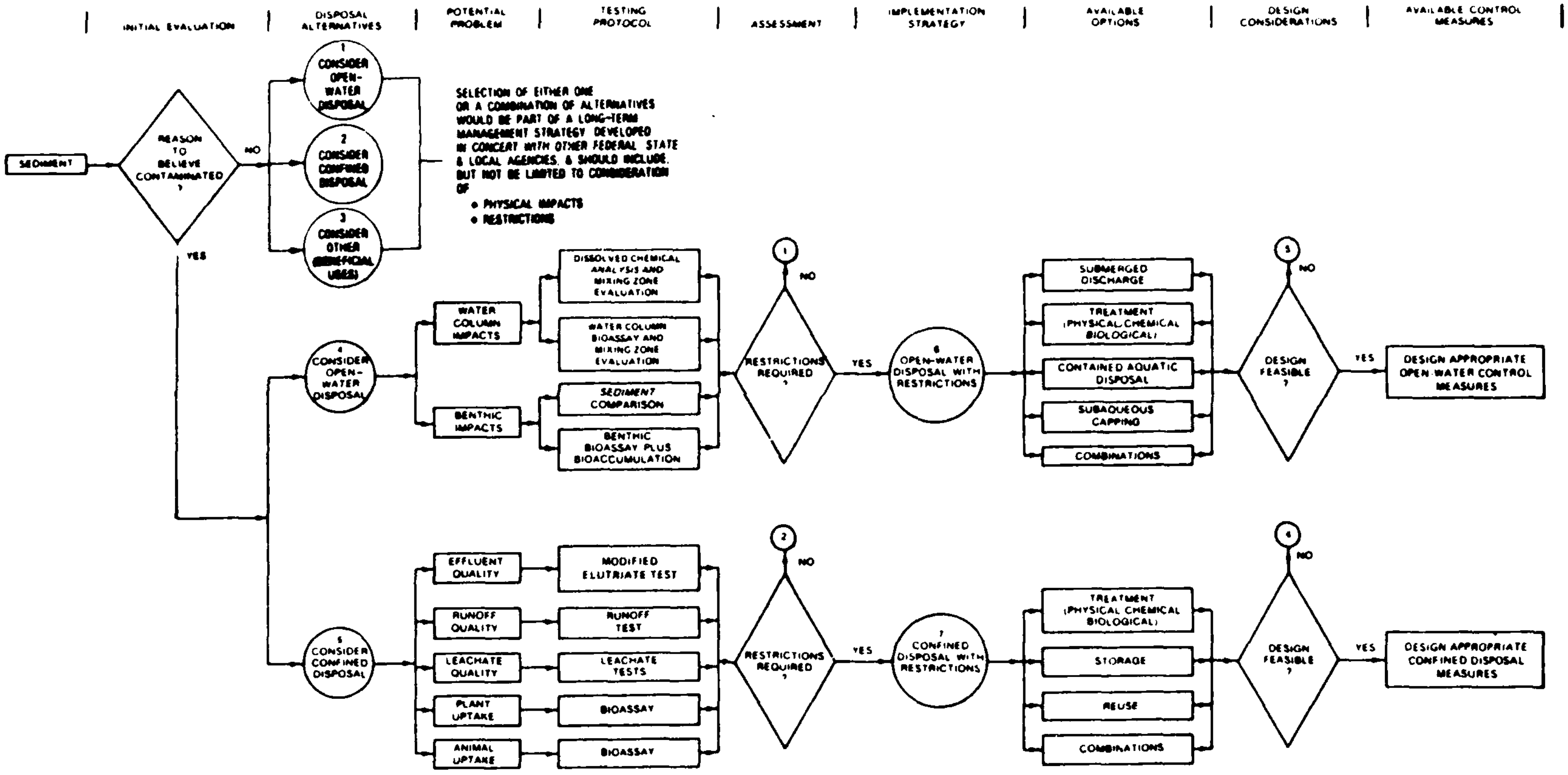

Figure 9.1. Management strategy flowchart

The starting point of the DMASS is the presumption that the materials to be dredged are contaminated to such an extent that dredging/transportation/ disposal restrictions will be necessary to prevent adverse environmental impacts. This presumption is based on the techniques presented in the DMF (Lee et al. 1985, Peddicord et al. 1986). Once the initial presumption of contamination impacts is made, the DMASS provides a methodology for selecting the potential alternatives capable of providing the appropriate level of environmental protection.

Unfortunately, there is no distinct dividing line between the contaminant analyses and disposal alternative selection portions of the general flowchart. The fact that restrictions are needed may result from a particular problem that would suggest a particular solution. For example, excessive resuspension during dredging would suggest some sort of control during the dredging phase, but not necessarily any further controls. In addition, detailed analysis during assessment of dredging/transportation/disposal alternatives might show that special restrictions are not necessary when considering a specific location. The opposite might also be true; restrictions greater than initially thought might be necessary for environmentally sensitive dredging or disposal sites. In these cases, reassessment of the type of contamination, in conjunction with certain types of dredging/transportation/disposal alternatives and certain locations, might be necessary. In other words, the decisionmaker would need to loop back from the framework assessing dredging/transportation/ treatment options to the flowchart determining whether more special restrictions are necessary. Therefore, the evaluation of alternatives used in the DMASS relies to a great extent on the detailed technical assessment presented in Lee et al. (1985) and Peddicord et al. (1986).

Terminology

Additional Restrictions. The term "restrictions" refers to any action that is taken in response to the indication that a sediment may be contaminated and require special consideration. Actions that are taken for the dredging/transportation/disposal of noncontaminated dredged material will be used as the base or minimum design case. These so-called "routine or normal" actions may not be uniform and will probably vary from one locality to another.

However, for ease of presentation in this report, routine actions will be assumed to be the following:

a. Dredging - Mechanical or hydraulic dredging with no actions to control resuspension.

b. Upland and Nearshore Disposal - Construction of a fenced diked disposal area, allowing for runoff, seepage, and evaporation of moisture (Appendix D).

c. Aquatic Disposal - Uncontrolled release of material over a predesignated, subsurface site.

Technologies. A technology is a single class of action that is implemented to minimize or eliminate contaminant migration. Parts II through VI of this report discuss technologies that are available or potentially available to restrict contaminant migration during all phases of dredging operations. Examples of technologies include covers, liners, and special purpose dredges.

Restriction Scheme. A restriction scheme consists of one or more technologies combined to address all contaminant pathways of concern at any site. An example of a restriction scheme would be implementation of both a cover and liner at a site to address the surface runoff and leachate/ground-water pathways.

Alternatives. An alternative is the site-restriction scheme combination. An example of an alternative is the implementation of a cover and liner system at a single disposal site to meet the required restrictions at that specific site.

General Approach to Alternative Selection

Strategy Overview

Goal of Process. The overall goal of the framework is to provide a means to assist planners, engineers, and decision makers when selecting proper control and treatment options for dredged material that requires restricted disposal. The intent is to provide uniform guidelines in order to assure that all aspects of the problem are taken into consideration in a consistent, relatively objective way. In addition, the process allows flexibility, in that regional, state or local authorities may emphasize different concerns accomplished via "regional administrative decisions" identified in the framework.

Starting Point. Use of the guidelines begins with knowledge of the type and level of contamination present. This information is the result of a series of biological and chemical tests and is presented in the form of potential pathways of contamination (eg. plant uptake, animal uptake, leachate contamination of groundwater, human exposure, etc.).

Logic of the Strategy. The purpose of the framework is to limit the number of dredging/treatment/disposal alternatives that need to be evaluated in detail, without eliminating any that are worth considering for the final design. This goal is accomplished via a series of sequential screenings of various aspects that make up alternatives. These include: disposal sites; dredge, transport, treatment, and containment technologies; and alternatives. At each successive screening the evaluation is more complex, with the final step requiring a fairly thorough analysis of the remaining alternatives. The intent of this process is to minimize the resources spent on detailed evaluation of alternatives that would not be suitable for selection, and eliminate them early in the process.

The number of possible dredging/transportation/disposal alternatives that must be evaluated for a single dredging project can be quite large. For example, consider the disposal of a contaminated sediment in an upland environment. Assume that five different potential disposal sites have been selected for evaluation. In addition, assume that eight different restriction schemes are available to meet environmental protection requirements. A thorough analysis requires assessment of up to 40 alternatives: each of the eight schemes at each of the five sites. Clearly as other types of disposal sites (aquatic and nearshore) and other technologies are considered, the number of potential alternatives requiring evaluation increases dramatically.

Alternatives can be eliminated at different stages in the DMASS process and can be eliminated for different reasons. Elimination will be done by screening out alternatives using one or more of the criteria discussed below or other region-specific criteria deemed appropriate by local decisionmakers. The DMASS is a five phase sequential process that: (1) selects potential sites and screens out poor ones after a detailed site assessment; (2) selects potential technologies that are appropriate to the remaining potential sites and screens out poor options based on knowledge of how well the technologies address the contaminants and migration pathways of concern; and (3) determines alternatives based on site/technology combinations and further screens these, based on a broader consideration of the criteria. Once a few good alternatives have been identified they are evaluated in detail and arrayed for final selection. Details of this process are covered in later sections.

The use of screens at different points in the strategy allows for successive elimination of poor aspects of an alternative. To alleviate confusion with use of terminology, the following conventions are used throughout the report: Site screening addresses potential sites and eliminates poor ones; technology screening is aimed at eliminating inappropriate technologies; and alternative screening is applied to fully developed alternatives.

In addition, the detailed evaluation and ranking of the remaining alternatives involves a final screening. At each of these stages different evaluation factors can be applied since certain factors are more appropriately applied to specific considerations. Evaluation factors are recommended (or used as examples) in this part; however, their selection during implementation of the strategy is left as a regional decision.

The level of detail that is considered in the selection strategy may vary from one point to another. The intent is to include as much detail as is possible without making the process too cumbersome. For example, different technologies will be considered to allow assessment in terms of effectiveness, cost, etc. Further specifications as to the specific type of a technology will not be addressed. An example of this delineation is liners for upland disposal sites: the selection strategy will consider liners as an appropriate technology; however, the selection strategy will not consider such items as the type of liner (clay or one of the many synthetic membranes) or the thickness of the liner. These issues should be part of the concept design, after a few promising alternatives have been selected.

One additional note; the DMASS is a procedure to assist in planning for an operation involving the dredging, transport, and disposal of contaminated dredged material. It is not intended to provide a project design, although the results will assist in the preliminary design of dredging/transportation/disposal options.

Sequence of DMASS

The sequential development of the five phases contained within the DMASS are shown in Fig. 9.2. Each phase involves a number of detailed considerations that will be described thoroughly in following sections of this report. Phase I (presumption of contamination pathway) represents the results of the process presented by Lee et al. (1985) and Peddicord et al. (1986). During this phase, the need for restrictions is primarily determined from tests performed on the sediment to be dredged. Phase II (confirmation of a site-specific contamination pathway) represents a major part of the alternative selection process. During this phase, knowledge of the sediment obtained during Phase I is combined with detailed information on specific disposal sites to confirm that there is a contaminant migration pathway of concern and that appropriate restrictions should be imposed at the specific site under investigation. Phase III, also a major part of the selection strategy, develops and screens alternatives by addressing technologies and combinations of technologies that may be available to meet the site-specific migration pathway restrictions identified in Phase II. Phase IV includes a detailed evaluation of alternatives surviving the screening process and an assessment of each according to specific evaluation criteria. The final phase, Phase V, of the selection strategy is simply the selection of one alternative and preliminary design of the project. The five phases of the DMASS process are summarized in Table 9.1.

Figure 9.3 shows an expansion of the five general phases and allows a more detailed look at the steps involved in the selection strategy process. The series of boxes in the upper left corner of Fig. 9.3 represent the potential problems and associated tests shown in Part 1 of Fig. 9.1. Those tests for aquatic, upland, and nearshore disposal are grouped together since the flowchart in Fig. 9.3 is general and can be used for all three types of disposal.

It will be apparent from the following discussion that, wherever possible, considerable flexibility has been built into the selection strategy process, allowing decisionmakers some choice in how the steps are followed. The flow-chart should be approached with an eye to the overall process, rather than simply addressing one step and then moving on to the next one. Conditions and characteristics of specific applications will vary and sometimes require slight modifications to the sequence presented in Figure 9.3. One

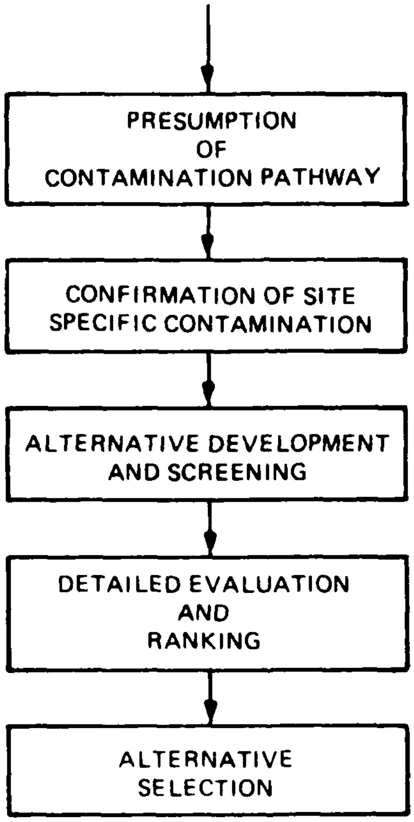

Figure 9.2. Phases in the Dredged Material Alternative Selection Strategy (DMASS)

Table 9.1

Summary of the DMASS Process

Phase	Step	Purpose	Criteria used
I. Presumption of contamination pathway		DMF to identify contaminant type and level and pathway	DMF and related RADS
II. Confirmation of contamination pathway	1. Select potential sites	Eliminate poor or inferior sites	1. Availability 2. Distance 3. Capacity 4. Cost 5. Impact
	2. Assess site characteristics	Determine attributes of sites	
	3. Identify pathways of concern	Is pathway identified in Phase I as concern at site?	
	4. Select dredge/transport technique	For potential sites and paths, eliminate poor transport combinations	1. Impact 2. Cost 3. Compatibility
	4. Site constraints		
	5. Check compatibility	Are remaining site-dredge/transport options compatible?	
III. Alternative development and initial screening	1. Select potential technologies	Identify suitable combinations of technologies	1. Impact 2. Cost 3. Accepted engineering practice
	2. Develop alternatives	Combine technologies and sites	

(Continued)

Table 9.1 (Concluded)

Phase	Step	Purpose	Criteria used
	3. Screen alternatives	Eliminate poor or inferior alternatives	
IV. Detailed evaluation and ranking	1. Evaluation of alternatives	Extensive evaluation of remaining alternatives	1. Cost 2. O & M 3. Reliability 4. Safety 5. Regulatatory requirements 6. Implementability and availability 7. Public acceptance 8. Environmental impact 9. Technical effectiveness
	2. Ranking of alternatives	Arraying of alternatives for easy comparison	
V. Alternative selection			

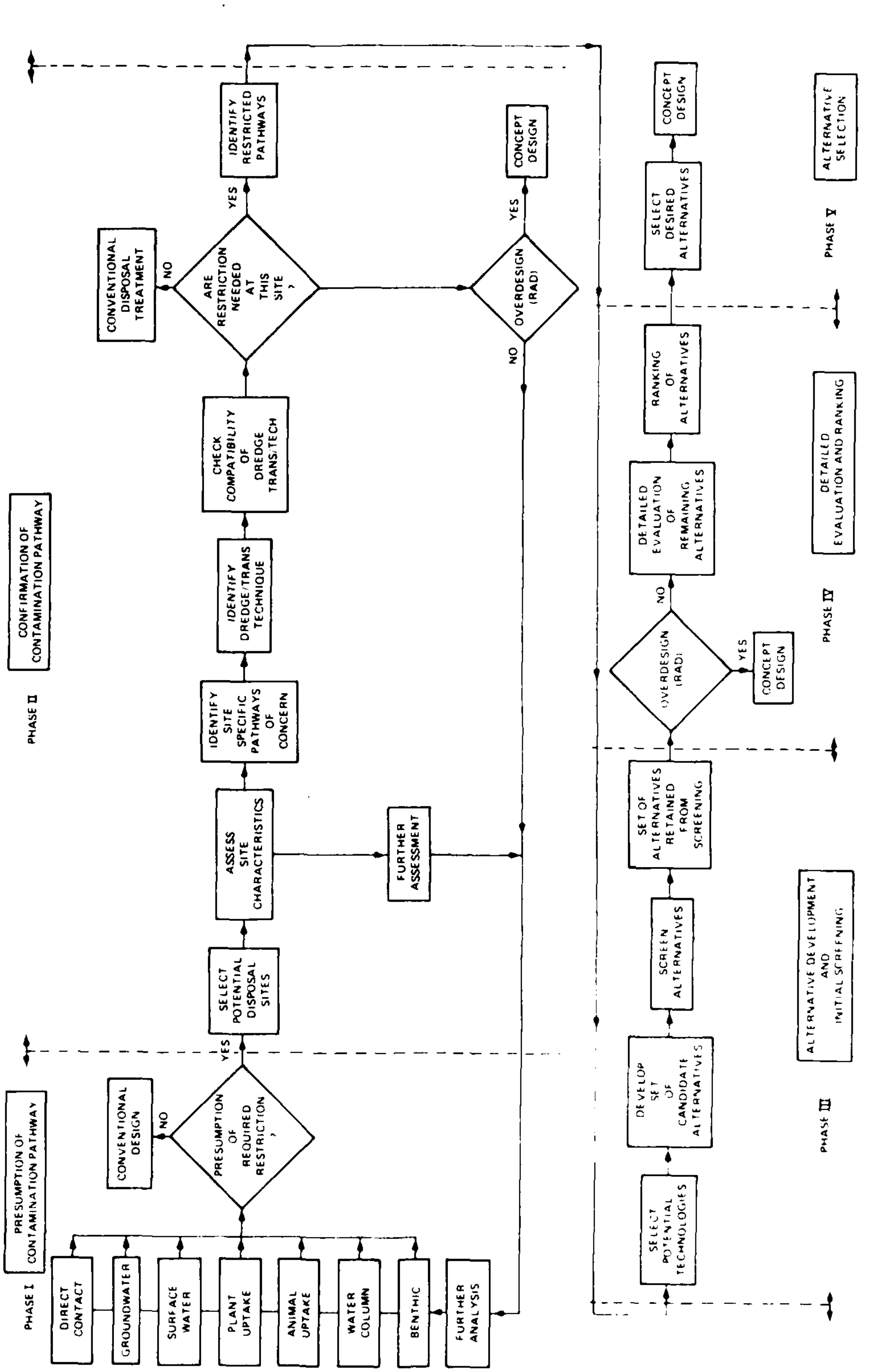

Figure 9.3. Detailed flowchart for the DMASS

example is the sequence of site selection followed by technology selection. In some cases, these two could be done concurrently rather than sequentially. Using the flowchart by looking two steps ahead gains further flexibility, possibly saving time and energy.

Evaluation Factors

The selection of alternatives necessitates the formulation of factors by which the alternatives are to be evaluated and criteria by which these factors are to be measured. A number of factors and a variety of criteria have been proposed for the evaluation of dredged material disposal projects. The selection of appropriate evaluation factors and criteria may depend on both the characteristics of the sediment to be dredged and the proposed dredging/transportation/disposal alternative to be implemented. Therefore, the selection of alternative evaluation factors and criteria is a local or regional decision.

Evaluation factors and criteria are developed as a means of assessing the relative merits of a set of proposed alternatives. Although the selection of factors is relatively trivial, the development of criteria by which these factors are measured or compared is much more difficult. Criteria can be quantitative or qualitative. The alternative assessment and selection process can be less subjective if the criteria can be expressed in quantitative terms; however, for criteria other than costs, it is usually not possible to quantify the factors in absolute terms. In such cases, decision makers usually resort to the relative numeric ranking of alternatives. These relative numeric rankings are usually based on the subjective evaluation of the likelihood that a specific qualitative criteria can be obtained.

Quantifiable Factors

Quantifiable factors include cost, technical effectiveness, and operation and maintenance.

Costs. The cost factor addresses the overall cost of implementing a control/treatment alternative. Overall cost includes capital as well as operation and maintenance costs and should be quantified as the present worth or equivalent annual cost of the alternative. In general, it is desirable to select an alternative with the lowest overall cost. There are difficulties in basing decisions solely on cost since other important factors may be overlooked. Therefore, the criteria by which the cost factor should be measured is cost effectiveness. The cost effective alternative is the least cost alternative that acceptably meets the criteria established for the other evaluation factors.

Technical Effectiveness/Efficiency. The technical effectiveness/efficiency factor addresses the ability of an alternative to meet control/treatment requirements. Since control/treatment alternatives are implemented in response to requirements of the decision making framework (Lee et al. 1985, Peddicord et al. 1986), the technical effectiveness/efficiency alternatives under consideration should be evaluated in terms of the testing protocols performed in accordance with the decision making framework. The ability of an alternative to meet these requirements should be assessed by comparison of the allowable contaminant release at a specific site with the estimated contaminant release after implementation of the control/treatment option.

The criterion for the technical effectiveness/efficiency factor is therefore the ability of the alternative to meet contaminant release requirements. The evaluation process is conducted by estimating the contaminant containment efficiency, for all pathways, of the alternative and proceeding through the decision making process outlined in the decision making framework.

Operation and Maintenance. The operation and maintenance (O&M) evaluation factor addresses the material and resource requirements necessary to operate and maintain the control/treatment alternative. The impact of O&M requirements is typically expressed as a cost. While it is generally desirable to minimize these costs, the effect of O&M cost reductions must be assessed in terms of the overall cost of the alternative evaluated as a present worth or equivalent annual cost. That is, reductions in O&M costs are frequently offset by increases in capital costs. Evaluation of methods having similar total overall costs must consider the preferability of capital costs (i.e., present costs) to O&M costs (i.e., future costs). The relative preference of costs should be based on the certainty of cost data and the source of funding. In general, there is more certainty with capital (present) costs than with O&M (future) costs. The criterion by which O&M will be evaluated is costs.

It is difficult to set an absolute quantitative value for the criterion for this evaluation factor because of the effects of site specific conditions and uncertainties associated with control/treatment alternative costs. The following criterion is provided for general guidance in evaluating alternatives: among alternatives having approximately equal total cost effectiveness, the alternative having the minimum O&M cost should be selected.

Non Quantifiable Factors

Non quantifiable factors include: reliability, implementability/availability, environmental concerns, safety, regulatory requirements, and public acceptance.

Reliability. The reliability evaluation factor addresses the uncertainty associated with performance of an alternative. In general, efforts are made to formulate reliable alternatives and select alternatives having the maximum reliability. This may appear to be trivial since, in theory, all candidate alternatives should be reliable, i.e. an alternative would never be planned to be unreliable. The difficulty lies in quantifying and subsequently assessing in absolute terms the performance uncertainty associated with a specific control/treatment alternative. This uncertainty can be minimized through the use of alternatives which have already been proven in application under similar conditions. Unfortunately, this requirement would preclude the use of new alternatives that may provide acceptable contaminant containment, however, which have not been used on the field scale.

To further complicate the evaluation of reliability, the consequences of failure must be taken into account. A general guideline for acceptable consequences of failure should be comparison with the no restriction alternative. That is, as a minimum, complete failure of the alternative to provide contaminant containment should not result in consequences greater than the no restriction option. Alternatives that meet this guideline can be subjected to further review.

In consideration of the above, three general guidelines are suggested for assessment of alternative reliability. These guidelines are based on the discussion of technologies found in Part VIII.

a. Alternatives that incorporate field demonstrated technologies are preferred.

b. Alternatives that incorporate proven technologies are acceptable.

c. Alternatives that incorporate demonstratable technologies will be considered if the consequences of complete failure are not greater than the consequences associated with the no restriction alternative.

d. Alternatives that incorporate conceptual technologies are unacceptable.

Implementability/Availability. The implementability factor addresses site specific conditions which may impact on implementation of the proposed control/treatment alternative. Typically, implementability concerns the technical feasibility of constructing or operating the control/treatment option under site specific conditions. For example, because of poor soil conditions at a nearshore disposal site it may be technically infeasible to construct a flexible membrane liner to address a ground-water contamination problem. Availability, on the other hand, concerns the requirements for specific equipment, materials, and/or conditions that may be necessary to implement a proposed control/treatment alternative. For example, lining of an upland disposal site with low permeability natural soil may be infeasible because such lining material is not available within an acceptable distance of the disposal site. Another example would be limited availability of dredging equipment. Generally, alternatives should be selected which do not require equipment, materials, or conditions not readily obtainable.

If required equipment, materials, or conditions are not readily obtainable, a proposed alternative may still be technically possible to implement. This is usually accomplished by increasing the expenditure of monetary resources until the cost becomes prohibitive or extending the time frame for project completion. Thus, two criterion are selected for the assessment of implementability/availability: impact on cost and impact on timing.

The cost criterion can be stated as a maximum, i.e., in order to be considered as implementable, the cost of the alternative should not be greater than the maximum reported unit cost of implementation at other sites. The timing criterion is simply stated as: can the alternative be implemented within the required time frame.

In addition to these absolute criteria, the evaluation of relative implementability/availability of an alternative is also important. Some alternatives are easier to implement than others. This can only be accomplished through relative subjective ranking. Obviously a major criterion by which the relative implementability of an alternative is evaluated is the relative cost of the alternative.

Environmental Concerns. The Decisionmaking Framework (Lee et al. 1985, Peddicord et al. 1986) addresses those direct environmental impacts associated with the release of contaminants from the dredged material. These contaminant release issues are addressed through the technical effectiveness/efficiency and reliability evaluation factor. The environmental concerns evaluation factor, on the other hand, addresses environmental consequences other than those associated with the releases of contaminants. Although these consequences may be significant, for purposes of discussion they will be defined as the secondary impacts of contaminated dredged material disposal. These secondary impacts include such things as loss of habitat, noise, and esthetics. Identification of these secondary impacts is highly site-specific. Quantification is difficult and the best analysis will usually be based on a qualitative assessment and relative ranking of alternatives. In general, it is desirable to select control/treatment alternatives that minimize the secondary impacts of disposal and those alternatives with fewer secondary impacts are preferred.

Safety. The safety evaluation factor addresses the issue of whether the proposed control/treatment alternative can be safely implemented. The safety of both on-site personnel and the general public should be addressed. Whereas the technical effectiveness/efficiency and reliability evaluation factors address the consequences of the migration of contaminants from the dredged material, the safety evaluation factor considers those direct hazards associated with implementation of the control/treatment alternatives. Examples of concerns addressed by this evaluation factor include.

a. Can the proposed control/treatment alternative be safely constructed or operated?

b. Will special personnel protection be required during the construction process?

c. Will transportation of material endanger the general public during active project performance?

Alternatives should be selected that minimize safety hazards to both on-site personnel and the general public. Although safety requirements impact the cost of alternatives, in most cases the relative safety of alternatives can only be addressed in subjective and qualitative terms.

Regulatory Requirements. The regulatory requirements evaluation factor addresses the impact of compliance with applicable laws, ordinances, and regulations on the implementation of the proposed control/treatment alternative. Regulatory requirements are extremely important in that they may determine the overall acceptability of an alternative, and at the very least impact on the cost and time required for implementation. Since it is assumed that all alternatives must comply with all appropriate regulations, it may be argued that these requirements would have an equal impact on all alternatives. However, not all regulations will apply equally, if at all, to all alternatives. For example, only those alternatives resulting in discharges to surface waters would have to comply with state water quality standards under Section 404 of the Clean Water Act.

It is usually difficult to quantify the impact of regulatory requirements on the implementation of control/treatment alternatives. In many cases, the interpretation of regulations by regulatory agencies is subjective and carried out on a case-by-case basis. This can lead to uncertainty in the evaluation of the regulatory requirements factor.

In quantitative terms, both a time and cost criteria can be developed for the regulatory requirements factor. In terms of cost, the criteria is that the cost of regulatory compliance associated with the implementation of a control/treatment alternative should not constitute a significant increase in costs beyond those required to meet contaminant containment requirements. In terms of time, satisfying regulatory requirements should not result in extension of the project time frame beyond acceptable limits.

For those alternatives meeting the above minimum criteria, a subjective ranking of the regulatory difficulty associated with each can be prepared. Alternatives with fewer regulatory difficulties are preferable.

Public Acceptance. The public acceptance evaluation factor addresses the concerns of the public about implementation of control/treatment alternatives, including all of those factors perceived by the public as being important. Addressing public concerns has proven to be a vital consideration in a number of cases, particularly those involving siting. A major difficulty in dealing with public concerns is that they are often problems of perception, not based solely on technical considerations; nonetheless, they cannot be dismissed solely on a technical basis.

Alternatives that are acceptable to the public should be selected wherever possible. The measurement of public acceptance and comparison with a criteria is difficult since public acceptance often involves intangibles and cannot be easily quantified. The evaluation of public acceptance may best be expressed in terms of a cost criterion. The cost of achieving public acceptance of a control/treatment alternative should not result in a significant increase in cost beyond that required to meet the primary contaminant containment requirements.

Alternative Selection Strategy

Phase I: Presumption of Contamination Pathway

The first phase of the DMASS is the initial determination that the sediment to be dredged is contaminated and that there is some reason to believe that some type of restriction will be required during dredging/transportation/disposal operations. The presumption that contaminant migration is a concern is made using the decisionmaking framework proposed by Lee et al. (1985) and Peddicord et al. (1986). The pertinent flowcharts from these studies are repeated in Figs. 9.4 through 9.17. The various flowcharts used in this phase will be utilized again in the alternative development and screening phase. As different restrictions on dredging/transport/disposal are considered, their effectiveness will be analyzed by proceeding through the flowcharts again to see if there is still an adverse impact and if further restrictions are needed.

Phase II: Confirmation of Contamination Pathway

The end product of Phase I is a listing of contaminant-migration pathways potentially requiring restrictions. It is assumed that this information indicates the need for some restrictions or at least the need for further detailed analysis of the environmental consequences of a proposed dredging/transportation/disposal option. These concerns must now be evaluated in terms of the characteristics of a specific dredging and disposal site. It is highly possible that one site may require restrictions whereas another site may have characteristics that require different or possibly no restrictions. For example, assume that initial testing of the sediment indicates that generation of contaminated leachate may have an impact on ground-water or surface-water resources at a disposal site. This is the presumption of a contamination pathway. As individual disposal sites are assessed, it may be determined that one site requires a liner while another site, because of fortuitous geological circumstances, may make a liner superfluous. Thus, the presumption of a contaminant migration problem based on sediment testing must be confirmed by site-specific evaluations.

Potential Site Selection. The selection of sites for contaminated dredged material disposal is likely to be a local or regional decision.

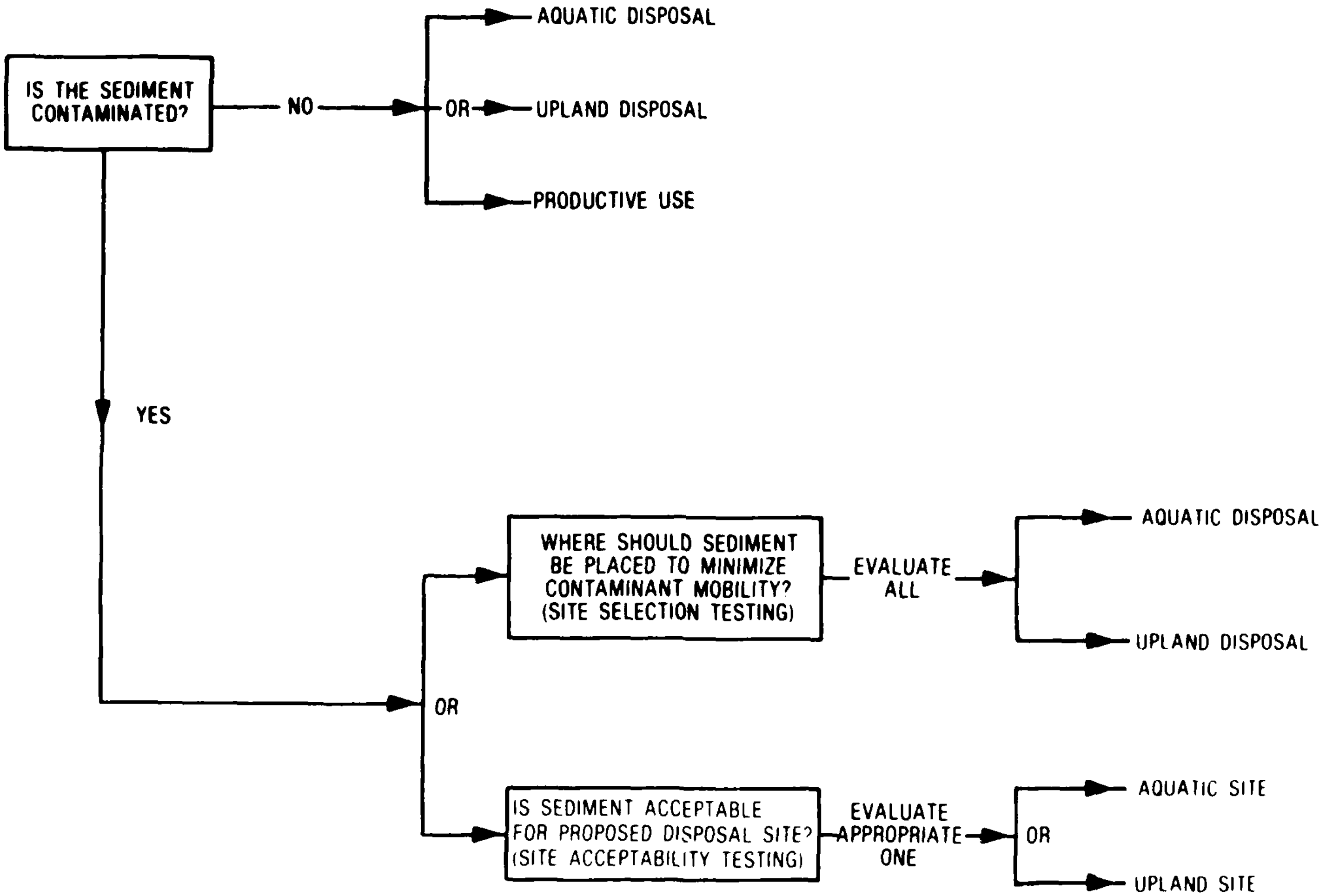

Figure 9.4. Flowchart for initial decisions for using the decisionmaking framework

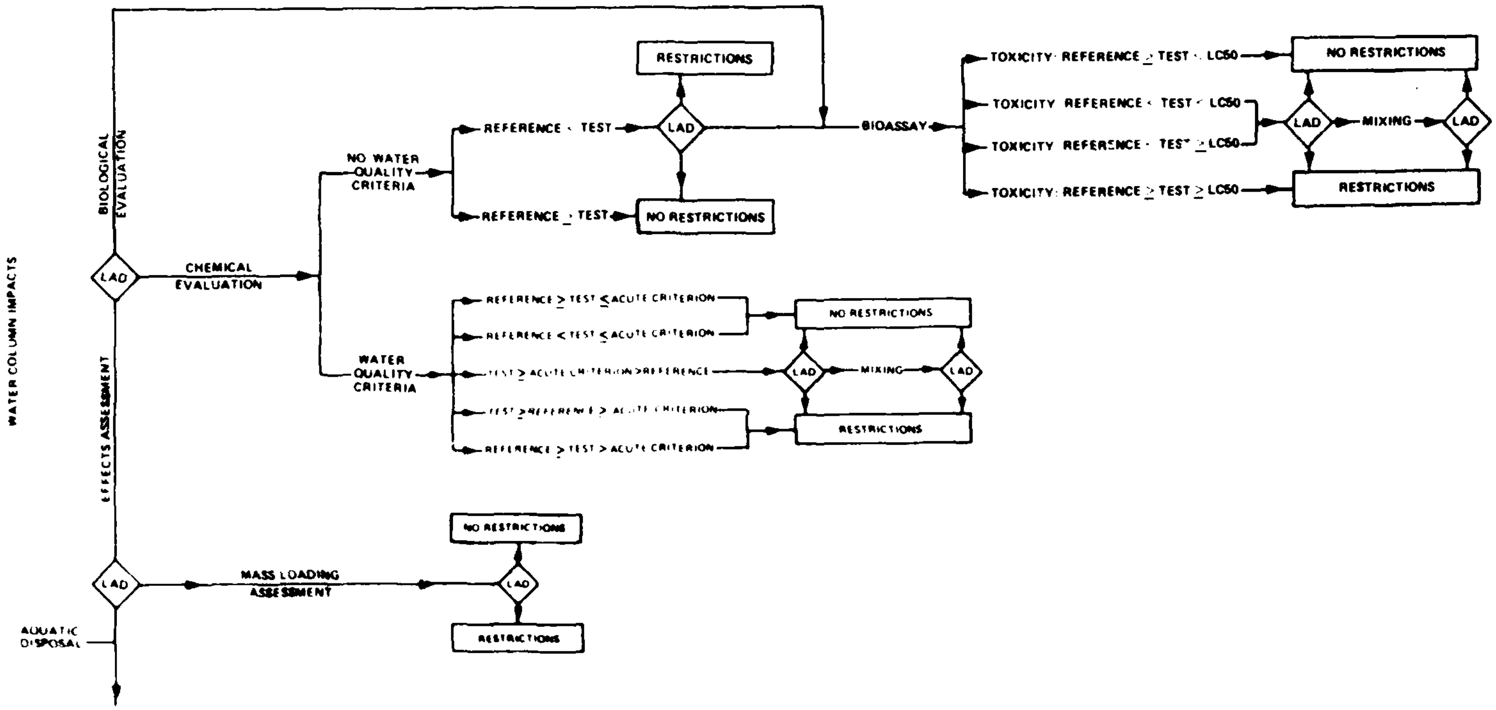

Figure 9.5. Flowchart for decisionmaking for aquatic disposal water column impacts with a mass loss assessment

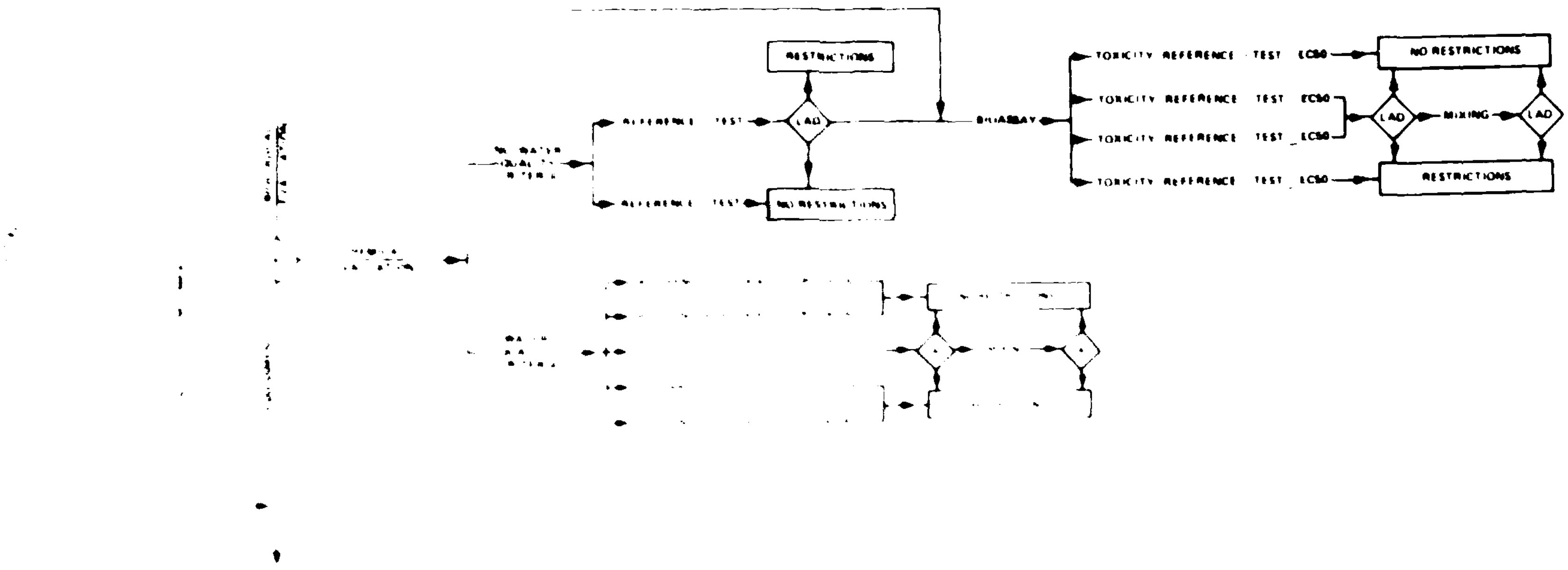

Figure [illegible]. Flowchart for decisionmaking for aquatic disposal water column impacts without a mass loading assessment

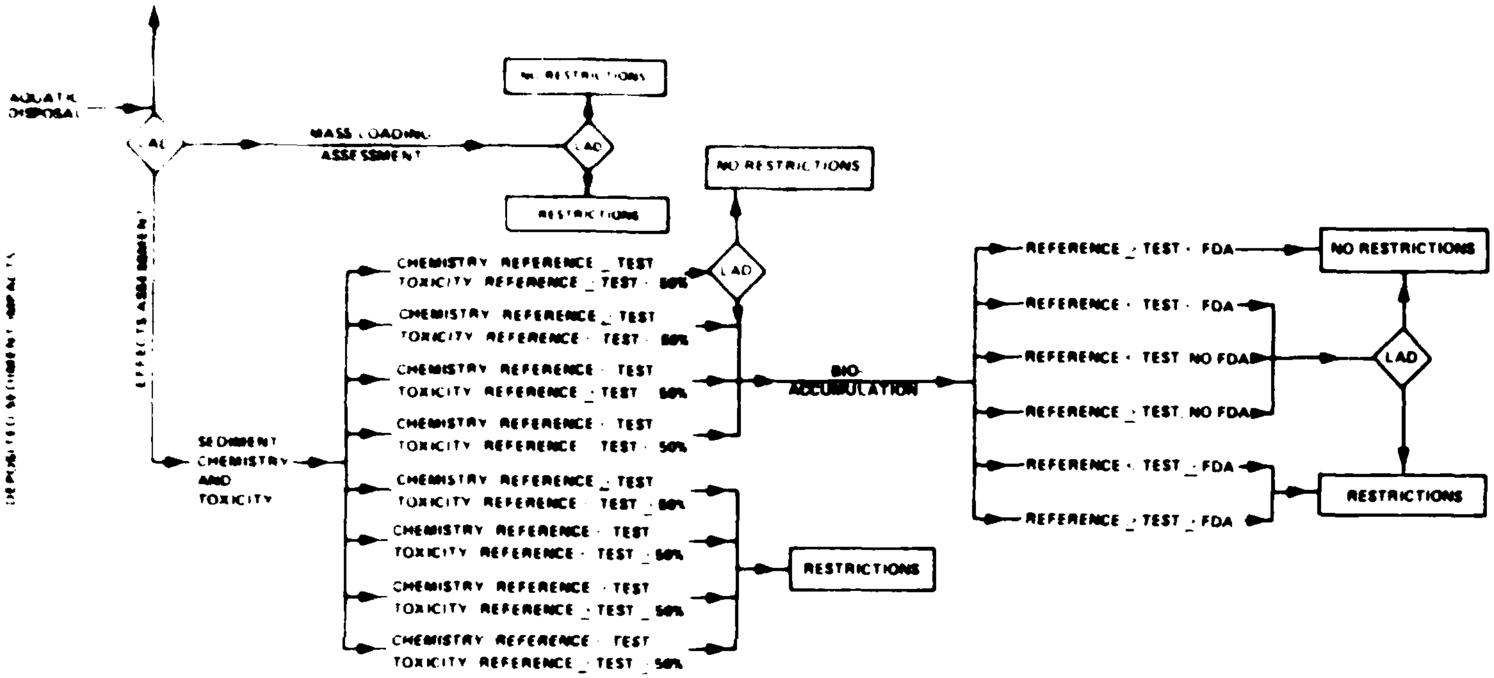

Figure 9.7. Flowchart for decisionmaking for aquatic disposal deposited sediment impacts with a mass loading assessment

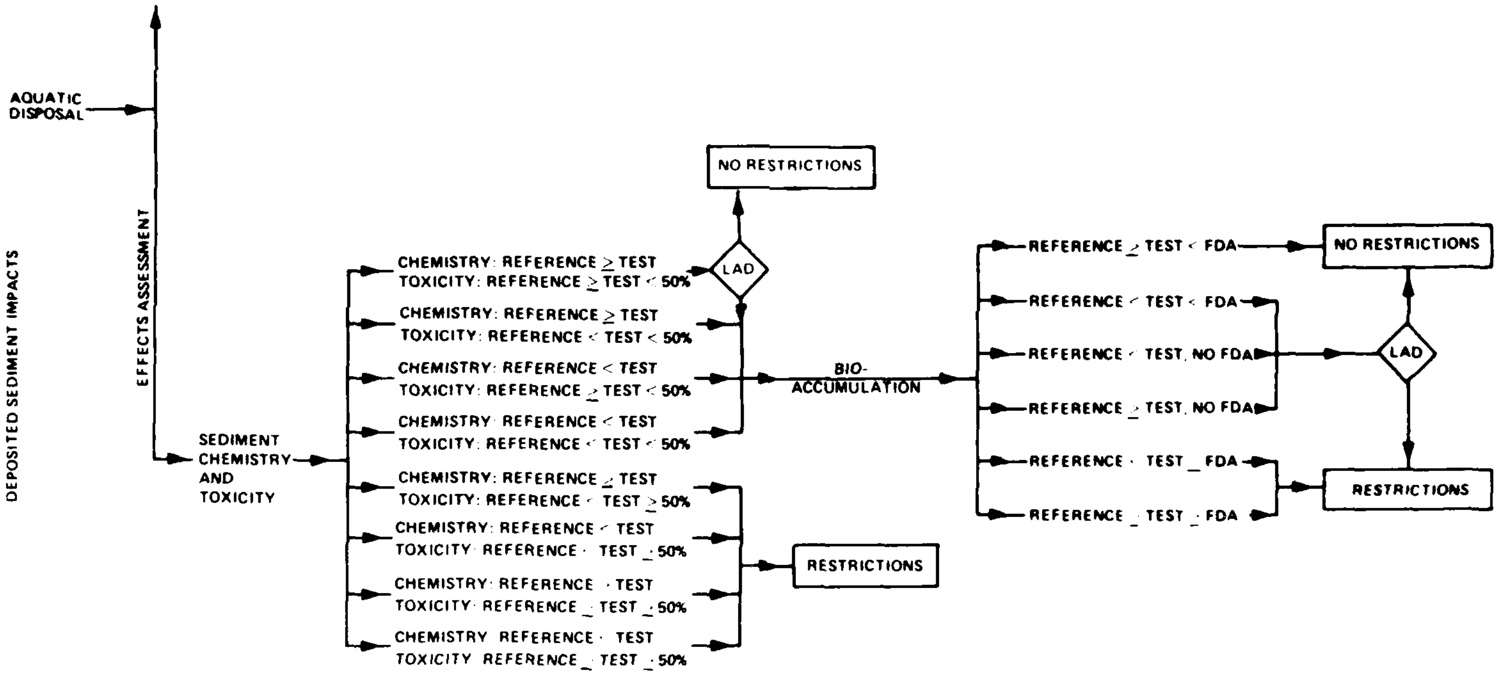

Figure 9.8. Flowchart for decisionmaking for aquatic disposal deposited sediment impacts without a mass loading assessment

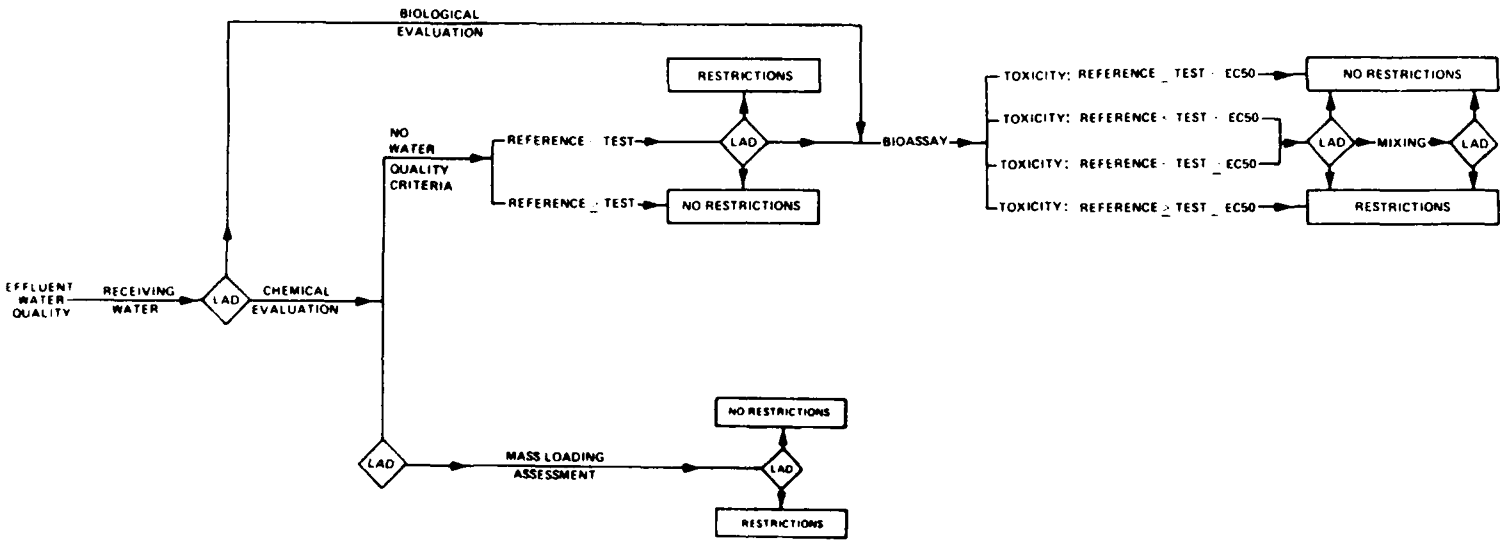

Figure 9.9. Flowchart for decisionmaking for unfiltered effluent water quality with a mass loading assessment

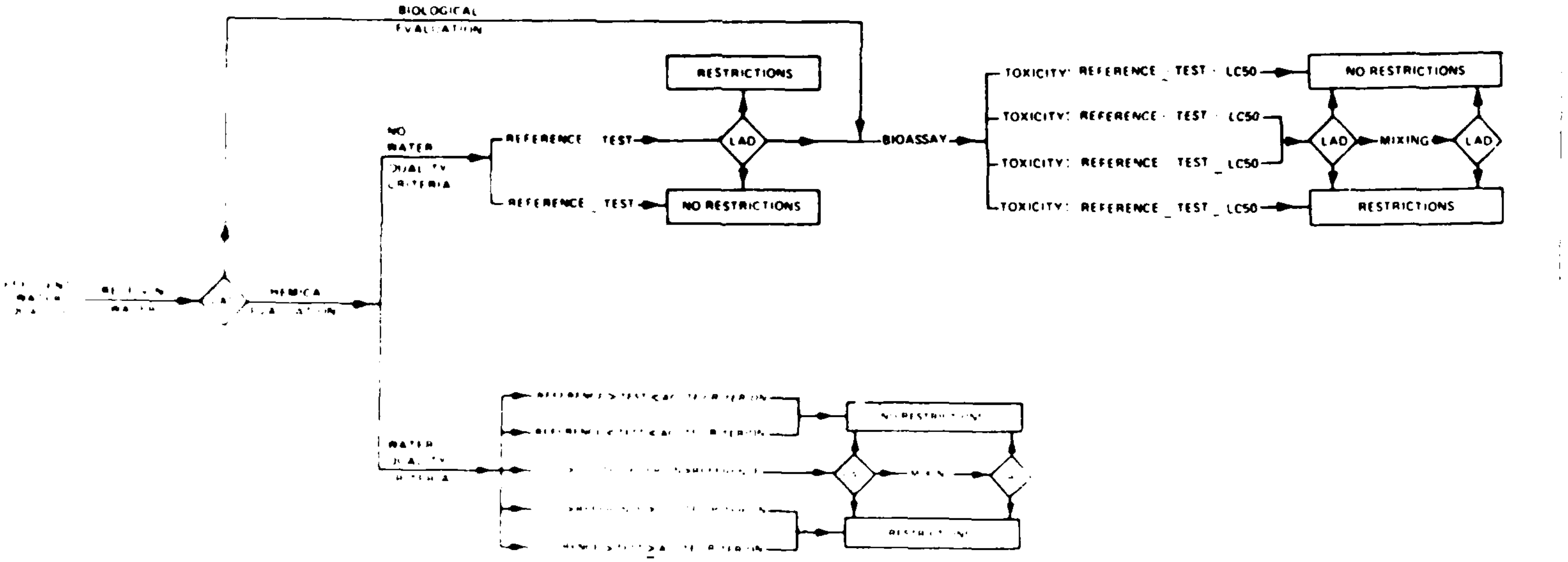

Figure 9.10. Flowchart for decisionmaking for effluent water

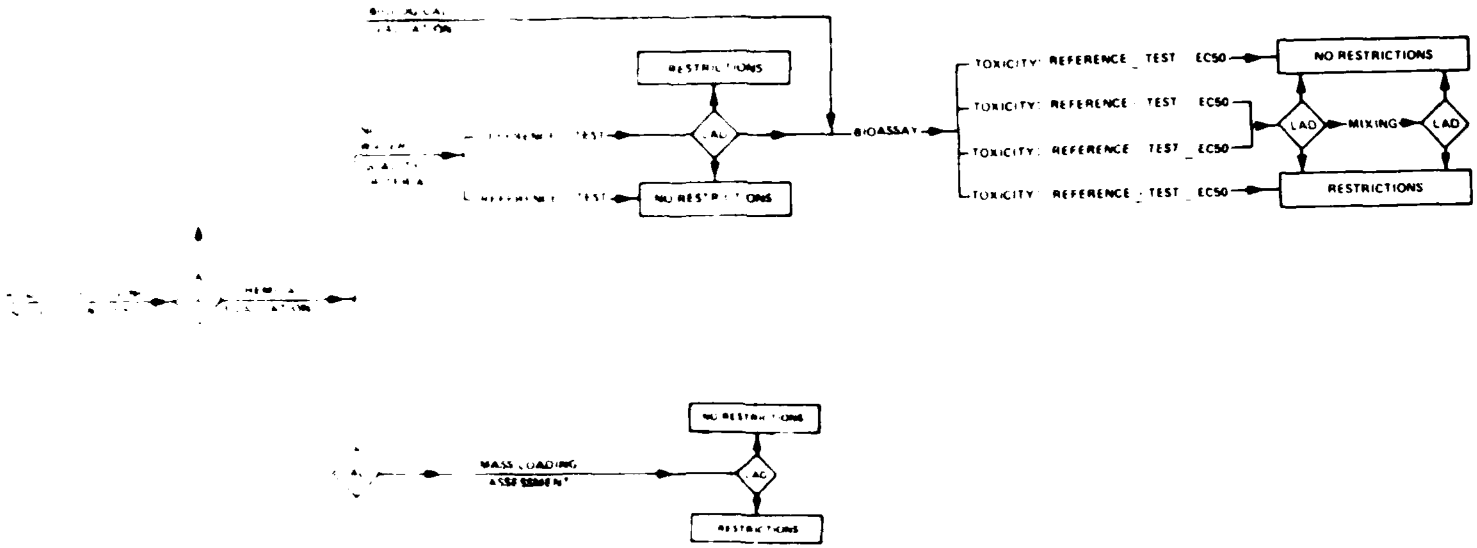

Figure [illegible] Flowchart for decisionmaking for unfiltered surface runoff water quality with a mass loading assessment

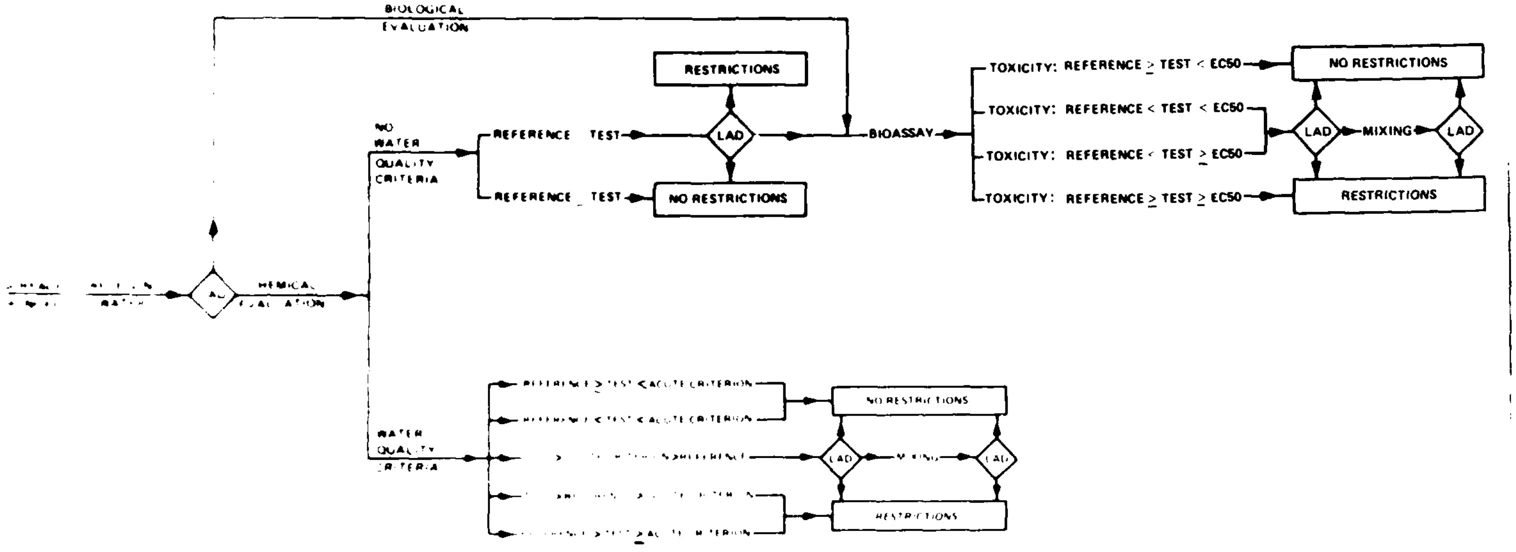

Figure 9.12. Flowchart for decisionmaking for surface runoff water quality

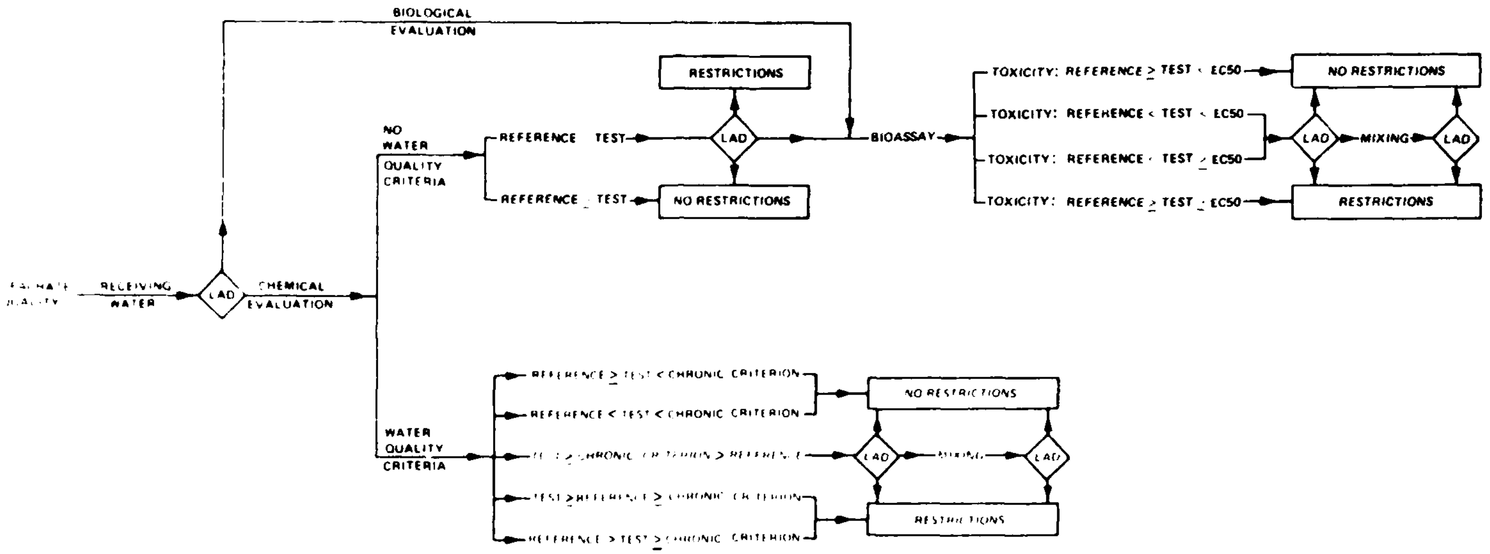

Figure 9.13. Flowchart for decisionmaking for leachate seepage quality impact to surface water

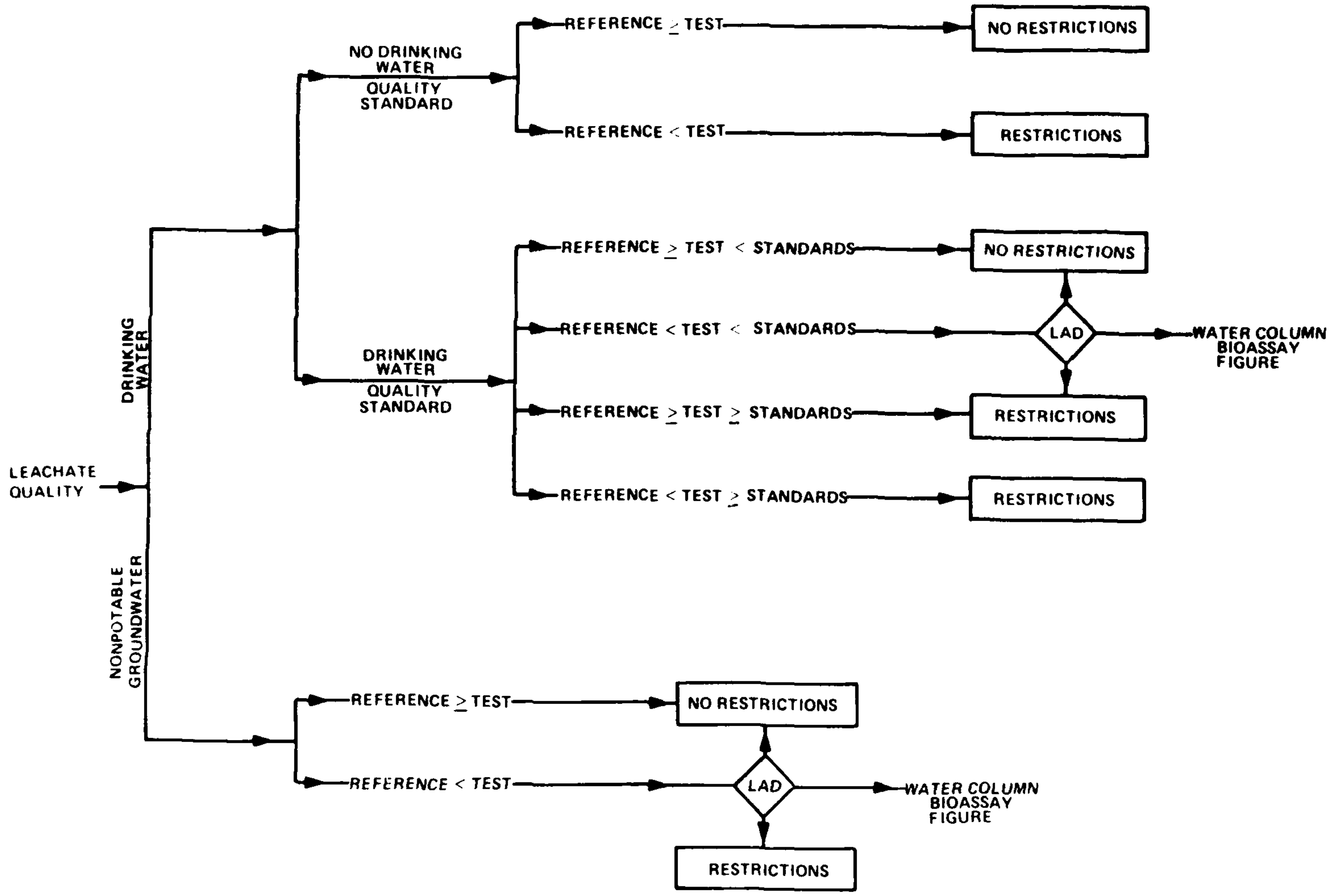

Figure 9.14. Flowchart for decisionmaking for leachate impacts to ground water

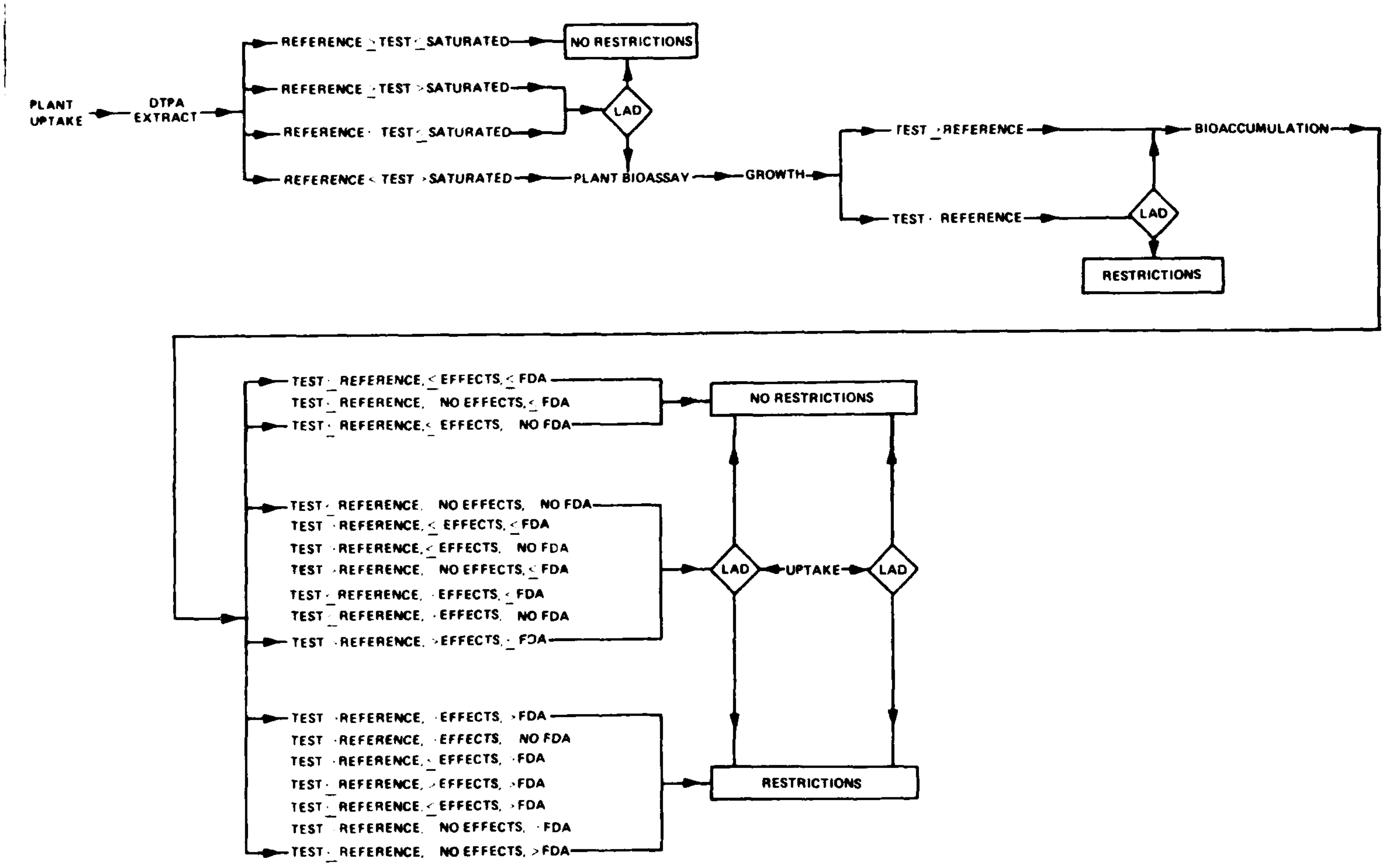

Figure 9.15. Flowchart for decisionmaking for potential plant uptake

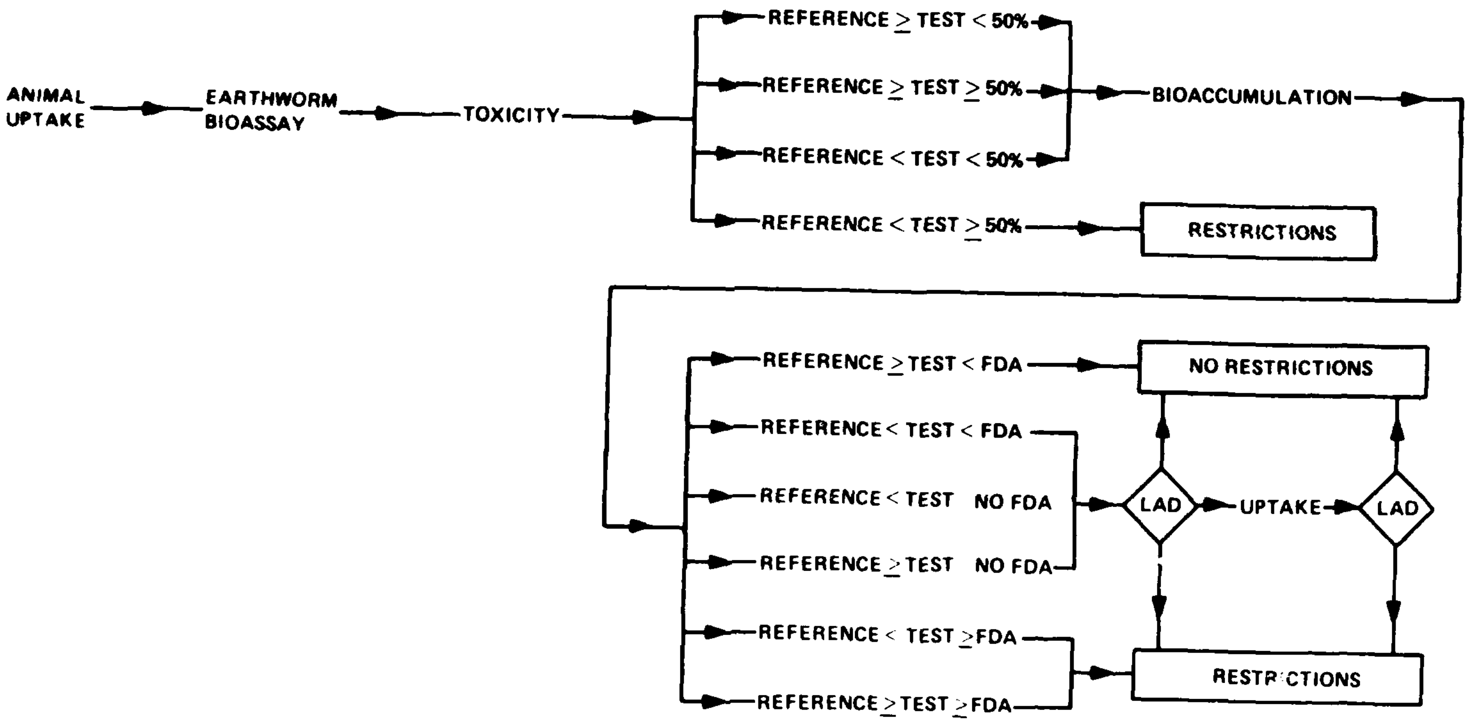

Figure 9.16. Flowchart for decisionmaking for potential animal uptake

Figure 4.17. Flowchart for decisionmaking for potential human exposure

Potential sites will probably be identified, at least on a preliminary basis, during or prior to Phase I of the DMASS. Many potential sites can be eliminated through a preliminary screening process consisting of up to three steps. These include elimination of sites based on: (1) absolute criteria values; (2) a relative comparison of sites; and (3) site-specific characteristics. Whether all three of these criteria are used, and the extent to which they are used, will depend upon specific characteristics of the application, with the number of available sites being a prime factor.

Where there are a large number of candidate disposal sites, some can be eliminated because they do not achieve the cutoff point for one or more criteria. The simplest example is proximity of a disposal site to the dredge site. Proximity is an easy measure to use and incorporates aspects of three of the criteria discussed earlier: cost, safety, and public acceptance. The cutoff distance must be far enough to allow retention of a reasonable number of candidates, even after other screening criteria have been imposed. The cutoff distance can often be determined on a logical basis. For example, if dredged material is barged, a certain distance is possible using a continuous two-barge operation. A greater distance is possible using three barges, etc. A similar argument can be made for pipeline distances, given pumping capacities and elevation changes. Another logical measure would be site capacity. Ideally the selected disposal site must be capable of accommodating all of the dredged material. However, under some circumstances, two or even several sites may be used. However, sites with limited capacity may be ruled out early on in the evaluation process.

Once the first step has been completed, more of the candidate sites can be eliminated based on a relative ranking of appropriate criteria for the remaining sites. If only a few candidate sites remain after the initial site screening step, it might be wise to retain all of them. However, if there are many, those that are clearly inferior can safely be dropped from further consideration.

The choice of which factors to use for this screening process is a local or regional decision. Of the nine evaluation factors described earlier, some are more applicable (although not totally) to the control/treatment technologies to be employed at the disposal site and not to the site itself. These include reliability, implementability and availability, technical effectiveness, operation and maintenance, and safety. The rest of the criteria (environmental concerns, cost, regulatory requirements, and public acceptance) relate closely to the proximity of the disposal site to (1) the dredge site (cost), (2) environmentally sensitive areas (environmental concerns and regulatory requirements), and/or (3) populated areas (public acceptance, regulatory requirements).

The last step in the screening process requires the assessment of all sites for any site-specific factors likely to jeopardize the use of a site for dredged material disposal. Political climate, zoning, and ownership are examples of factors that should be considered.

Detailed Site Assessment. The evaluation of a site for disposal of contaminated dredged material involves a determination of all characteristics that might affect the performance of the technologies including the no-restrictions (no-action) alternative.

Since the site assessment performed during this stage is likely to be far more detailed than previous site evaluations, it is appropriate to examine whether restrictions are indeed necessary at the specific site being evaluated. The evaluation of sites might involve different factors, but should take into consideration all avenues that have a potential for creating an adverse impact. As such, those migration pathways of concern identified in Phase I should be given special consideration.

Assessment of a single site could include a variety of studies involving considerable expense. No attempt will be made to detail specific types of analyses that are available, although general approaches will be mentioned. Decisions on the type of analyses to perform and the extent to which they are carried out are decisions that should be made at the regional or local level. A brief discussion of some site-assessment concerns is presented below.

Two aspects of aquatic disposal need to be considered: effects on the water column and effects on the benthic population.

The initial assessment of the potential effects on the water column above [illegible] aquatic disposal site may have involved a conservative approach by assuming [illegible] mixing zone. To include the natural assimilative capacity of the receiving water at the site, more detailed analyses of how discharged dredged material [illegible] be dispersed in the water column are necessary. Unfortunately there are [illegible] satisfactory techniques that are simple and quick to perform. Existing [illegible]ated mathematical models could be calibrated to the site to determine [illegible] disposed material might be distributed throughout the water column. The techniques could be used for analyzing [illegible] the potential resuspension following restricted upper water [illegible]

Other site-specific factors that would be [illegible] determination of background [illegible] regional or local authorities [illegible] outside a prespecified mixing zone [illegible] must be known.

Site-specific characteristics [illegible] determined since benthic organisms [illegible] extended periods of time. [illegible] be performed on indigenous animals [illegible] a likely possibility, and since the [illegible] process, they should be determined [illegible] water hardness, and temperature.

Contaminant pathways for [illegible] therefore, their discussion is combined below.

Effects on surface water [illegible] (1) during active disposal versus after [illegible] discharge as opposed to uncontrolled surface runoff [illegible] general, a weir discharge effluent will result during the active phase of operation while uncontrolled surface runoff may be of greater concern after completion of the active phase.

Dredged material that is placed in an upland area undergoes sedimentation with the supernatant being discharged (possibly after treatment) to a receiving water body. To evaluate the fate of contaminants that might be in the effluent, characteristics of the receiving water body would need to be determined. For a stream, these include low-flow rate, background concentration, temperature, and physical characteristics of the stream. Conventional mathematical models can be used to determine concentrations after discharge to the stream and following transport downstream. For aquatic biota, bioassays could be performed when information on standard chemical analyses is not available.

Surface runoff is a concern when run-on and/or rainfall picks up contaminants as it flows over the area. General topography and climatic data are necessary for proper analysis.

Determining the impact on ground-water quality is a difficult task. The concentration of leachate after it enters the natural environment will change as it is dispersed and attenuated. Determination of the concentration that may end up in the ground water will depend on type of soil, depth to ground water, and attenuative capabilities of the soil. A complete geologic survey of the area is necessary to determine the type(s) and extent of soil and how it will affect the flow of leachate from a disposal site.

Characterization of the ground water is necessary, including background contaminant concentrations (if possible) and intended use of the aquifer (e.g., domestic water supply). Ground water quality models are available that can be used to predict contaminant concentration and flow once it reaches the saturated zone. Prediction of flow in the unsaturated zone is more difficult. Where appropriate, leaching tests should be performed to determine possible geochemical effects on the leachate.

Uptake of contaminants by plants is not necessarily a site-specific problem except to determine the types of plants that may invade the site. Plant bioassay tests using indigenous species should be conducted to determine what eventual management practices should be planned.

Like plant uptake, assessment of animal uptake is only a site-specific problem in determining indigenous species that may be exposed to contaminated material or plants which may have accumulated contaminated material. Bioaccumulation of contaminants via plant and then animal uptake is a real concern, making analysis of potential effects an important consideration. Since it is assumed that all upland sites will be fenced, certain animals will be kept from direct contact with sediment and affected plants. Flying and burrowing animals however must be considered, and bioaccumulation via herbivorous animal to carnivore may be a concern.

Dredge and Transport Selection. Allied with the selection of potential disposal sites is the selection of the type of dredge and the type of sediment transport once it has been dredged. Indeed, the availability of a disposal site may be a driving force in the selection of an appropriate dredging/transportation alternative. This link is particularly true for aquatic disposal of dredged material.

The two boxes shown in Fig. 9.3 (identify dredge/transport technique and check compatibility of dredge/transport technique) must be expanded to include several aspects. Fig. 9.18 shows this expansion, which is based on the

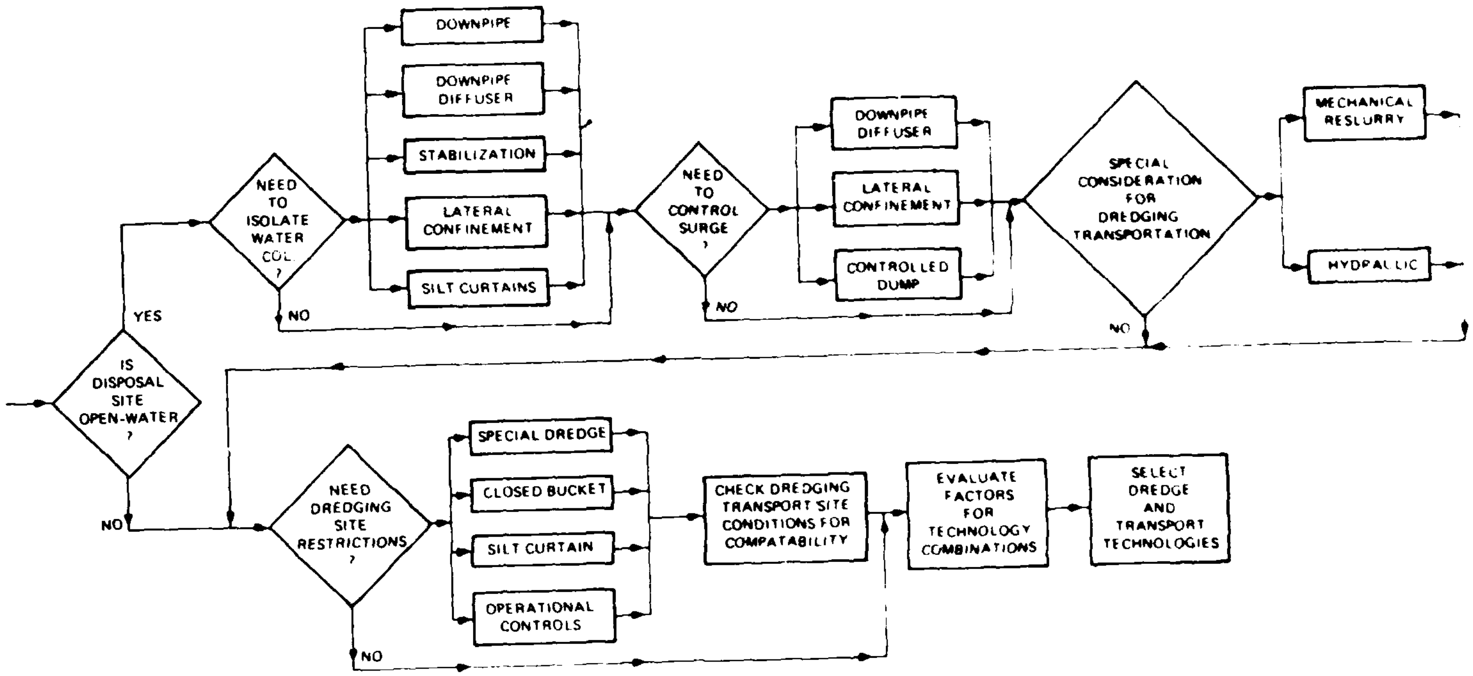

Figure 9.18. Flowchart for selection of dredge and transport techniques

premise that characteristics of the disposal site are the dominant factors in the selection process. As a result, questions regarding the disposal site are asked first, resulting in possible special considerations at the dredging site and/or in the means of transport. For aquatic disposal, the first consideration is the effect on the water column. At this stage, information from analysis of the sediment in the first phase has determined that there is (or is not) likely to be an adverse impact on the water column. If no impact is likely, the process considers the next question. If an impact is thought to be likely, then site-specific conditions are considered for each potential site. For a particular site, local considerations may be such that there is no adverse impact on the water column, in which case the next step in the process would be considered. For another site, local conditions may indicate that there would be an adverse impact. In this case, restrictions, such as a downpipe, would be necessary at that site. Once a restriction has been determined as necessary, the effect of its use should be checked to ensure that no further restrictions, above and beyond the initial effort, are still necessary.

The second step in the process is to consider the need to control the surge resulting from the impact of the disposed material on the bottom. Again, information from the detailed assessments of potential sites would indicate whether this aspect is a problem. If it is, controls, such as a downpipe and diffuser or a controlled dump (assuming no problems with the water column), should be assessed to see if their implementation would alleviate the problem.

Once these two questions have been addressed, it is necessary to determine if resulting restrictions will have an effect on the type of dredge and/or type of transport. The primary factor here is simply whether previously determined restrictions require hydraulically pumped sediment or not. For example, use of a downpipe and diffuser would require a slurry. This would mean that the sediment needs to be: (1) hydraulically dredged and piped; (2) mechanically dredged, slurried, and piped; or (3) mechanically dredged, barged, and then slurried.

There are a number of other factors to consider at the dredge site that are independent of the disposal method, yet which would affect the choice of dredging techniques. These include aspects such as depth, resuspension at the dredge site, volitalization, maneuverability, etc. Consideration of these factors might reveal the need for a mechanical over a hydraulic dredge (or vice versa) or even the need for a special purpose dredge.

After all restrictions and special considerations have been determined for disposal site, transport, and dredge site, the decisionmaker must check the compatibility of all techniques and/or equipment that have been selected. The result of this sequence of steps should be a number of options, each representing a combination of compatible techniques and disposal sites. These options, do not necessarily represent full-scale alternatives since long term considerations have not yet been addressed; only those problems associated with the transport and disposal of the sediment have been considered. Long term considerations, such as animal uptake, bottom scour, etc. may require the use of additional technologies, such as capping or lateral confinement of an aquatic disposal site.

For nearshore and upland disposal, the process is not as complicated since the type of disposal technique and site characteristics do not have a great an influence on the types of dredge and transport techniques. Consideration must be given, however, to the restrictions at the dredge site that may have an effect on the type of subsequent treatment and/or disposal that is considered. For example, for nearshore or upland disposal sites where the surface water pathway is restricted, it may be desirable to consider only mechanical dredging techniques. Thus, a tradeoff is made between increased resuspension at the dredging site and the reduced discharge of contaminants at the disposal site. The relative merits of each is addressed through the development of a total alternative package that combines technologies for dredging, transportation, and control/treatment of contaminated sediment during disposal operations. These linkages are considered later, when treatment/disposal techniques are discussed. In Fig. 9.18, when considering upland or nearshore disposal, the upper part of the flow chart is bypassed and only those restrictions at the dredge site are considered.

Reassess Need for Restrictions. Once site characteristics have been more thoroughly assessed, the question of whether restrictions are necessary should be reexamined. It is possible that specific dredged material/disposal site combinations may require no restrictions beyond those for the minimum design case. For example, an upland disposal site that is underlain by clay and receives no run-on and little rainfall, would need nothing more than containment dikes surrounded by a fence, which is the normal minimum design.

If such an alternative is identified, the flowchart can be exited and the conventional process would be followed. The minimum design alternative (no special restrictions) can also be retained for comparison with other alternatives. This option may be beneficial, since when all the evaluation criteria are considered it is possible that a restricted disposal option may fare better in the long run. For example, the no-restriction alternative might be cheap and reliable, but experience considerable resistance from permitting officials and the public.

The detailed site assessment may reveal that more information is necessary to make an informed decision. The proposed alternative selection strategy allows for feedback loops where additional studies could be performed to get more information on site conditions or dredged material characteristics.

Phase III: Alternative Development and Screening

Phase III of the DMASS includes the development of candidate alternatives for accomplishing the required restrictions on contaminant migration. The primary objective of applying control treatment alternatives at a site is to reduce risk (a function of contamination, the pathways, and the receptors) by minimizing release and resultant exposure along each of the pathways. The initial site characterization and assessment serves to identify the critical migration pathways for a specific site. Criteria for each of the migration pathways should be developed and compared to the migration potential as determined from the presumptive tests initially applied to the dredged material. In cases where migration potential exceeds allowable criteria values for a specific site, design alternatives consisting of one or more technologies can be formulated that, when applied at the site under study, will reduce the effects of contaminant migration to within acceptable criteria limits.

Technology Screening. Individual contaminant control/treatment technologies have been discussed in Parts II through VI of this report. Many of these technologies are still theoretical or conceptual and have not been applied in the field-scale environment for the control or treatment of contaminants released from dredged material. Other technologies presented have been proven in related applications, however, they have not been applied to the control/treatment of contaminants released from contaminated dredged material. As a result, most of the technologies presented are not considered as a demonstrated technology when applied to contaminated dredged material. Part VIII of this report discussed the status of the various control/treatment technologies.

The purpose of identifying technology schemes is to consider as many technologies as possible so that feasible cost effective alternatives are not overlooked. Subsequent screenings and detailed analyses of schemes and alternatives serve to single out those technologies and alternatives that are most cost effective in meeting the objectives at a particular site. Alternative identification begins with a preliminary evaluation of all the potential technologies available and the identification of all those that are potentially applicable to the sites that are consistent with the objectives. An initial screen to eliminate clearly inappropriate technologies can be made on the basis of the migration pathways of concern and the chemical nature of the contaminated dredged material. Tables 9.2 and 9.3 show a general applicability matrix for those technologies discussed in Parts II through VI of this report. Table 9.2 presents an evaluation of proven or demonstrated technologies while Table 9.3 presents an evaluation of demonstratable technologies. The evaluation of applicability to any particular migration pathway is presented in qualitative terms of high, low, or no applicability. Reference to these tables permits selection of the family of technologies applicable to any combination of migration pathways and contaminants. For example, if the objective is to reduce the risk from organic compounds via direct contact, then site security would be potentially applicable. On the other hand, if the objective were to reduce the risk from inorganic contaminants via ground water, then site lining would be potentially applicable.

In many cases, there will be multiple critical migration pathways at a specific site. For example, at a site located in a densely populated area over an aquifer recharge zone, both the direct contact and ground-water pathway may be critical. In such cases, technology schemes potentially applicable to all pathways should be considered. The preliminary identification of appropriate technology scheme should be broadly construed. If there is any question, the technologies should be included in the more detailed screening and evaluation processes conducted further into the alternative selection process.

Since technology restriction schemes can consist of one or more technologies, there are potentially thousands of control/treatment options that

Table 9..

Technology-Pathway Applicability Matrix for Proven and Demonstrated Technologies

Proven Technology	Migration Pathway*										
	Direct Contact	Ground Water	Surface Water Active Operation	Surface Water Long Term	Air	Plant Uptake	Animal Uptake	Tidal Pumping	Water Column	Benthic	Resuspension at Dredge
Dredging											
Mechanical dredges	N	N	H	N	L	N	N	N	H	H	H
Hydraulic dredges	N	N	H	N	L	N	N	N	H	H	H
Operational controls	N	N	H	N	L	N	N	N	H	H	H
Silt curtains	N	N	N	N	N	N	N	N	H	H	H
Other barriers (dikes, weirs, sheet piles)	N	N	N	N	N	N	N	N	H	H	H
Transport											
Hopper dredges	L	N	N	N	N	N	N	N	H	H	H
Specialized barges	L	N	N	N	N	N	N	N	H	H	H
Pipeline Controls	L	N	N	N	N	N	N	N	L	L	H
Pump controls	L	N	N	N	N	N	N	N	L	L	H
Route/navigation controls	L	N	N	N	N	N	N	N	L	L	L
Loading/unloading controls	L	N	N	N	N	N	N	N	L	L	L
Truck transport controls	L	L	N	N	L	L	L	N	N	N	N
Rail transport controls	L	L	N	N	L	L	L	N	N	N	N
Disposal (Upland)											
Covers (natural)	H	H	N	L	H	H	H	N	N	N	N
Dikes and berms	L	H	L	H	L	N	N	L	N	N	N
Grading	L	H	L	H	L	N	N	L	N	N	N

(Continued)

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* H - High Applicability; L - Low Applicability; N - No Applicability

Table 9.2 (Concluded)

	Migration Pathway*										
Proven Technology	Direct Contact	Ground Water	Surface Water Active Operation	Surface Water Long Term	Air	Plant Uptake	Animal Uptake	Tidal Pumping	Water Column	Benthic	Resuspension at Dredge
Revegetation	H	H	N	H	H	H	H	N	N	N	N
Channels and waterways	L	H	L	H	N	N	N	N	N	N	N
Chutes and downpipes	L	H	L	H	N	N	N	N	N	N	N
Terraces and benches	L	H	L	H	N	N	N	N	N	N	N
Sedimentation ponds	L	L	H	L	N	L	L	N	N	N	N
Liners (natural)	N	H	N	N	N	N	N	L	N	N	N
Subsurface drains	N	H	N	N	N	N	N	L	N	N	N
Ground-water pumping	N	H	N	N	N	N	N	L	N	N	N
Slurry walls	N	H	N	N	N	N	N	H	N	N	N
Sheet piling	N	H	N	N	N	N	N	H	N	N	N
Leachate collection and removal	N	H	N	N	N	N	N	L	N	N	N
Site security	H	N	N	N	N	H	H	N	N	N	N
Slurry Treatment											
Settling basins	L	H	H	H	L	L	L	N	N	N	N
Stationary screens and sieves	L	H	H	H	L	L	L	N	N	N	N
Moving screens	L	H	H	H	L	L	L	N	N	N	N
Hydraulic classifiers	L	H	H	H	L	L	L	N	N	N	N
Spiral classifiers	L	H	H	H	L	L	L	N	N	N	N
Disposal											
(Open water)											
Capping (sprinkling)	L	N	N	N	N	N	N	N	H	H	N
Lateral confinement	L	N	N	N	N	N	N	N	H	H	N

* H - High Applicability; L - Low Applicability; N - No Applicability

Table 9.3

Technology-Pathway Applicability Matrix for Demonstratable Technologies

Demonstratable Technology	Migration Pathway*										
	Direct Contact	Ground Water	Surface Water Active Operation	Surface Water Long Term	Air	Plant Uptake	Animal Uptake	Tidal Pumping	Water Column	Benthic	Resuspension at Dredge
Dredging											
Foreign dredges	N	N	H	N	L	N	N	N	H	H	H
Special purpose dredges	N	N	H	N	L	N	N	N	H	H	H
Operational controls	N	N	H	N	L	N	N	N	H	H	H
Other barriers (dikes, weirs, sheet piles)	N	N	H	N	L	N	N	N	H	H	H
Transport											
Specialized barges	N	N	N	N	L	N	N	N	H	H	L
Hopper dredges	N	N	N	N	L	N	N	N	H	L	L
Disposal (Upland)											
Covers (synthetic, floating)	H	H	L	H	H	H	H	L	N	N	N
Surface sediment stabilization	H	H	L	H	H	H	H	N	N	N	N
Liners (synthetic)	N	H	N	N	N	N	N	H	N	N	N
Slurry walls	N	H	N	N	N	N	N	H	N	N	N
Grouting	N	H	N	N	N	N	N	H	N	N	N
Slurry Treatment											
Cyclones and hydrocyclones	H	H	H	[illegible]	[illegible]	H	H	[illegible]	N	N	N

(Continued)

* H - High Applicability; L - Low Applicability; N - No Applicability

Table 9.3 (Concluded)

Demonstratable Technology	Migration Pathway*										
	Direct Contact	Ground Water	Surface Water Active Operation	Surface Water Long Term	Air	Plant Uptake	Animal Uptake	Tidal Pumping	Water Column	Benthic	Resuspension at Dredge
Solidification/ stabilization	H	H	H	H	H	H	H	H	N	N	N
Chemical destruction	H	H	H	H	H	H	H	H	N	N	N
Incineration	H	H	H	H	H	H	H	H	N	N	N
Disposal (Open water)											
Submerged diffuser	L	N	N	N	N	N	N	N	H	H	N
Gravity-fed downpipe	L	N	N	N	N	N	N	N	H	H	N
Hopper dredge pumpdown	L	N	N	N	N	N	N	N	H	H	N
Solidification/ stabilization	L	N	N	N	N	N	N	N	H	H	N

---

* H - High Applicability; L - Low Applicability; N - No Applicability

could be applied at a specific dredging disposal site. Fortunately, since many of the technologies are not demonstrated or do not appear to be demonstratable in the near future, the number of feasible control/treatment alternatives needing evaluation can usually be held to a reasonable number. Other technologies can be eliminated on the basis of cost. Promising alternatives using one or more technologies for restricting contaminant migration are presented in Table 9.4 and briefly discussed below.

The control of leachate/ground-water contamination is usually accomplished using covers and/or liners. There may also be several subalternatives involving design considerations such as the cover and liner material, e.g., flexible membrane versus natural soils. If leachate collection is involved, alternative development must include methods for treatment or disposal of the leachate.

The development of schemes that address the surface water pathway must consider both short- and long-term contaminant release. Short-term releases result from the discharge of effluents during active dredging operations, particularly hydraulic dredging operations. Long-term releases result from direct rainfall runoff, rainfall runon and subsequent runoff, leachate or contaminated ground water collected to protect the ground-water pathway, and dredged material dewatering processes. For schemes where collection of contaminated runoff is included, alternative development must include provisions for the treatment and disposal of collected waters.

In those cases where the leachate/ground-water and/or surface water pathways are restricted at nearshore or upland disposal sites, the selection of dredging technique may have a significant impact on the cost of disposal. Thus, it is important to include alternate dredging techniques in the total package of alternatives being considered for implementation of a project. The important consideration is the comparison of mechanical versus hydraulic dredging alternatives. In general, mechanical dredging will result in higher contaminant concentrations at the dredging site and hydraulic dredging will result in higher contaminant concentrations at the disposal site. Which of these conditions is more desirable is based on site specific conditions and control/treatment alternatives to be implemented. By including the selection of dredging technique in the alternative development phase, the tradeoffs can be assessed.

Table 9.4

Typical Control/Treatment Alternatives Addressing Contaminant Migration

Migration Pathway	Typical Alternative
Leachate/Groundwater	Runoff/Runon Controls Runoff/Runon Controls + Cover Runoff/Runon Controls + Single Liner Runoff/Runon Controls + Cover + Single Liner Runoff/Runon Controls + Double Liner Runoff/Runon Controls + Cover + Double Liner Runoff/Runon Controls + Cover + Single Liner + Leachate Collection Runoff/Runon Controls + Cover + Double Liner + Leachate Collection Solidification/Stabilization of Dredged Materials Mechanical versus Hydraulic Dredging
Surface Water	Collection and Treatment of Effluent Mechanical versus Hydraulic Dredging Runoff/Runon Controls + Cover Runoff/Runon Controls + Direct Rainfall Collection and Treatment Runoff/Runon Controls + Cover + Direct Rainfall Collection and Treatment
Plant and Animal Uptake	Site Security Chemical treatment Covers Site Security + Covers
Direct Contact	Site Security Covers Site Security + Covers
Air Pathway	Buffer Zones Covers Buffer Zone + Covers Solidification/Stabilization of Dredged Material
Resuspension at Dredge (Mechanical)	Operational Controls Operational Controls + Water Tight Bucket Operational Controls + Water Tight Bucket + Silt + Curtains

(Continued)

AD-A184 930 GUIDELINES FOR SELECTING CONTROL AND TREATMENT OPTIONS 5/8
FOR CONTAMINATED DREDGED MATERIAL(U) ARMY ENGINEER
WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR..
UNCLASSIFIED M J CULLINANE ET AL. SEP 86 F/G 24/3 NL

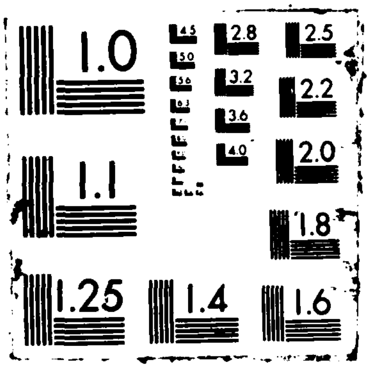

1.0
4.5
5.0
5.6
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Table 9.4 (Concluded)

Migration Pathway	Typical Alternative
Resuspension at Dredge (Hydraulic)	Operational Controls Operational Controls + Dredge Modifications Operational Contrast Dredge Modifications + Silt Curtains Special Purpose Dredges Special Purpose Dredges + Silt Curtains
Water Column or Benthic (Open Water Disposal)	Operational Controls Operational Controls + Downpipe Operational Controls + Downpipe + Diffuser Lateral Confinement Capping Lateral Confinement + Capping

The development of schemes that address the loss of contaminants to the water column at open-water disposal sites must consider both short- and long-term release of contaminants. Short-term releases are those that occur during placement operations and have an impact on the water column from the surface to the bottom. Long-term water column impacts result from the interface between the deposited dredged material and the overlying water column and continue long after dredging operations cease.

The development of schemes that address the impacts on the benthic community at open-water disposal sites also must consider both the short-term and long-term release of contaminants. Short-term releases are those occurring during placement operations whereas long-term impacts result after placement of the material and are handled by site controls.

Alternative Development. The preceding paragraphs addressed generic technology schemes and described how inappropriate measures can be eliminated based on the knowledge of potential contaminant pathways. Obviously this step cannot be completed without knowledge of where the technology schemes will be placed since one site may be very different from another. The two steps (selection of potential technologies and alternative development), therefore, must overlap to a certain extent. For example, when developing an alternative (applying a technology scheme to a potential site), Tables 9.2 and 9.3 are applicable.

The main function of the alternative development step is to apply technology schemes to different sites. For example, if runoff-runon controls, a cover, and a liner are considered appropriate for the contaminant, this technology scheme, when applied to all upland sites, would result in several possible alternatives, one for each upland site. At this point, however, the technology/site compatibility must be addressed. For example, if one or more upland sites has a natural underlying clay layer, installing a liner as part of a technology scheme may be unnecessary.

In short, the process of considering contamination pathways started in the technology selection step is continued and applied to a greater extent as technology schemes and sites are combined to form alternatives.

Screening of Alternatives. Once the list of candidate alternatives has been developed, it is necessary to narrow the list for further more detailed analysis. The screening process is designed to retain appropriate alternatives while eliminating clearly inferior ones, thus reducing the effort required for detailed analysis. The choice of possible alternatives is likely to be accomplished based on the knowledge of how well various technologies have performed under similar circumstances. Experience and judgement are likely to play as large a role in this process as scientific information. It is possible that only a few alternatives may remain before the screening process. In such a case, the analyst or decisionmaker may wish to bypass the screening, retaining all alternatives for a more detailed analysis.

Three different types of screening processes are available to the decision-maker, allowing some choice in how the screening step is accomplished. Figure 9.19 shows a flowchart for the selection of the type of screening process, including the option of bypassing the screening altogether. The first step in the flowchart is to decide whether to screen or not. This decision is most likely to be based on the number of alternatives available for evaluation. If there are only a few, it may be advantageous not to screen and retain all options for detailed evaluation. The second step is to decide whether screening should be based primarily on the cost criterion. If so, two options are available that require values for the cost criterion to be determined for all alternatives. Alternatives are then addressed according to increasing costs and the remaining criteria are determined as each alternative is considered. If the decisionmaker prefers not to start by ranking alternatives solely by cost, a third screening approach is possible. If the first or second screening options are preferred, the last decision concerns whether alternatives should be screened so that the process retains alternatives for each type of site. These three screening processes are described in greater detail below.

The first approach simply ranks alternatives according to cost. The basis for the approach is the tenet that a few of the lowest cost alternatives that satisfy the remaining criteria should be chosen, regardless of location. Figure 9.20 shows the flowchart for the approach. Once alternatives have been formulated, the cost for each is determined and all alternatives are ranked according to cost. Starting with the least-cost alternative, values for the remaining criteria are then determined. If the alternative is deemed acceptable based on the evaluation of the criteria, it is selected for detailed evaluation. If not, the next alternative from the ranked list is chosen and

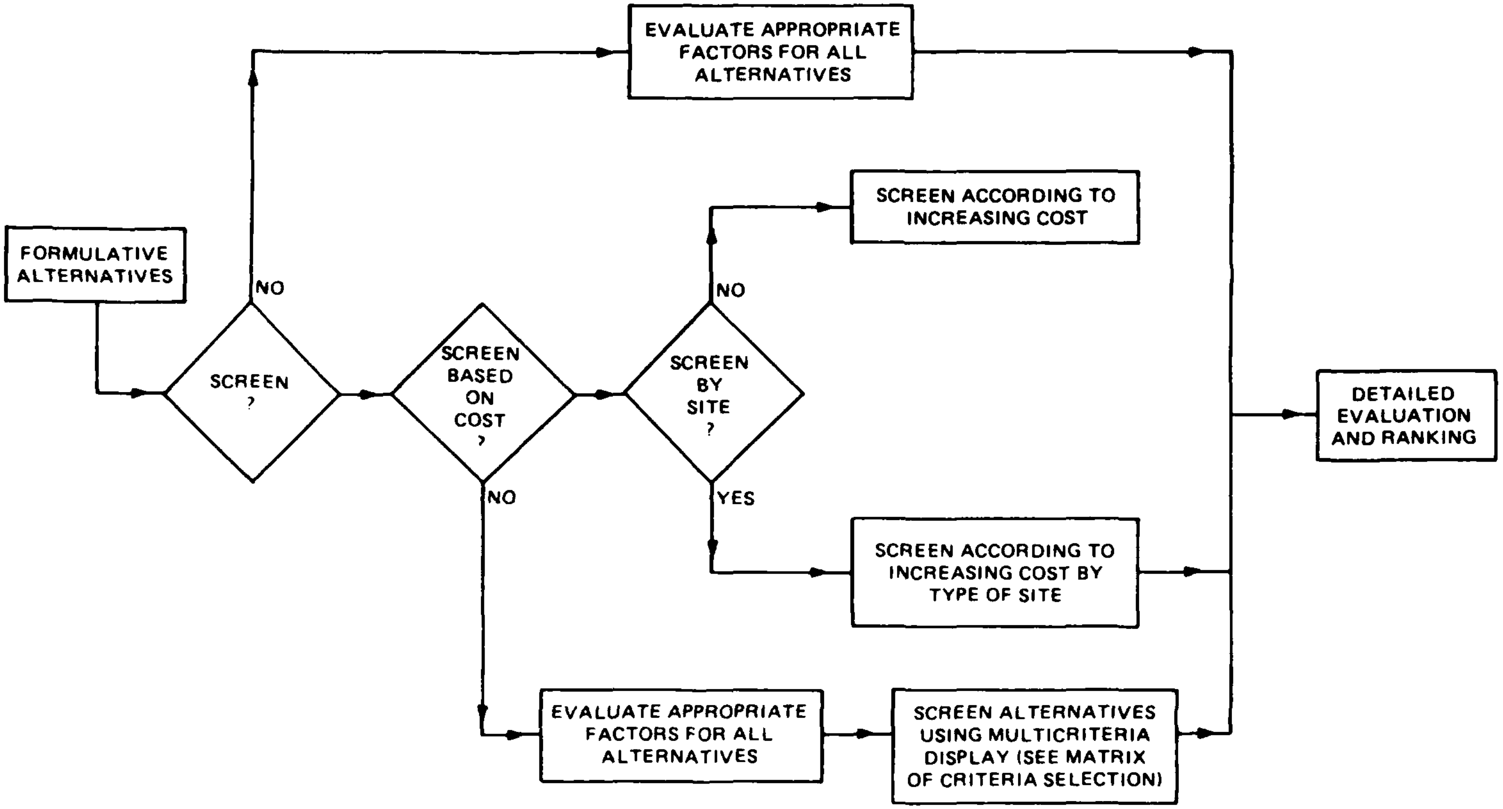


Figure 9.19. Overall flowchart for alternative screening

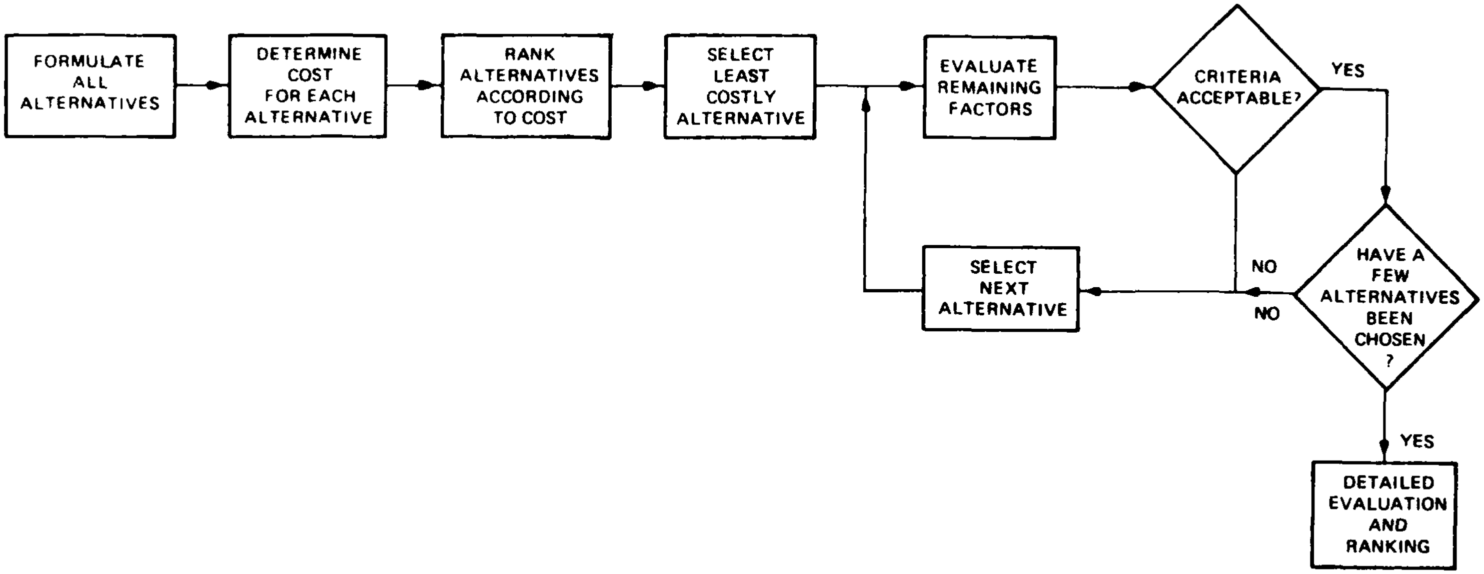


Figure 9.20. Flowchart for screening of alternatives by cost

the proc [illegible] is repeated until a few acceptable alternatives are found (in this context [illegible] few" is a number to be designated by the decisionmaker).

The second approach is a variation on the first. It allows decisionmakers to retain one or more alternatives at each type of site (aquatic, upland, and nearshore). The approach calls for sequential evaluation (based on cost) for each site type so that (presumably) not all alternatives need to be evaluated.

Figure 9.21 shows the flowchart for this approach. One type of site is chosen, and all alternatives are formulated for that site type. Costs are determined for each alternative and alternatives are ranked by cost. For the least costly alternative, the remaining criteria are evaluated and, if all are acceptable, the alternative is saved for detailed evaluation. If not, the next alternative on the ranked list is chosen. The process is repeated until a few acceptable alternatives are found.

The final approach also allows the decisionmakers to narrow the number of alternatives that must be fully evaluated before a decision is made. However, cost is not the dominant criterion. Once all alternatives are formulated, criteria values are assessed for each and the screening is based on values for all pertinent criteria. Alternatives can be evaluated using a matrix of criteria or a multicriteria display. These methods are discussed in detail later in this part of the report. A few good alternatives can be selected from the results of the screening process for further more detailed analysis.

Choosing among the three screening approaches is left to the analyst or decisionmaker. The first two approaches start with the lowest cost alternatives and stop once a specified number are found that satisfy minimum values for the other criteria. The only difference between the two is that the second approach ensures that each type of site is represented in the remaining list of alternatives. If the analyst/decisionmaker desires such a representation, the second approach should be chosen. A variation on the second approach is possible, where one or more alternatives are generated for each site. The steps in the approach would be the same except that the flowchart would be repeated for each site rather than each site type. If sites within a site type have appreciably different characteristics, the modified approach would be advantageous.

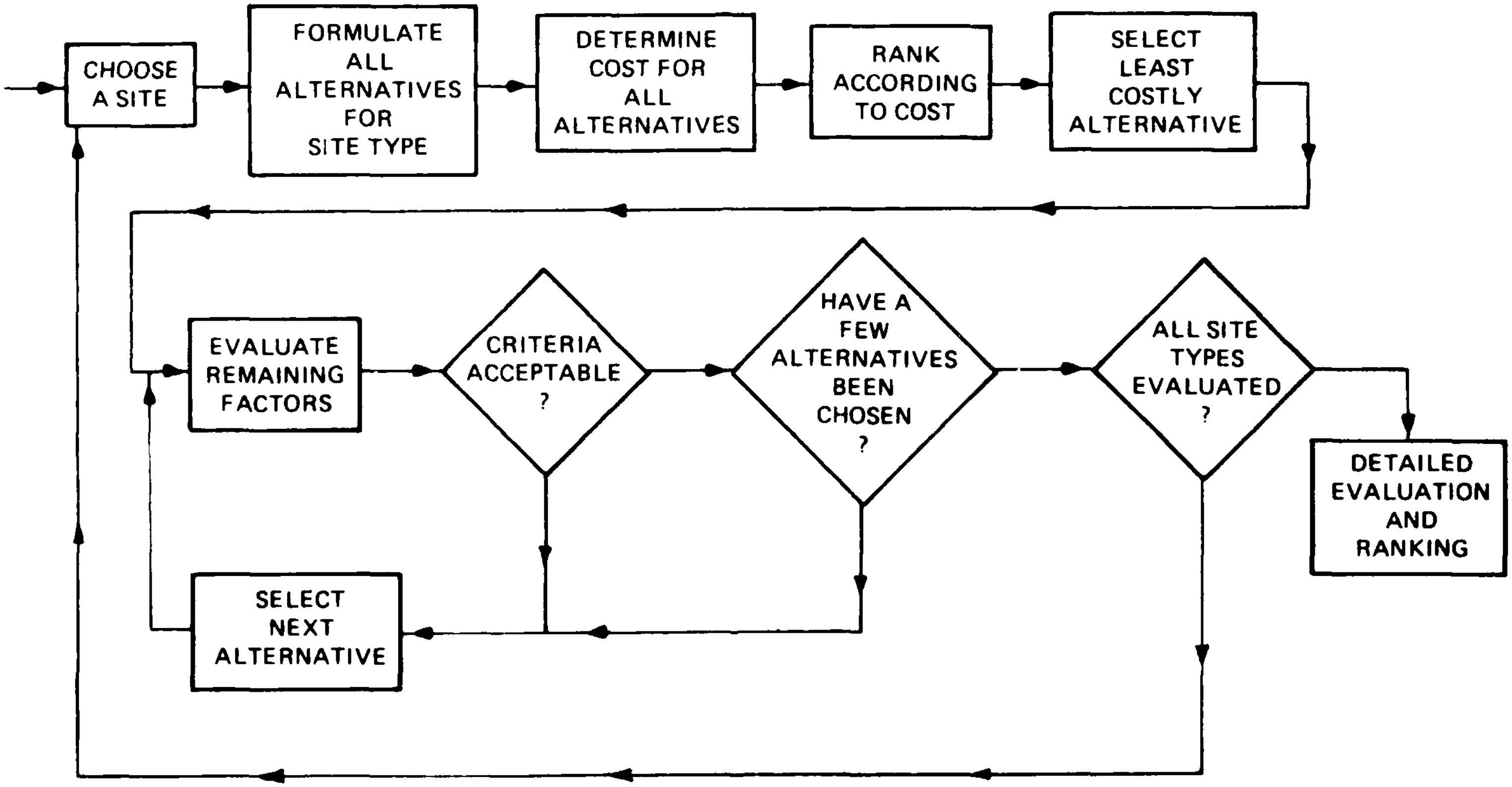


Figure 9.21. Flowchart for screening of alternatives categorized by type of site

Both of the first two approaches require that values for the cost criterion be determined for all alternatives (in order to rank the alternatives). However, determination of values for the other criteria is not necessarily required for all alternatives, since these criteria are evaluated at each step and only until the desired number of alternatives have been selected.

For the third approach, values for all criteria for all alternatives must be determined before the screening process. This shortcoming is balanced by the advantage of having assessed all alternatives. The approach may yield an alternative that is more expensive (and would not have been retained with either of the first two approaches) but is advantageous because it performs very well in terms of the other criteria. In other words, for a slightly greater cost, an alternative may have, for example, very minimal environmental impact.

Evaluating Screening Criteria. The process of screening is proposed by the National Contingency Plan (NCP). The NCP suggests that initial screening be performed on three criteria: environmental, public health, and costs. For actions involving the dredging/transportation/disposal of contaminated dredged material, screening should be accomplished on the bases of implementability, technical effectiveness, and costs.

The evaluation of the implementability criteria is designed to ensure that the proposed alternative is technically feasible, i.e., can be constructed and/or operated. Feasible alternatives are those that are within accepted engineering practice given site-specific conditions. If an alternative is technically feasible, it is considered an applicable and reliable means of addressing the problem. Evaluation of technical feasibility can also ensure, if desired, that only proven technologies be considered. Evaluation of the criterion can be used as the point at which the decision is made to attempt the use of demonstratable technologies rather than proven or demonstrated technologies.

If an alternative is technically feasible, the technical effectiveness of the alternative should be evaluated in terms of its capabilities relative to the objectives and performance requirement, (i.e., can the proposed alternative achieve the desired level of contaminant control?). If the alternative fails to meet the required contaminant-control criteria, the alternative should not be considered further. Technical effectiveness can be evaluated in terms of the criteria presented in the decisionmaking framework (Lee et al. 1985, Peddicord et al. 1986). Figures 9.22 through 9.30 present modified flow charts from the DMF (Lee et al. 1985) that can be used to make the evaluation of the technical effectiveness of alternatives.

The assessment of technical effectiveness of control/treatment alternatives is most often accomplished using best engineering judgement, usually using some qualitative approach. Laboratory and field data from other sites are often interpreted in light of site-specific conditions. In many cases, data must be extended beyond the conditions for which they were developed. The data on the performance of individual technologies must also be combined with the site data to define anticipated environmental impact. Mathematical models can be used to supplement engineering judgement and provide a quantitative assessment of site conditions and control/treatment technology technical effectiveness. The use of mathematical models to quantify effectiveness may provide more accuracy and confidence in decisions concerning the technical and cost effectiveness of control/treatment technologies.

The number and complexity of models available for evaluation of control/treatment options can be confusing when selecting an appropriate model. The planner must be familiar with the important site criteria and available models, which may range from simple analytical equation to complex numerical models. The USEPA faces a similar problem in evaluating hazardous waste remedial action performance and published an extensive guidance document on the selection of appropriate modeling strategies (USEPA 1985). Guidance is provided in the form of a series of flow charts and matrices leading to model selection.

The guidance provided includes: the type and level of model(s) needed to evaluate a control/treatment technology or group of technologies; the model dimensionality and grid configuration needed to represent site-control/treatment technology interaction; model parameter adjustment required to simulate the effect of implementing an action; control/treatment configurations and design objectives; and techniques and literature data useful in estimating model parameter values. Model application guidance is presented in terms of the general capabilities of different types of models, including sources of information on specific models; factors to consider when linking different

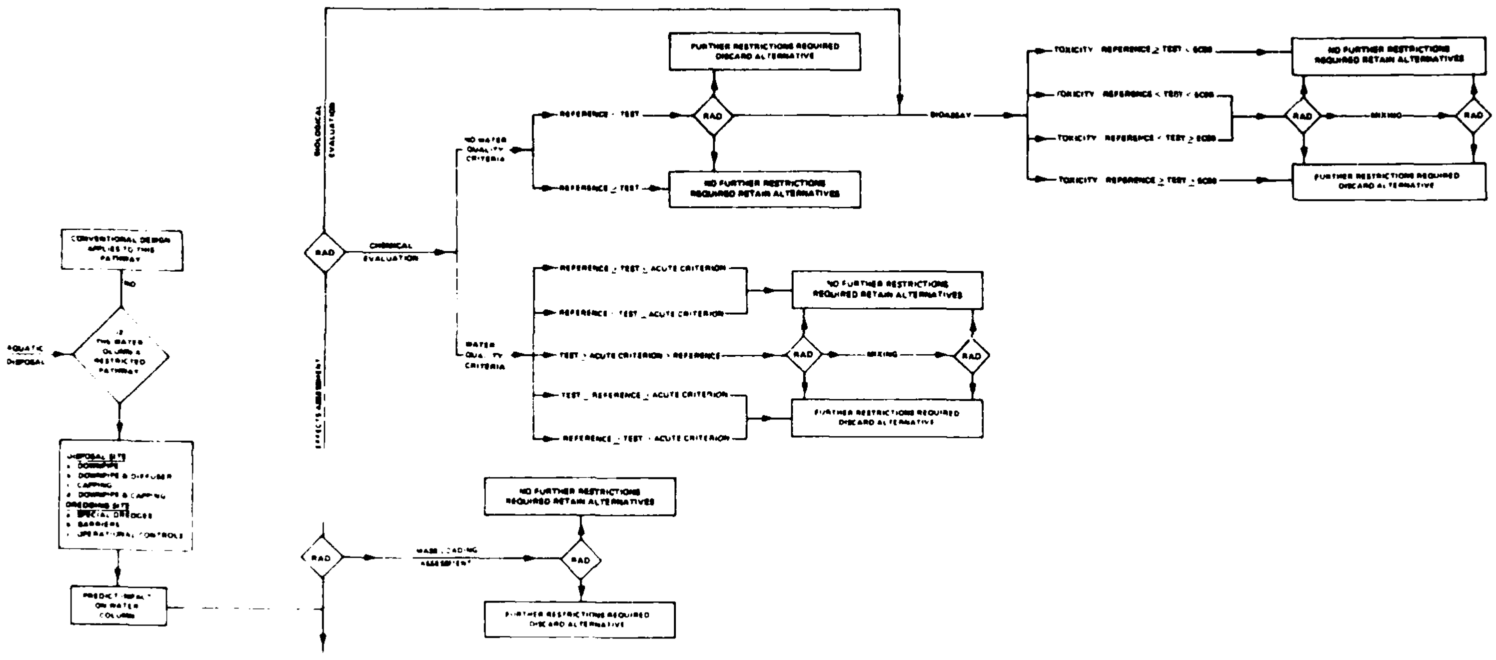


Figure 9.22. Modified flowchart for alternative selection for aquatic disposal water quality impacts

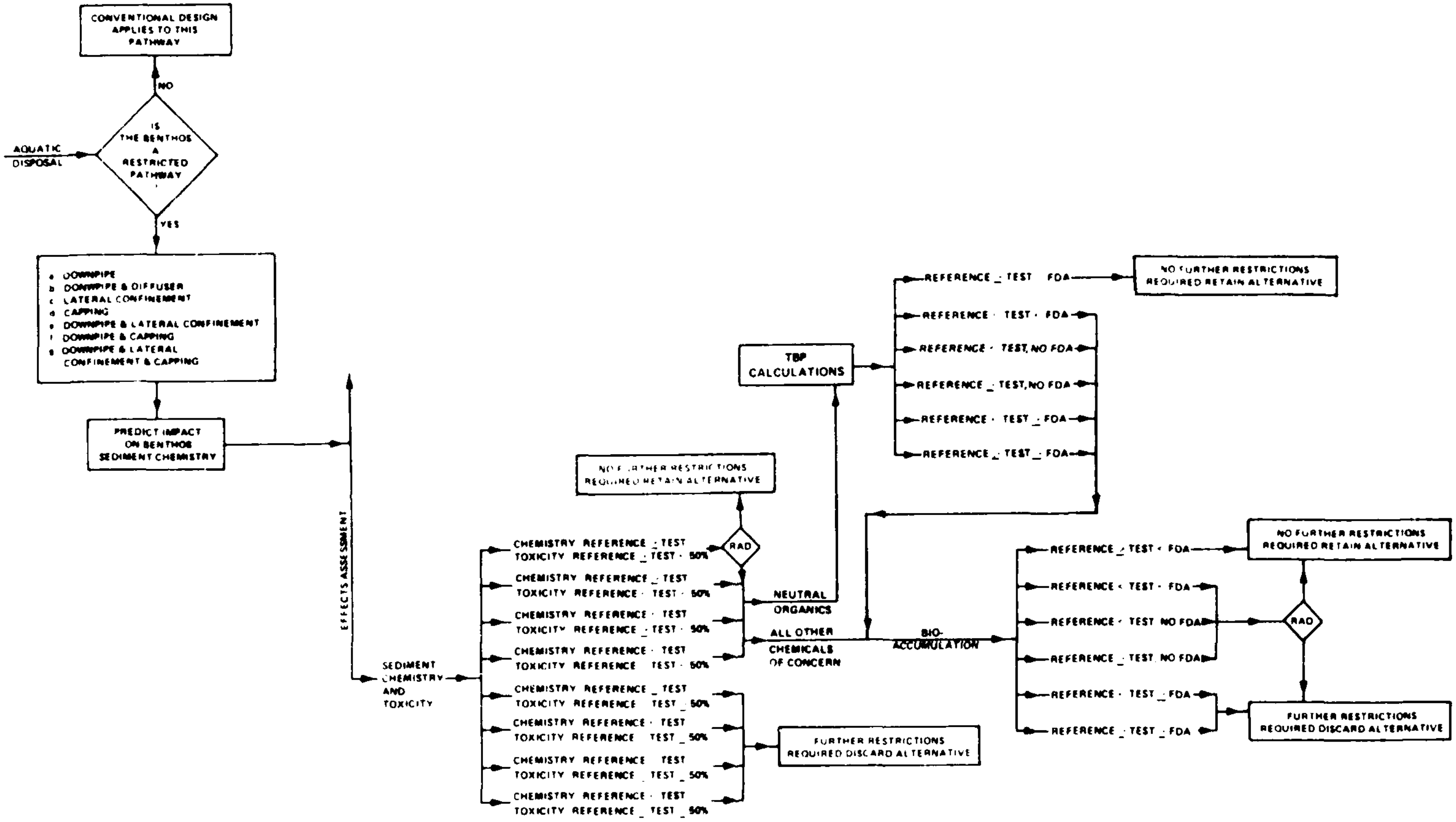


Figure 9.23. Modified flowchart for alternative selection for aquatic disposal benthic impacts

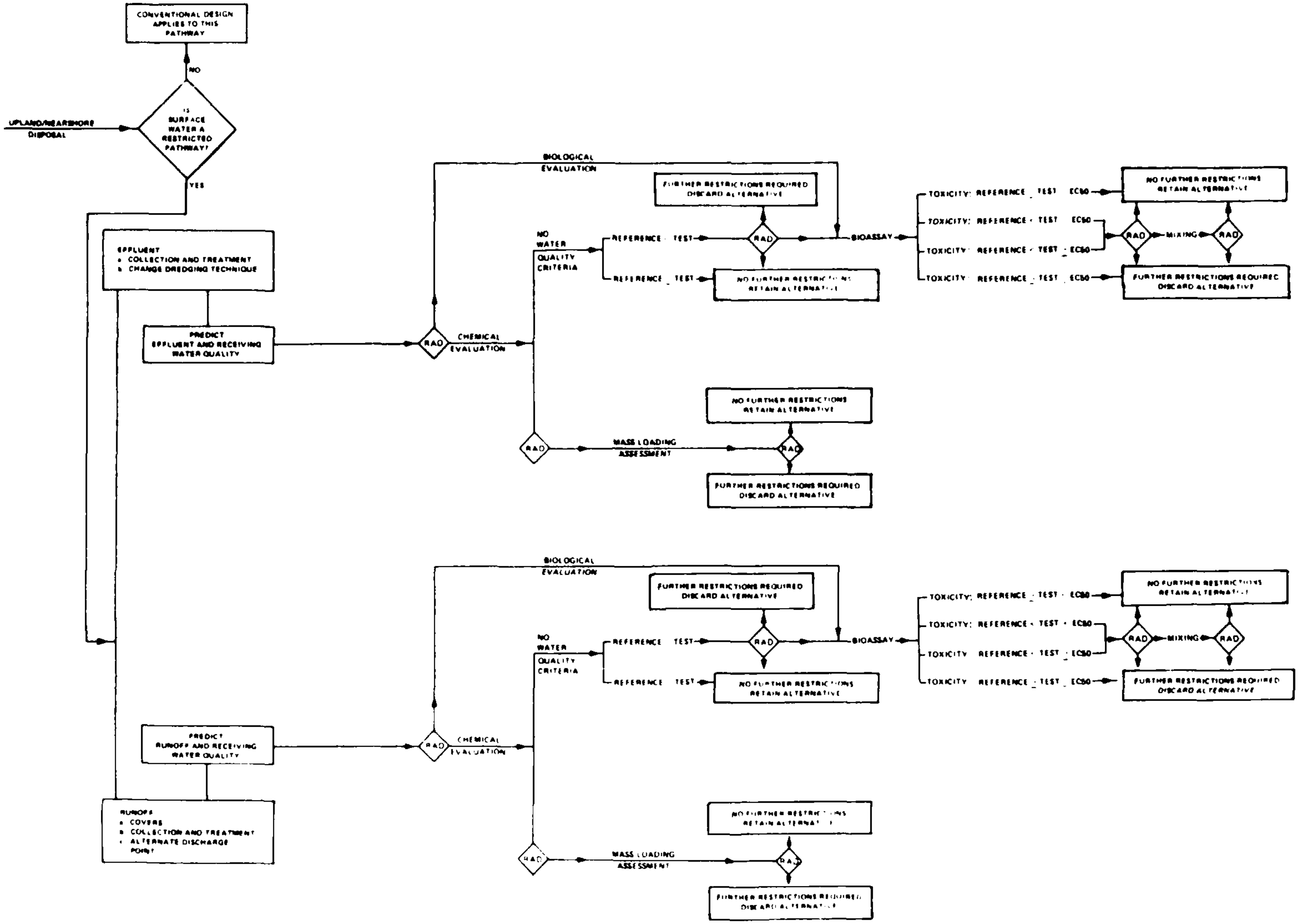


Figure 9.24. Modified flowchart for alternative selection for upland/nearshore disposal surface water pathway

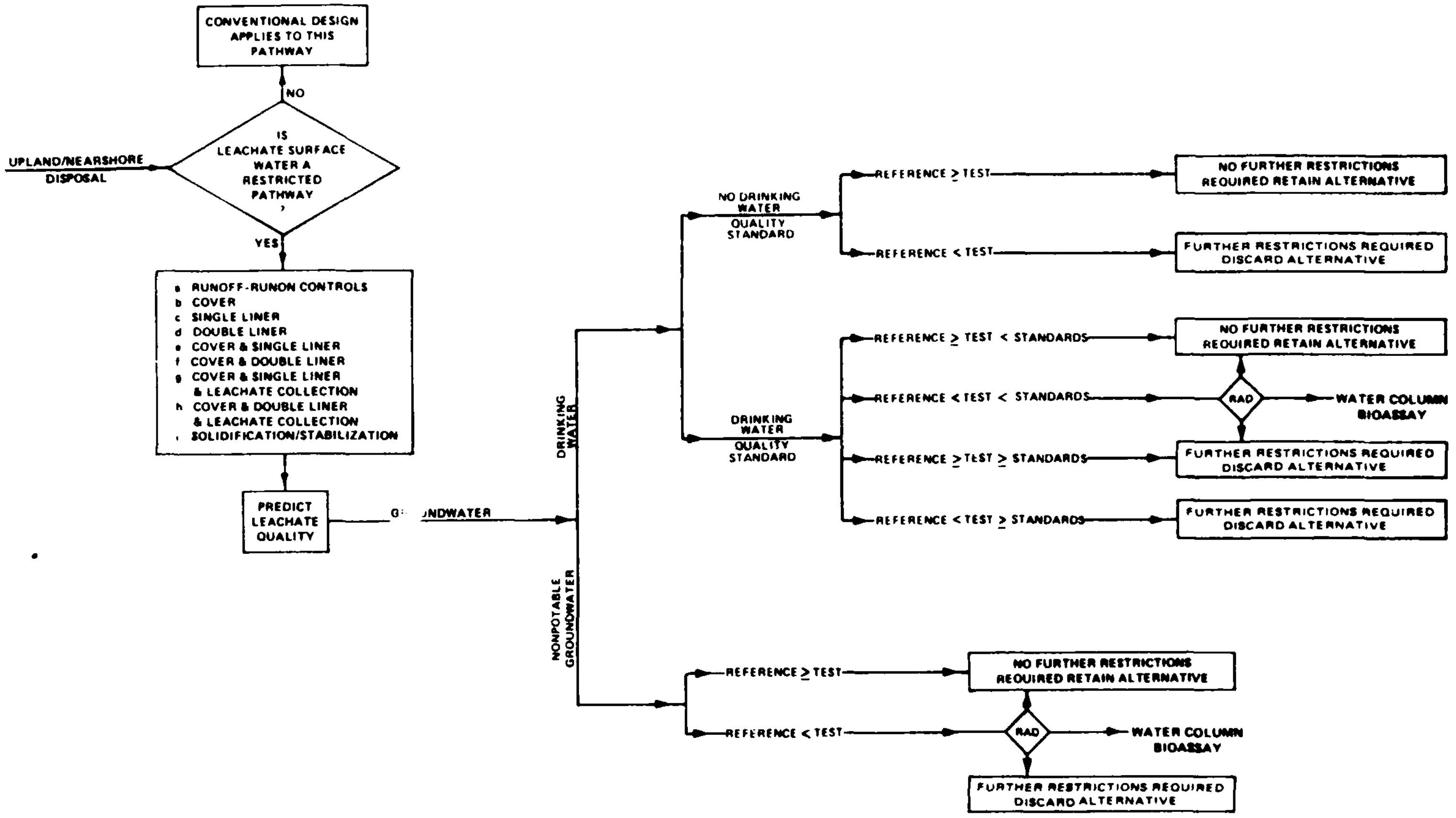


Figure 9.25. Modified flowchart for alternative selection for upland/nearshore disposal leachate-groundwater pathway

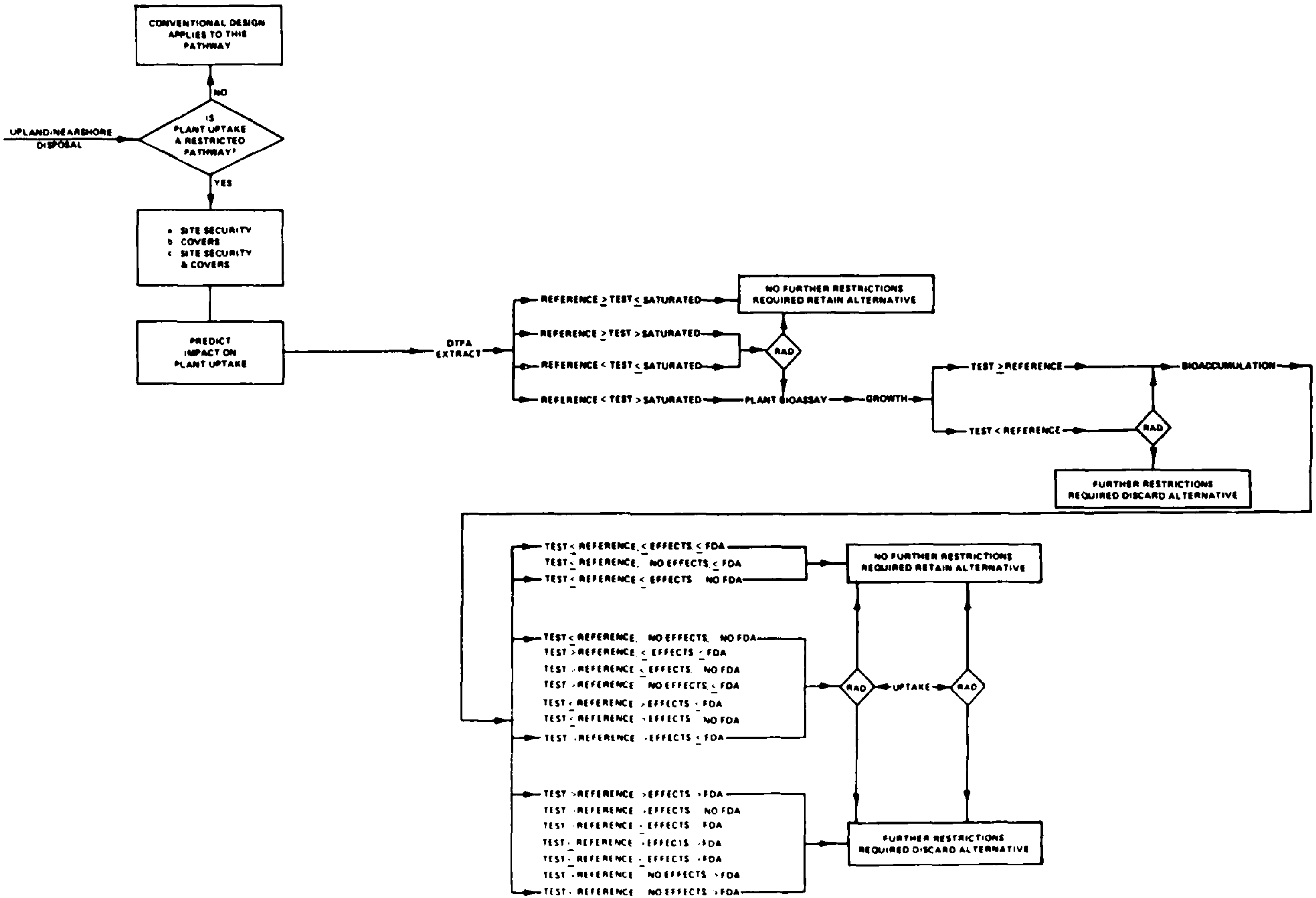


Figure 9.26. Modified flow-chart for alternative selection for upland/nearshore disposal plant uptake pathway

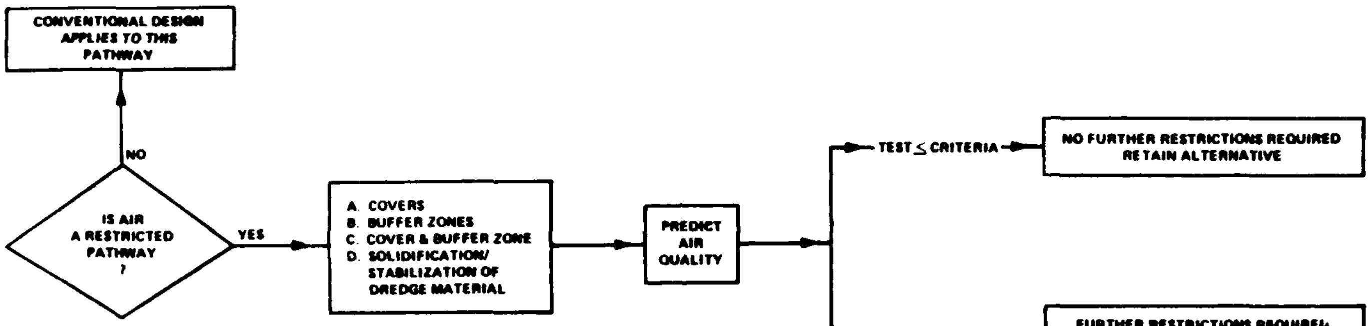


Figure 9.27. Modified flowchart for alternative selection for upland/nearshore disposal air pathway

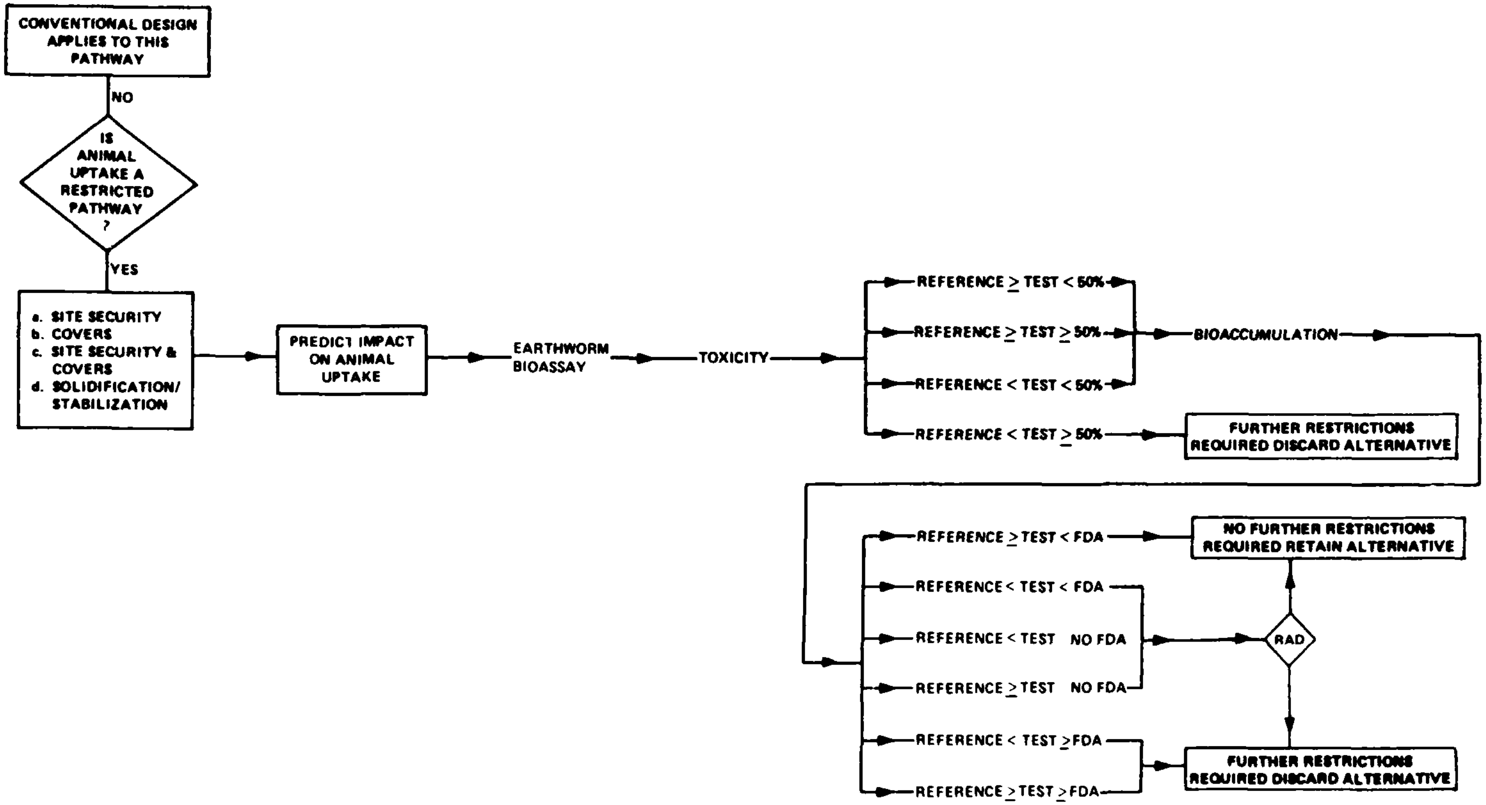
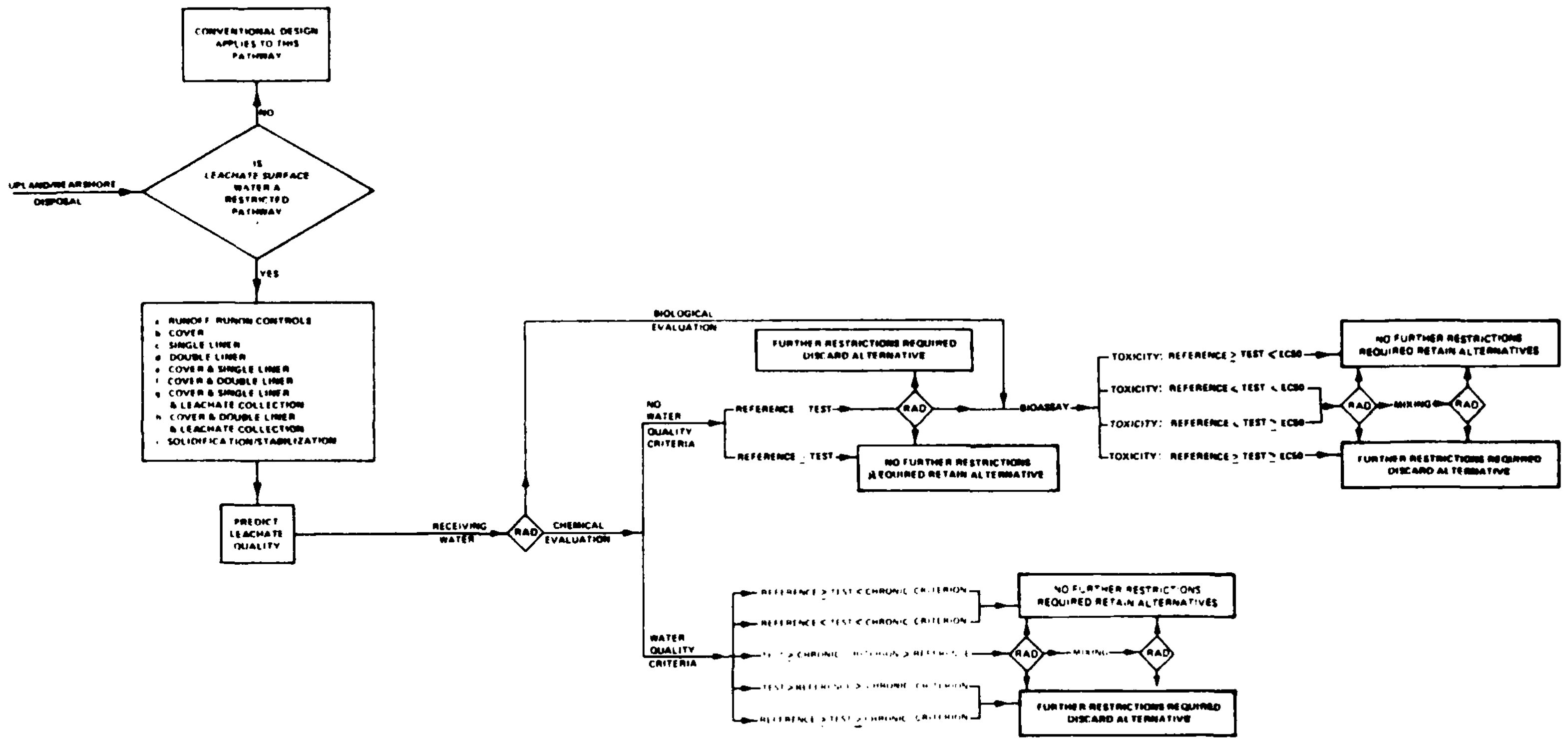


Figure 9.28. Modified flowchart for alternative selection for upland/nearshore disposal animal uptake pathway



Figures 9.29. Modified flowchart for alternative selection for upland/nearshore disposal leachate/surface-water pathway

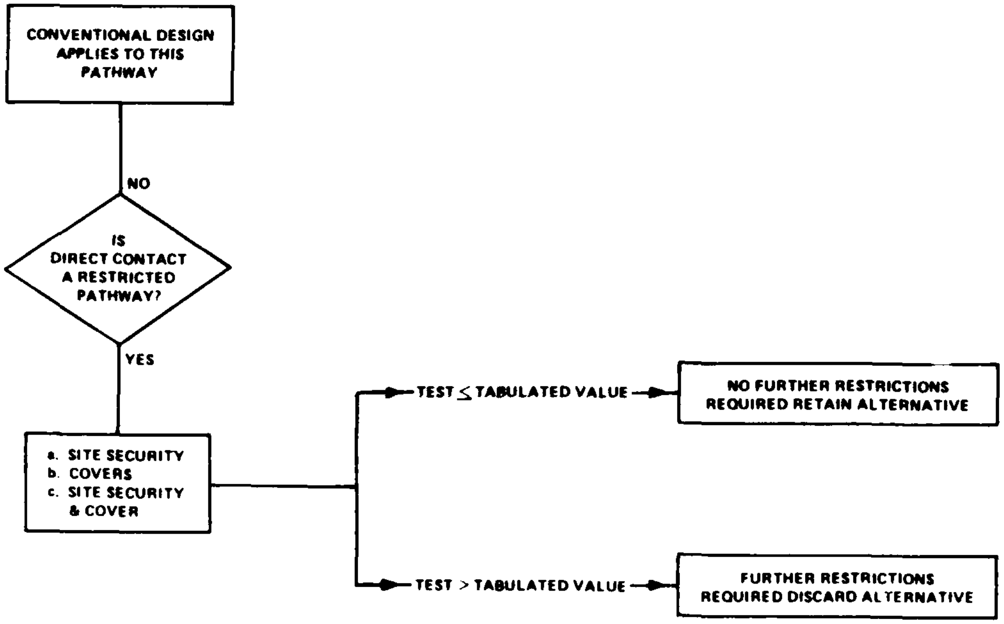


Figure 9.30. Modified flowchart for alternative selection for upland/nearshore disposal direct contact pathway

numerical models to assess complicated site conditions and control/treatment alternatives; the steps required in applying models for control/treatment alternative assessment; user expertise and resource requirements; alternative ways of analyzing control/treatment technology performance; and key assumptions and limitations affecting the use of specific models.

Another measure of technical effectiveness, in addition to those proposed in the DMF (Lee et al. 1985), is the concept of mass loss. These losses will occur in the short and long term through the sediment, water, and gas media. In most cases, the largest fraction of the contaminants will be bound to sediment, and the water will contain greater numbers and levels of contaminants than the gas. Since volatiles will rarely present a concern and since control of sediment particles is fairly well understood, the key to effective contaminant containment will be the type and amounts of soluble or easily-solubilized contaminants in the sediment.

Loss of contaminants during all three phases of dredging operations (dredging/transport/disposal) is inevitable. The interrelationship between the dredging/transport/disposal alternative and overall contaminant loss must be evaluated.

Because of project specific conditions, the importance of contaminant loss during any phase of operations will vary. For hydraulic dredging, the relative importance of losses at various times and from various phases during the sediment handling process is shown below, listed in order of decreasing importance.

a. Short-term loss of sediment and water.
b. Long-term loss of water.
c. Short-term loss of volatiles.
d. Long-term loss of volatiles.
e. Long-term loss of sediment.

For mechanical dredging, a and b may be equally important, as more easily solubilized contaminants are retained and available for possible long-term loss from the dredge material. For hydraulic dredging, disposal will normally result in greater short-term loss of sediment and water than will mechanical dredging. Mechanical dredging can result in greater loss at the dredging site than at the disposal site. Where treatment is not done or is not available, long-term loss of water can be more important in upland situations than short-term losses, due to the higher contaminant concentrations that are possible in the long-term discharges. For volatiles, short-term losses may be equivalent to long-term volatilization if in situ gas volumes are low. For open-water disposal, long-term sediment losses can be more important than losses of volatiles.

The influence of sediment contamination on dredging/transport/disposal decisions will be keyed to the relative magnitude of potential contaminant releases and to the potential impacts of these losses. Based on the above ranking of importance, short-term sediment and water loss during disposal will be the usual first consideration and the basis for selecting disposal method and treatment level. Concurrently, but on a secondary basis, the contribution of dredging to this loss should be evaluated. The next step should be selecting appropriate treatment, monitoring, and remedial response to address long-term loss of waterborne contaminants. Consideration of items c - e above would depend on sediment and site-specific conditions.

Operating characteristics of dredges have been discussed in Part II of this report. The important characteristics affecting the technical effectiveness of dredges in preventing contaminant loss are summarized in Table 9.5 (Phillips et al. 1985). Resuspension values, while representative to the extent that they fall within normal ranges for a given dredge, were derived from various sources with unique conditions. Therefore, these values have not been normalized and comparisons between dredging methods must acknowledge their variability. In terms of sediment resuspension at the dredge site, this table illustrates that special-purpose hydraulic dredges produce less resuspension than conventional hydraulic dredges; and, with the exception of hopper dredge overflow, conventional hydraulic dredges produce less resuspension than mechanical dredges.

In terms of slurry water that may require treatment at the disposal site, mechanical dredges do not produce a slurry; conventional hydraulic dredges produce abundant slurry water; and special-purpose dredges fall somewhere in between. In terms of cost, dredges are for the most part comparably priced. However, job-specific factors can produce substantial cost differences between dredge types. Many of the dredges listed in the table are readily available for use in Puget Sound. The notable exception is the group of special-purpose dredges for which availability could be a major cost factor to be considered.

Table 9.5

Summary of Dredge Operating Characteristics

	Percent Solids in Slurry or Transported Material by Weight*	Sediment Resuspension Above Background, mg/l**		Approximate Range of Production Rates	Dredging Depths ± ft		Vertical Dredging Accuracy	Vertical Dredging Accuracy	
		Near Bottom	Near Surface	c.y./hr	Minimum	Maximum	± ft	± ft	Availablity
Bucket	up to 100%	106	134	30-600	0†	150††	2	1	Pacific Coast
Suction	up to 15%	--	--	25-5,000	5-6	50-60‡	1	2-3	Pacific Coast
Dustpan	10-20%	--	00	25-5,000	5-14	50-60‡	1	2-3	Mississippi River
Cutterhad	10-20%	35	134	25-5,000	3-15	12-65	1	2-3	Pacific Coast
Hopper	10-20%	272‡‡	627	500-2,000	10-28	65‡	2	10	Pacific Coast
Mudcat	10-40%	145.	500	60-150	1	15	1	1	Pacific Coast
Pneuma	up to 80%	4	23	60-390	0†	150‡	1	1	Chicago, Illinois
Oozer	up to 80%	0	--	450,650	--	100-150	1	2-3	Japan
Clean-up	30-40%	2.6	13.5	200-1,300	20	60	1	2-3	Japan

NOTES:

- * Percent solids shown are normal working ranges.
- ** Resuspension values shown are considered representative. However, very wide ranges are reported.
- † Zero if used alongside of waterway; otherwise, draft of vessel will determine.
- †† Demonstrated depth; theoretically could be used much deeper
- ‡ With submerged dredge pumps, dredging depths have been increase to 100 ft or more.
- ‡‡ Value shown is average at 3 ft below surface.

Until recently, many of the special-purpose dredges have had lower production rates than conventional equipment. This is still true for several of these dredges, but newer equipment such as the Refresher and Oozer appear to have production rates comparable to conventional hydraulic dredges. For barge or hopper-hauled dredged material, production will vary depending on proximity of the disposal site, but it is usually less than what can be obtained by a continuously operating cutterhead dredge.

Hydraulic dredges produce less solids resuspension at the dredging site and have a higher removal efficiency for liquid and solid phases than do mechanical dredges. Hydraulic dredges with passive heads (e.g., suction, Pneuma, etc.) and shrouded heads (e.g., Refreshers, Mudcat, etc.) produce less resuspension than do exposed active heads (e.g., cutterhead). However, use of a hydraulic dredge to obtain high removal efficiency at the dredging site involves a tradeoff requiring consideration of slurry water and sediment consolidation at the disposal site.

Different dredging methods appear more appropriate for certain contaminant classes. For loss of volatile contaminants during dredging, mechanical dredges will likely perform better than hydraulic dredges. For sediment-bound contaminants, greater removal is obtained by hydraulic dredges than by mechanical dredges and appropriate technology exists for control of solids at the disposal end. Soluble contaminants can be removed more efficiently by a hydraulic dredge, but they are difficult to control at the disposal end and treatment of the effluent water may be required.

Most projects are likely to contain all three types of contamination, confounding a decision on appropriate dredging technique. In terms of overall contamination, sediment-bound contaminants usually represent the bulk of the contamination, suggesting use of hydraulic equipment for maximum recovery and extraction efficiency. The amount of volatiles that may be lost during dredging are not likely to be a source of major concern in many projects. Therefore, as the types and amount of soluble, or easily solubilized, contaminants increase in a sediment to be dredged, greater consideration should be given to the relative cost and environmental impact of mechanical dredging with watertight equipment to that of hydraulic dredging and water treatment at the disposal site. This evaluation is likely to be the key to selecting a dredge for a given contaminated sediment.

A variety of equipment modifications, discussed in Part II, are appropriate for dredging contaminated sediment. Many of the practices that increase production of a hydraulic dredge will also reduce sediment resuspension and contaminant loss. The walking spud and ladder pump are prime examples. Production meters installed in the pipe will contribute to reduced resuspension and are readily available and adaptable to existing equipment. Use of large, watertight buckets will substantially reduce sediment resuspension and loss of interstitial water during mechanical dredging.

Operational modifications to be considered for hydraulic cutterhead dredges include minimizing cutter-revolution speed, controlling swing speed, and not overdigging the maximum cut depth. Additional research is ongoing to quantify the effect of these practices. The problem of limiting the environmental impact of dredging contaminated sediment through reducing resuspension of sediment is being addressed by the WES of the Corps of Engineers under a research program known as the Improvement of Operation and Maintenance Techniques (IOMT) Program. For hopper dredges, operating in sandy silt or silty sand without overflow can have a significant impact on cost. Therefore, it may not be practical to use a hopper dredge for projects with high concentrations of soluble contaminants. For mechanical dredging, sweeping the bottom with the bucket and digging fine-grained sediment from underneath (heavy buckets penetrating through soft surface materials) are practices to be avoided in contaminated areas. During first-time use of modifications, such as operator controls or operational modifications, serious consideration should be given to hourly rental of dredging equipment. This approach, as opposed to bidding may help maintain control of project costs and better define cost factors.

Short-term losses of soluble contaminants represent the key in selecting dredge type. These losses can be estimated by assuming a slow rate of contaminant transfer between phases during dredging and using a modified elutriate test. For hydraulic dredging, test results are used to predict weir concentrations (total and dissolved) expected for a given site. Predicted values can be compared against decisionmaking criteria with or without consideration of dilution in the receiving waters. It is more difficult to predict losses for mechanical dredging. Bucket size, sediment characteristics, and other job-specific factors will influence the actual losses in the field. As a usual rule, within the options that are generally considered for large-volume dredging of sediments with low-level contaminants, hydraulic dredging with particulates control will likely provide greater confinement per given cost than will mechanical with watertight equipment for situations where a low percentage of the contamination is soluble. As the percentage of soluble contaminants increases, the confinement-per-cost indicator will begin to favor the mechanical approach.

However, when considering high-level contaminated sediment, the greater extraction and transport efficiency of hydraulic dredging is an important factor. Overall, the technology for addressing contaminated sediment is better known for hydraulic dredges than for mechanical dredges.

Selection of a dredge requires consideration of all the factors discussed in Part II and of the disposal and treatment options available. Several dredges may be able to meet criteria by employing one or many of the available dredging techniques. Therefore, identification of the criteria that are to be met is the first and most important task in selecting appropriate equipment.

Evaluation of disposal methods with the idea of defining the appropriate and most efficient means of confining contaminants in the long term is difficult. Contaminants gradually will move back into the environment from wherever they are placed. The factors that influence the speed with which they will release from the disposal site are the mobility of the contaminant, the phase with which the contaminant has associated itself in the sediment (gas, liquid, solid), and the physical/chemical environment into which the contaminant has been placed. Given that most projects will contain more than one class of contaminants, the evaluation becomes complex and variable.

The key considerations involved with disposal method effectiveness are:

a. The class of contaminants of concern.

b. The similarity of the disposal site conditions to in situ conditions.

c. The number and magnitude of transport mechanisms operating at the disposal site.

d. The degree of control or treatment possible to intercept migrating contaminant fractions.

e. The risk of significant adverse effects from contaminants released by the disposal method.

Table 9.6 provides the major evaluation factors pertinent to disposal methodology and rates the three general disposal methods against those factors.

It is important to know what classes of contaminants are associated with the sediment, what phase the contaminants are associated with in the sediment, and how they are partitioned between phases in situ in order to predict long-term mobility. In general, leaving or disposing of contaminated sediment in a chemical environment as close as possible to their in situ state favors contaminant retention (especially metals). However, placing the sediment into different or into shifting physical or chemical environments (upland and nearshore) will encourage some contaminants to move between phases. Geochemical changes associated with air and oxygen in these disposal sites can change sediment pH (mobilizing metals) and alter sediment organic carbon (mobilizing organics). For organic contaminants, the influence of these geochemical changes on contaminant mobility may be outweighed by the effect of water exchange occurring at the site. It is also important to note that while contaminant mobility and release can serve to define disposal method effectiveness, release of contaminants will have different environmental effects in different disposal sites (i.e., greater mobility at one site may be less damaging than lesser mobility at another site).

Transport mechanisms have been identified and explained in the DMF (Lee et al. 1985) for the several disposal methods and designs. Open-water sites, especially those in deep water, have fewer mechanisms (air is absent) than upland sites. Nearshore sites have the most transport routes available and are located in a very active environment; therefore, nearshore disposal is the least preferred method from a contaminant confinement point of view.

In general, contaminants bound tightly to sediment are the easiest to handle and contain. Disposal method considerations involve maximizing containment of solids within the disposal site. Upland and nearshore disposal offers the greatest potential for retaining dredged material, whether hydraulically or mechanically dredged. Open-water disposal, because of depth and currents, allows some fraction of the disposed material to escape. Since the material that would normally escape is fine grained and more typically associated with chemical contaminants, open-water disposal is less efficient at accepting discharges of contaminated sediments. There are other considerations, however. Aerobic and unsaturated conditions favor release of heavy

Table 9.6

Comparison of Disposal Method Contaminant Containment

Disposal Method	Geochemical Effect on Contaminant Mobilization	Magnitude of Contaminant Transport Mechanisms	Available Control/ Treatment Options	Environmental Risks From Contaminant Release
Open-water, capped	Low	Diffusion: high Convection: medium Bioturbation: varies Erosion: medium	Few	Low due to dilution (resource risk)
Upland, confined	High	Diffusion: low Convection: low Volatilization: high Bioturbation: varies Erosion: low	Many	Varies by contaminant (human health risk)
Nearshore, confined	High in unsaturated zone; medium in saturated zone	Diffusion: high Convection: high Volatilization: high Bioturbation: varies Erosion: low	Some	Medium (human health & resource risks)

metals from sediment surfaces into solution. Sediment placed in upland and in the unsaturated nearshore disposal sites would be subjected to chemical stresses (oxidation, pH decrease, activation of other compounds) due to the less stable (in the long term) environment. Contaminant fractions would release as gas or into solution and migrate along seeps or leach into ground water. For heavy metals, disposal in open water eliminates the conditions favoring release and aids retention. However, contaminated sediment rarely contains only heavy metals. Though many of the organic contaminants found in Commencement Bay are relatively hydrophobic and have high sorption coefficients, there is no known way to keep organics bound to the sediment, and all are somewhat soluble. Placing these compounds in saturated conditions with high water exchange greatly favors contaminant mobility. In these terms, the nearshore has greater water exchange than the upland, and upland has greater exchange than open water.

Volatile contaminant fractions may be lost during dredging or be released only under unsaturated conditions. The key to the mobility of volatiles is the extent of surface area and length of time exposed to air. Material that has been hydraulically dredged will probably have lost all in situ gases by the time it is placed in the disposal site. Slurry placed into an open-water site may still contain a small percentage of entrained gases that will release until the site is capped; mechanically dredged material will still retain most of its in situ gases. Once capped, the stable saturated conditions underwater will result in losses of volatiles about an order of magnitude less than the other disposal methods due to less air exchange. Sediments placed in upland disposal sites will drain, and volatilization will occur. Disposal in nearshore environment will result in greater release from the unsaturated layer than the saturated layer. Mechanically dredged material that requires rehandling (for transport to or within the disposal site) will tend to lose volatiles more readily than slurried sediments or than sediments that are not rehandled. Over longer periods of time, in situ gases will likely build up in the sediment and provide a mechanism for loss of volatiles. This loss is not likely to be a source of major concern for most projects.

Soluble contaminants, or contaminants with the greatest potential to go into solution under certain conditions, are of more concern because these are less readily contained. Soluble contaminants in situ at the time of disposal will be lost if hydraulically discharged in open water or may require treatment as effluent from upland or nearshore confined sites. In the effluent, these contaminants will be diluted by the volume of new water slurried. Mechanically dredged sediment would retain more interstitial water and there would be less quantity to treat, although contaminant concentrations would be higher. In the longer term, contaminated sediment placed in open water will lose its soluble fraction to diffusion and convection; although this release will be gradual due to the reduced magnitude of transport mechanisms. Material placed in upland disposal sites also will tend to release its soluble fractions over time. Due to the more active physical processes (precipitation, ground-water infiltration, etc.) and the unstable chemical environment, this release will be more rapid than in open water; however, it also will be more concentrated and easily intercepted. The near-shore environment is the most active, having all of the transport mechanisms of the uplands and the addition of much more active water exchange than in the open water due to tidal activity.

Therefore, in terms of contaminant retention, disposal method selection is more a matter of controlled release than total confinement. Control of the releases and/or concern with the effects of the release must be considered. Beyond designation of the type of cap or liner thickness, open-water disposal allows for very limited control of releases. This retards contaminant mobility and encourages a constant gradual release to the overlying water body once the cap has been saturated by the migrating contaminants. The levels of contaminant concentration released will be low and will be diluted by the overlying water. The risk of significant damage in this environment is low and would not likely affect human health. Upland disposal, on the other hand, allows for the greatest control, through design considerations, monitoring capabilities, backup contaminant intercept systems, and treatment facilities. Environmental risks incurred may be higher than in open water because of potential human health concerns. The nearshore disposal option does allow for some greater control of contaminants than in open water, but many fewer than are available in an upland situation. In addition, the risks to the environment and to human health are much greater than in open water and, in most situations, are greater than at an upland site. Looking ahead to development of criteria for appropriate disposal methods, the interplay of site control and contaminant mobility suggests, as a generalization, that nearshore sites should receive the low-level contamination, open-water sites the low- to medium-level contamination, and upland sites the high-level contamination.

If an alternative survives the noncost screening criteria, a preliminary cost screening is performed. The object of cost screening is to eliminate alternatives that have significantly higher costs, but that do not provide significantly greater environmental benefits or reliability. Although guidance varies on the cutoff to be used, typical criteria call for the elimination of those alternatives with costs an order of magnitude greater than other alternatives providing essentially the same environmental benefits or reliability.

In preparing the cost estimates for screening, certain limiting factors should be considered to control the level of effort expended in compiling the estimates. These factors include accessibility of data sources, the time available, and the acceptable degree of accuracy. Where possible, costs should be based on standard cost-guidance references. In many cases, particularly for emerging technologies, accurate costs will be difficult to develop. The time for preparing the screening cost estimates should be limited to a few days. The objective in calculating the screening level costs is an accuracy within -50 to + 100 percent (USEPA 1985).

Costs include capital, operating, and maintenance costs. Capital costs should include the following:

a. Relocation costs.
b. Costs of land acquisition or obtaining permanent easements.
c. Land and site-development costs.
d. Cost of buildings and services.
e. Equipment costs.
f. Replacement costs.
g. Disposal costs.
h. Engineering expenses.
i. Construction expenses.
j. State and local legal fees, licenses, and permit costs.
k. Contingency allowances.
l. Startup and shake-down costs.
m. Costs of anticipated health and safety requirements during construction.

Operation, maintenance, and monitoring costs include:

a. Operating labor costs.

b. Maintenance materials and labor costs.

c. Costs of auxiliary materials and energy.

d. Purchased service costs.

e. Administrative costs.

f. Insurance, taxes, and licensing costs.

g. Maintenance reserve and contingency fund.

The costs of dredging/transportation/disposal of contaminated sediment is extremely variable and depends on a number of site-specific factors. Phillips et al. (1985) identified the cost factors in a checklist which is presented in Table 9.7.

Of the three phases of a dredging operation, the unit cost of dredging is probably the most variable. For example, the cost of mobilizing a dredge will vary with equipment availability and will be amortized into the quantity of material being dredged. As the distance between the disposal site and dredging location increases, the requirement for additional barges, pipeline booster pumps, or hopper downtime will affect cost. Production rates (which can vary greatly for different equipment, physical sediment characteristics, and site conditions) also will affect cost. However, the traditional considerations of production rates and cost must be considered in reference to the objective of efficient removal of contaminants. In some cases, operational conditions that maximize production rates will also improve contaminant confinement (e.g., high solids concentrations for pipeline dredging). In other cases, improved production will result in greater contaminant loss (e.g., hopper-dredge overflow). Table 9.8 summarizes typical costs for various types of dredging.

The dredges themselves are for the most part comparably priced and do not account for most of the cost variability. However, job-specific factors can produce substantial cost differences between dredge types. Many of the dredges described are readily available for use in Puget Sound. The notable exception is the group of special-purpose dredges for which availability could be a major cost factor to be considered.

Hydraulic pipeline cutterhead dredges generally have the widest range of application of dredge types and are usually also among the least expensive to

Table 9.7

Cost Factors Checklist

Dredging

- Dredge type and equipment modifications
- Equipment mobilization and demobilization
- Transport distance and vertical lift
- Transport method
- Production rate
- Operational modifications

Disposal

- Site acquisition
- Site information needs
- Site preparation
- Discharge controls (weirs, vertical diffuser)

Control and Treatment

- Flow rate
- Level and type of treatment
- Treatment end-products management (e.g., sludge disposal)

Monitoring

- Types of monitoring
- Frequency of monitoring
- Duration of monitoring
- Remedial response to monitoring indications

Table 9.8

Typical Dredge Characteristics and Costs*

	Size or Capacity	Production Rate, cu yd/hr	Cost Per Cubic Yard, $
Cutterhead**	6	71	5.00
	8	79	4.50
	10	225	4.00
Pipeline diameter, in.	12	405	3.50
	14	525	2.15
	16	656	1.80
	20	1,024	1.50
	24	1,211	1.35
	30	1,875	1.20
Hopper†			
Hopper capacity, cu yd	3,000 with overflow	1,200	1.39
	3,000 without overflow (if nec.)	600	3.03
Bucket††			
Bucket size, cu yd	5	200	2.50
	15	650	1.60
Suction	-	25-5,000	1.50
Dustpan	-	25-5,000	1.50
Mudcat	-	60-150	1.50
Pneuma	-	60-390	1.05-3.05
Oozer	-	450-650	
Clean-Up	-	500-2,000	1.23

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* Values shown are representative for Commencement Bay for the cutterhead, hopper, and bucket dredges. Values for other dredges were derived by relation to conventional equipment. Variability may exceed ± a factor of 2-3.

** Mobilization costs not included. Price based upon 1-mile transport distance, 20-ft lift, soft sandy silt material, 1983 pricing, and maximum single-pass excavation depth.

† Based upon 35 cu yd/minute pumping, 8 knots average dredge speed, 5 minutes for disposal, silty sand shoaled materials, 80 percent effective working time, 3 miles distance to disposal site, and cost of dredge operation at $1,300/hr.

†† Based upon dredging silty sand with disposal site at a 3-mile transport distance, and 1983 prices.

operate. Their widespread use and availability is an important cost factor. There are many cutterhead dredges available in the Northwest. Conventional cutterhead dredges are not self-propelled and require towboats to move them between dredging locations. Thus, mobilization and setup are major and costly undertakings. A large dredge can cost between $150,000 and $200,000 to mobilize and demobilize. Large- to medium-sized pipeline dredges should only be considered for use on projects where quantities to be dredged are sufficient to spread mobilization costs.

The costs per cubic yard for the suction and dustpan dredges are comparable to those for cutterhead pipeline dredges as is shown in Table 9.8. Since all dustpan dredges are located on the Mississippi River at this time, relocation of any of these dredges would be an important cost factor.

Operational costs for hopper dredges range from $700/per hour to over $2,000/per hour. Table 9.8 shows cost and production rates for a hopper dredge working in a Commencement Bay waterway and disposing at the existing DNR open-water disposal site. Since hopper dredges are self-propelled, mobilization and demobilization costs are usually not a significant factor in their use.

Very little information exists on the cost of using special-purpose dredges, either due to lack of experience or to the proprietary nature of these machines. Typically, these dredges are used in relation to material requiring some degree of special handling and predisposal treatment. In these cases, treatment and disposal would represent the bulk of the cost and would be the cost controlling factors, not the dredging. Available cost information usually does not make the distinction between dredging and treatment costs. Modifications of conventional equipment (such as the Clean-up or Refresher dredges), once installed and without considering developmental maintenance costs, would move material at a cost proportional to production rate obtained and comparable to conventional equipment. The Pneuma pump, on certain smaller jobs such as berth cleaning, has been shown to be more cost effective than a cutterhead dredge.

The bucket dredge typically operates at speeds of 30 to 60 buckets per hour. Larger buckets generally resuspend less material per cubic yard removed and are most cost effective. Table 9.8 compares cost, production rates, and dredging depths for medium and large bucket dredges. These dredges are abundantly available in the Pacific Northwest; consequently mobilization costs are not a significant cost factor.

Phillips et al. (1985) presented an excellent discussion of the costs associated with various disposal options. This discussion is briefly summarized below.

The costs of contaminated dredged material depends on three major factors: site acquisition, site preparation, and control/treatment requirements. Each of these is highly site-specific and general cost information is not readily available. Phillips et al. (1985) developed site-preparation costs for five upland and eight nearshore disposal sites (Table 9.9) and costs for several site control alternatives (Table 9.10). In addition to these costs, the treatment of liquid wastes must also be considered. Tables 9.11 and 9.12 present data for cost associated with various levels of treatment for 30- and 80-acre upland disposal sites, respectively (Phillips et al. 1985).

The selected disposal method will have less influence on cost than will the specific disposal site, i.e., the key to cost evaluation of disposal is not necessarily the method (open-water, nearshore, or upland), but the location of the particular disposal site and the site preparation needs it might require. Open-water disposal, for which there are normally no acquisition costs, may have a total cost comparable to the other methods due to site preparation costs (if needed), capping volumes necessary (resulting in increased dredging volumes and, hence, total cost), and the greater difficulty in monitoring. Site preparation costs for the other two methods are roughly similar, although they can vary widely based on specific site conditions.

Open-water disposal costs are normally relatively low for uncontaminated materials. For contaminated material, costs will increase depending upon the selected methods of site preparation and material placement, and upon measures taken to control contaminant release, such as capping and cap thickness. The use of an underwater diffuser increases open-water disposal cost. The construction or acquisition cost of an underwater diffuser is estimated to be between $50,000 and $100,000; however, no commercial firms are manufacturing diffusers at this time. A crane and barge would be required to operate the diffuser, and this would increase disposal costs by an additional $.50 per cu yd to $.75 per cu yd. If materials from a barge or hopper dredge are reslurried and pumped through the diffuser, cost would increase an additional $.75 to $1.25 per cu yd. For smaller or one-time dredging projects, it is

Table 9.9

Disposal Site-Preparation Costs*

Location	Capacity 10^3 cu yd	Dike and Weir Costs	Preparation Cost per Cubic Yard, $
Upland Sites			
Puyallup Mitigation	1000	185	0.19
Port of Tacoma "D"	100/1550**	62/275**	0.62/0.18
Puyallup River/Railroad	1300/3300**	505/1675**	0.39/0.51
Port of Tacoma "E"	1700	250	0.15
Hylebos Creek Nos. 1 & 2	775/1775**	264/1000**	0.34/0.56
Nearshore Sites			
Middle Waterway	650	303	0.47
Milwaukee Waterway	2160	925	0.43
Blair Waterway Outer Slip	892	788	0.88
Blair Waterway Middle Slip	945	412	0.44
Blair Waterway Inner Slip	600	341	0.57
Blair Graving Dock	200	90	0.45
Hylebos Waterway No. 1	1274	615	0.48
Hylebos Waterway No. 2	300	295	0.98

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* Site-acquisition costs not included.

** +20 ft MLLW/+35 ft MLLW.

Table 9.10

Cost of Disposal and Site Control Alternatives For Contaminated Sediments*

Activity	Cost**
Disposal	
Site preparation	
- upland/nearshore	$500,000†
Weir Construction	
- upland	$25,000
- nearshore	$35,000
Diking - imported materials	$4 cu yd
- onsite materials	$1 cu yd
Open-water vertical diffuser	
- construction	$50,000 - $100,000
- operation	+$1-2 cu yd
Offsite material transport	
- truck	+$.20 cu yd/mi
- barge	+$.20-.25 cu yd/mi
Site Control	
Open-water capping material	$1.40/cu yd
Liners - soil (volume)	$16.29-18.29/cu yd
- soil (area)	$1.81-2.03/ft^2
Surface covers	$1.27-24.20/yd^2
Underdrains	$2,500/ac
Sediment Stabilization	
- lime	$10,000-14,000/ac
- dust pallatives	$1,000-17,000/ac
- water sprinkling	$2,000/ac

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* Treatment costs not included because of their dependence on flow rates.

** U.S. dollars, January 1984.

† Average for potential sites identified in Commencement Bay. Includes diking and weir costs.

Table 9.11

Treatment Level Versus Cost for an 80-Acre Upland Disposal Site*

Cost Component	Cost, $1,000			
	Construction	4-Month O&M	Unit Process	Cumulative Total
Dredging 1,000,000 cu yd			1,500	1,500
Level I				
Plain Sedimentation	15,762	50	15,812	17,312
Chemical Clarification	213	220	434	17,746
Filtration				
Option 1 - Pervious Dike	75	5	80	17,826
Option 2 - Sandfill Weir	86	20	106	17,852
LEVEL II				(Assume Option 2 in Level I)
Precipitation	869	464	1,333	19,815
LEVEL III				
Carbon Adsorption - Option 1	5,000	495	5,495	24,680
Ozonation - Option 2	1,600	300	1,900	26,580**
LEVEL IV				(Assume Option 2 in Level III)
Distillation	47,850	4,452	52,302	78,882
Electrodialysis	24,850	827	25,677	52,257
Reverse Osmosis	28,850	598	29,448	56,028
Ion Exchange	21,350	987	22,337	48,917

* Costs for site control and treatment at an upland site cannot be directly compared to costs for a nearshore site; treatment levels contain different site control options.

** LEVEL III - Total cost includes Option 1 Carbon Adsorption plus Option 2 Ozonation.

Table 9.12

Treatment Level Versus Cost for a 30-Acre Upland Disposal Site*

Cost Component	Cost, $1,000 Construction	4-Month O&M	Unit Process	Cumulative Total
Dredging 1,000,000 cu yd			1,500	1,500
Level I				
Plain Sedimentation	5,880	50	5,930	7,430
Chemical Clarification	214	220	434	7,864
Filtration				
Option 1 - Pervious Dike	75	5	80	7,944
Option 2 - Sandfill Weir	86	20	106	7,970
LEVEL II				(Assume Option 2 in Level I)
Precipitation	869	464	1,333	9,300
LEVEL III				
Carbon Adsorption - Option 1	5,000	495	5,495	14,800
Ozonation - Option 2	1,600	300	1,900	16,700**
LEVEL IV				(Assume Option 2 in Level III)
Distillation	47,850	4,452	52,300	69,000
Electrodialysis	24,850	827	25,700	42,400
Reverse Osmosis	28,850	598	29,450	46,150
Ion Exchange	21,350	987	22,300	39,000

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* Costs for site control and treatment at an upland site cannot be directly compared to costs for a nearshore site; treatment levels contain different site control options.

** LEVEL III - Total cost includes Option 1 Carbon Adsorption plus Option 2 Ozonation.

roughly estimated that the use of the diffuser would increase the disposal cost of cutterhead pipeline dredged materials $1 per cu yd and increase the cost of hopper dredged or clamshell dredged material over $2 per cu yd. For larger projects, these costs can be expected to be somewhat less.

The costs of capping contaminated material discharged at an open-water disposal site will either be an additional cost (if the cap material is being dredged solely to provide a source of cap material) or part of the overall dredging cost (if the cap material is part of the required dredging).

Unconfined mounding of contaminated sediments generates a relatively large surface area to be covered. Assuming disposal of 100,000 cu yd of contaminated material, it is estimated that the cap volume to provide 3 feet of cover would range between three and five times the disposal volume. A volume of four times was selected (400,000 cu yd) to be placed by hopper dredge bottom dump. With a cost of capping material (dredging, transport, and discharge) estimated at $1.50 per cu yd, the total cost for this cap would be $600,000.

Confining the contaminated material by burial in a depression (possibly with partial underwater diking) results in less surface area requiring cover and allows the use of a vertical pipeline diffuser. For the same 100,000 cu yd disposal, only an additional 100,000 cu yd of clean material was assumed to provide adequate cover. Use of a cutterhead pipeline dredge at a base cost of $1.50 per cu yd, and adding to this the increased cost of the diffuser system at $1 per cu yd, capping costs would be $250,000. Use of a vertical pipe allows construction of underwater diking at a cost comparable to capping (about $2.50 per cu yd). Diking may totally encircle the site or be in combination with existing natural features (e.g., rock outcrop). This design is more expensive than deep-water mounding due to site preparation but may be easier to cap.

Cost of upland disposal will vary according to specific site characteristics. Factors include ownership of the site, amount of site preparation necessary, distance from the dredge site (may include transportation method), and, for the disposal of contaminated materials, the amount of treatment and monitoring required both during and after disposal and capping.

Where existing ground elevation is higher because of previous fills, the existing surface material may be utilized for diking. Use of existing materials would reduce the cost of diking to approximately $1 per cu yd. While coarser fill materials are easier to use for diking, finer soils that can be included in diking will reduce leakage of effluent water through the dike. An associated cost, though one not included in our analyses, involves the ultimate use of the land filled. If disposal can be designed to ultimately allow development to occur, at least some of the initial costs of disposal may be recoverable. This is not possible for open-water disposal.

The cost factors for confined disposal sites are described under upland disposal. Costs for nearshore disposal site preparation are normally higher than for upland as an adequate foundation for dikes and the weir must be provided. For the weir alone, additional cost was estimated at about $10,000 for a total estimate of $35,000. The primary cost advantage of nearshore disposal over open-water or upland disposal is that nearshore sites are normally located close to the dredging site(s), saving transportation costs. Additionally, most nearshore sites are ultimately planned to be developed so some cost recovery can be anticipated.

After developing the cost data for each alternative, these data must be reduced to either present worth or equivalent annual cost to enable direct comparison. This analysis should be based on the OMB prescribed discount rate, currently 10 percent. However, a sensitivity analysis using alternate discount rates may be desirable.

The screening process yields a set of alternatives that are of sufficient value to warrant detailed evaluation. Ideally, the set of initial alternatives will be ranked in accordance with their relative merits.

Phase IV: Detailed Evaluation and Ranking

The evaluation of alternatives involves a determination of criteria for each alternative and a systematic comparison of alternatives so that a decision can be made. The relative effort put into determination of values for the criteria for each alternative will depend on the emphasis or relative weighting given the criteria. Nine evaluation criteria have been proposed and were discussed previously. Only two of these criteria can easily be given quantitative values; initial cost and operation and maintenance cost can be valued in terms of dollars (either present or annual value). The remaining criteria need to be valued qualitatively to provide some sort of relative ranking of different alternatives. Going one step further, quantitative values for each criterion can be assigned, corresponding to the qualitative descriptions. As an example of how such an approach can be used, Table 9.13 presents rankings for the qualitative criteria. The operation and maintenance criterion is also include in Table 9.13 since it has aspects that are difficult to quantify, such as operator skills, etc. Tables 9.14 and 9.15 provide guidance on the application of these criteria values to the proven and demonstrable technologies, respectively, discussed in Parts II through VI of this report. It should be emphasized that the values in Table 9.14 and 9.15 are presented for guidance and may not be appropriate in all cases.

In most cases some alternatives will score higher with certain criteria and lower with others. Criteria for other alternatives might have rankings that are just the opposite, resulting in a tradeoff among criteria as the range of possible alternatives is considered. For example, four alternatives might provide four different levels of environmental protection with the most protective being the most expensive and with each more lenient alternative being progressively cheaper. If cost and environmental protection are weighted equally as criteria, a choice needs to be made among the alternatives.

The usual approach is to establish a minimum standard for a criterion, such as environmental impact, and choose the cheapest alternative that is environmentally acceptable. A similar approach can be taken for each of the other qualitative criteria; however, this process might be ineffectual, given the qualitative nature of the criteria. One approach for reducing the number of comparisons is presented later in this section.

Summing Weighted Criteria. For those criteria that can only be given qualitative number values (all those but cost and O&M), it is possible to combine the values to get one overall rank. If equal weight is assigned to each of the seven criteria, the individual criteria values are simply summed. The resulting number, called a composite qualitative criterion, represents the value of the alternative measure based on the seven qualitative criteria.

When decisionmakers place different weights on one or more of the nine criteria, a weighted summation would represent the overall value.

A similar approach can be taken for the two cost criteria, using traditional engineering economic analysis. The present value of annual operation and maintenance cost can be determined, using an appropriate interest rate and period of analysis, and added to construction cost.

Table 9.13

Example Numerical Ranks and Ranking Descriptions for Qualitative Criteria

Criterion	Rank	Rank Description
Reliability	4	Highly reliable
	3	Moderately reliable
	2	Minimally reliable
	1	Not reliable
Implementability and availability	4	Easy to implement
	3	Possible to implement
	2	Moderate difficulties in implementation
	1	Substantial difficulties in implementation
Technical effectiveness	4	Very effective
	3	Moderately effective
	2	Minimally effective
	1	Not effective
Environmental concerns	4	No anticipated environmental Impacts
	3	Minimal environmental impacts
	2	Moderate environmental impacts
	1	Substantial environmental impacts
Safety	4	No anticipated safety risks
	3	Minimal safety risks
	2	Moderate safety risks
	1	Substantial safety risks
Operation and maintenance	4	Extensive operation and maintenance
	3	Moderate operation and maintenance
	2	Minimal operation and maintenance
	1	No operation and maintenance

(Continued)

Table 9.13 (Concluded)

Criterion	Rank	Rank Description
Regulatory requirements	4	Easy to gain regulatory approval
	3	Possible to gain regulatory approval
	2	Moderate difficulties in gaining approval
	1	Substantial difficulties in gaining approval
Public acceptance	4	No anticipated public resistance
	3	Minimal anticipated public resistance
	2	Moderate anticipated public resistance
	1	Substantial anticipated public resistance

Table 9.14

Rating Factors for Proven Technologies

Proven Technology	Reliability	Implementability and Availability	Technical Effectiveness	Environmental Concerns	Safety	Operation and Maintenance	Cost	Regulatory Requirements	Public Acceptance
Dredging									
Mechanical dredges	3	3	3	3	3	3	2	3	3
Hydraulic dredges	3	3	3	2	3	3	4	2	2
Operational controls	3	3	3	3	4	4	4	3	3
Silt curtains	3	2	3	3	4	2	3	2	3
Other barriers (dikes, weirs, sheet piles)	2	3	3	3	3	3	3	2	2
Transport									
Hopper dredges	3	2	3	3	3	3	2	3	3
Specialized barges	4	2	3	3	3	3	2	3	3
Pipeline controls	2	3	2	2	2	2	3	2	2
Pump controls	3	3	2	3	3	3	3	3	3
Route/navigation controls	3	4	4	3	3	4	4	4	4
Loading/unloading controls	3	3	3	3	3	3	3	3	3
Truck transport controls	3	3	3	3	3	3	3	3	3
Rail transport controls	3	3	3	3	3	3	3	3	3
Disposal (Upland)									
Covers (natural)	3	3	3	3	4	4	4	4	4
dikes and berms	3	3	3	4	4	3	3	4	4
Grading	3	3	3	3	3	3	4	3	3
Revegetation	2	3	3	3	4	3	4	4	4
Channels and waterways	3	3	3	4	4	3	3	4	4
Chutes and downpipes	3	3	3	4	4	3	3	4	4
Terraces and benches	3	3	3	4	4	3	3	4	4

Table 9.14 (Concluded)

Proven Technology	Reliability	Implementability and Availability	Technical Effectiveness	Environmental Concerns	Safety	Operation and Maintenance	Cost	Regulatory Requirements	Public Acceptance
Sedimentation ponds	2	3	2	2	4	4	3	3	3
Liners (Natural)	3	3	3	3	3	2	1	3	3
Subsurface drains	3	3	3	3	3	2	2	3	3
Groundwater pumping	2	3	2	2	3	3	3	2	2
Slurry walls	3	3	3	3	3	2	2	3	3
Sheet piling	3	4	3	3	3	4	3	2	2
Leachate collection and removal	3	3	3	3	3	2	2	3	3
Site security	3	4	4	4	4	4	4	3	3
(Open Water)									
Capping (sprinkling)	2	2	2	3	3	2	3	2	2
Lateral confinement	2	2	3	2	3	4	3	3	3
Slurry Treatment									
Settling basins	3	3	3	3	4	4	4	3	3
Stationary screens and sieves	3	3	3	4	4	4	4	3	3
Moving screens	3	3	3	4	4	4	4	3	3
Hydraulic classifiers	2	2	2	3	3	3	2	2	2
Spiral classifiers	2	2	2	3	3	3	2	2	2

Table 9.15

Rating Factors for Demonstrable Technologies

Proven Technology	Reliability	Implementability and Availability	Technical Effectiveness	Environmental Concerns	Safety	Operation and Maintenance	Cost	Regulatory Requirements	Public Acceptance
Dredging									
Foreign dredges	3	1	2	2	3	3	1	2	2
Special purpose dredges	2	1	2	3	3	2	2	2	2
Operational controls	2	3	2	2	3	3	4	2	2
Other barriers (dikes, weirs, sheet piles)	2	3	3	3	3	3	3	2	2
Transport									
Specialized barges	2	1	2	3	3	2	2	2	2
Hopper dredges	3	2	3	3	3	3	2	3	3
Disposal (Upland)									
Covers (synthetic, floating)	2	3	3	3	3	2	2	3	3
Surface sediment stabilization	3	3	3	3	3	3	4	4	4
Liners (synthetic)	3	3	3	3	3	2	1	3	3
Slurry walls	3	3	3	3	3	2	2	3	2
Grouting	2	2	2	2	2	2	2	2	3
(Open water)									
Submerged diffuser	2	2	3	3	3	3	2	2	2
Gravity-fed downpipe	2	2	3	3	3	3	2	2	2
Hopper dredge pumpdown	2	2	3	3	3	3	2	2	2
Solidification/ stabilization	1	1	2	1	3	2	1	1	1

Table 9.15 (Concluded)

Proven Technology	Reliability	Implementability and Availability	Technical Effectiveness	Environmental Concerns	Safety	Operation and Maintenance	Cost	Regulatory Requirements	Public Acceptance
Slurry Treatment									
Cyclones and hydrocyclones	3	2	3	3	3	3	2	3	3
Solidification/ stabilization	2	2	2	2	3	3	1	1	1
Chemical destruction	2	1	2	1	2	2	1	1	1
Incineration	2	1	2	1	2	2	1	1	1

<u>Matrix of Criteria</u>. A straight-forward representation of the relative merits of several alternatives is possible using a matrix with each cell in the matrix representing a value rating for each alternative row and criterion (column of the matrix). Table 9.16 presents a matrix showing several alternatives with hypothetical values for the criteria and, for the qualitative criteria, using the numerical values described in Table 9.13. The matrix allows easy comparison among various alternatives, but does not necessarily aid in choosing one alternative over another. On the basis of the presentation, however, it is easy to eliminate alternatives that have particularly low values for one or more of the criteria. For example, a decisionmaker may arbitrarily rule out any alternative that has more than one criterion value of one. Using such a policy, alternatives 8, 11, and 12 from Table 9.16 would immediately be dropped from further consideration.

The composite criteria described in the previous section (composite cost criterion and composite qualitative criterion) can also be included in the matrix format if deemed appropriate. Values for the composite criteria for the 14 alternatives shown in Table 9.16 are illustrated in Table 9.17. Equal weights were assigned to the seven qualitative criteria for their computation. For the economic determination, an analysis period of infinity and an interest rate of 10 percent were used.

One way to assess the relative merits of different alternatives is to plot composite criterion values on a two-dimensional plot. Figure 9.31 illustrates the multicriteria display, showing values of cost on the vertical axis and values for the composite qualitative criterion (assuming equal weights) on the horizontal axis. Each point on the diagram represents an alternative taken from Table 9.17. Note that for each axis we desire to move away from the origin, values increase for the composite qualitative criterion and values decrease for the composite cost criterion.

Two aspects of this type of display are apparent: (1) some alternatives are inferior to others; and (2) it is impossible to differentiate among some alternatives without knowing the relative weighting of the two composite criteria. Using the numbered alternatives from the figure, examples for both aspects can be shown. Alternatives 1, 4, 6, 7, 8, 12, 13 and 14 are all inferior to alternative 10 since, for alternative 10, both criteria have better values. Likewise, alternative 12 is inferior to alternative 2. It is impossible, however, to say whether alternative 5 is inferior to alternative 10.

Table 9.16

Example Criterion Value Matrix

	Criterion								
Alter-native	Relia-bility	Implemen. & Avail.	Technical Effect.	Environ. Concerns	Safety	Operation & Maint.	Cost	Regulat. Req.	Public Accept.
1	4	2	3	2	2	$.2M	$20M	3	3
2	1	2	2	2	3	.05	5	2	2
3	2	3	3	3	3	.1	11	3	1
4	4	3	3	2	2	.3	18	2	3
5	3	2	3	4	3	.2	25	2	4
6	2	1	3	3	3	.04	30	2	2
7	3	2	2	2	2	.1	25	4	3
8	2	1	3	4	3	.2	17	1	2
9	4	2	3	2	4	.05	30	3	3
10	2	4	4	3	2	.2	15	2	3
11	1	3	2	1	1	.02	2	2	1
12	1	2	1	1	3	.2	8	3	1
13	2	3	3	2	2	.1	20	3	3
14	3	1	3	3	2	.2	24	2	3

Table 9.17

Example Composite Criteria Table

Alternative	Composite Cost Criterion $M	Composite Qualitative Criterion
1	22	16
2	5.5	14
3	12	18
4	21	19
5	27	21
6	30.4	16
7	26	18
8	19	16
9	30.5	21
10	17	20
11	2.2	11
12	10	12
13	21	18
14	26	17

Alternative 5 has a higher composite qualitative criterion, yet it is more expensive. In Fig. 9.31 there are six such alternatives (11, 2, 3, 10, 5, and 9), referred to as noninferior alternatives. A decisionmaker, however, is likely to focus on alternatives 3 and 10 since these alternatives seem to have a relatively good value for both composite criteria. This process allows one or more decisionmakers to concentrate on favorable alternatives (in this case, 3 and 10) and screen out unfavorable alternatives (the remaining 12).

It should be emphasized that this process is not meant to provide a final analysis. It is meant to narrow the choice of alternatives based on the two composite criteria. The composite criteria are a simplification of several complicated factors and may not sufficiently represent the relative values of various alternatives. Therefore, to choose the apparent best alternative on the basis of the multicriteria display might be illadvised without looking at all of the criterion values for those good alternatives (i.e., those that survive the cut for further scrutiny). In Fig. 9.31, alternatives 3, 4, 10, and 13 are likely good alternatives. Even though alternatives 4 and 13 appear

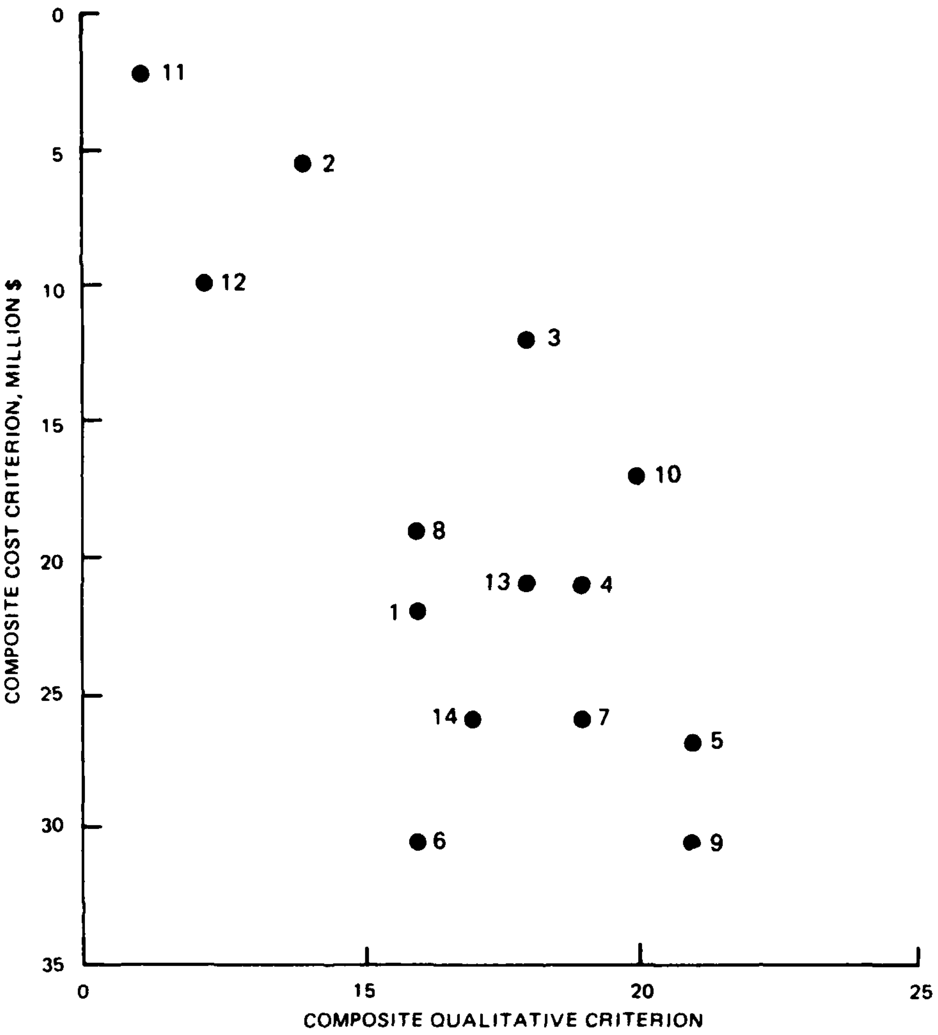

Figure 9.31. Multicriteria display of cost criteria and composite qualitative criteria

inferior on the plot, when individual criterion values are considered, they may appear in a better light. In addition, aspects of each alternative other than those described by the criteria (e.g., political considerations) may influence the final choice.

Ranking Alternatives. The possibility of ranking alternatives should be approached cautiously, with the realization that an exact ranked ordering is probably impossible. This caution about the use of a detailed ranking results from the fact that: (1) several assumptions were made in the process leading to the final evaluation; (2) in some cases, very little is actually known about the ultimate performance of alternatives (in terms of the various criteria); (3) tradeoffs exist among the various alternatives; and (4) different people will weigh the criteria differently. When considering these points, it should be obvious that rankings could easily change if, for example, the reliability of a technology were improperly assessed or the weighting of criteria were changed slightly. This fact, however, does not negate the process nor does it eliminate its usefulness. It simply says that, when using results of the process, an understanding of the vulnerability of the results is necessary. The best way to ensure this desire is to have the final decision made by the person or people who have followed through the process from beginning to end. Rarely, however, does the person who makes the final decision have a detailed knowledge of the steps taken and decisions made that lead to a final set of alternatives. One way of emphasizing the point to the decisionmaker is not to provide a ranking. Instead, groupings of alternatives (very good, good, fair, etc.) would emphasize the fact that there are uncertainties in the process. Another approach is to present alternatives in terms of a multicriteria display, as is shown in Fig. 9.31. If a ranked list of alternatives is presented, it should be noted that the ordering can only be relied upon in terms of the general location of an alternative in the list. In other words if an alternative is ranked fourth of 20, it represents a relatively good choice and could probably be ranked anywhere from first to tenth if slightly different assumptions were made.

Phase V: Alternative Selection

The framework presented in this chapter is not meant to be a substitute for a person or group of people who are responsible for making decisions. It does not make decisions, but assists in the descisionmaking process by narrowing the number of choices and presenting information in a logical and easily understood format. How the choices are narrowed depends in part on the decisionmaking sequence chosen by the analyst. It is important that decisionmakers understand the process that is followed since selection of the final alternative may be affected by the decisionmaking sequence chosen.

In many cases, selection of an alternative is a group decision, often with each member of the group emphasizing different factors. When a decision is a group effort (and often open to public scrutiny), it is best to have a process that conveys as much information as possible about the relative merits of the alternatives being considered for selection.

Testing and Regional Administrative Decisions

Implementation of the DMASS requires extensive testing and analyses as well as both administrative and substantive regional administrative decisions (RADS). This section discusses these issues.

Testing Protocols and DMASS

Part VII of this report discusses the various testing protocols that are available to assist in the development and analysis of dredged material disposal alternatives. These tests were classified into five major categories: sediment characterization, site characterization, contaminant release studies, and tests for control/treatment technology design. These tests are conducted during various phases of the DMASS. Table 9.18 summarizes the typical sequence of testing and the relationship between the phases of the DMASS and the implementation of the testing protocols. It should be stressed that the actual timing of the various testing protocols will vary with the nature and magnitude of the project being planned. In most cases, the issues covered by the various protocols will be addressed during the initial planning process using existing information and data. This information and data will then be supplemented during later phases of the planning process.

Regional Administrative Decisions

Implementation of the DMASS requires both administrative and substantive regional administrative decisions (RADs). These decisions must be made initially and then periodically throughout the implementation of the DMASS. RADs that must be made promptly in order to ensure timely completion of the DMASS process are discussed briefly below.

Table 9.18

Relationship of Testing Protocols to the DMASS Process

Phase	Step	Tests Required
I. Presumption of Contamination Pathway	Sediment Characterization	Bulk Chemistry Physical Tests
	Determine Available Generic Sites	Literature Investigations for Surface, Geologic, Ecological/Sociological Assessments
	Affected Contaminate Pathways	Open Water - Water Column Chemical Biological Mixing Aquatic Bioassay Benthic Bioassay Upland and Nearshore - Effluent Quality Surface Runoff Leachate Quality Plant Uptake Animal Uptake
II. Confirmation of Contamination Pathway	Determination of Specific Sites	Site Specific Assessment Identify Pathway of Concern Select Dredge/Transport Technique Site/Dredge/Transport Compatibility
III. Alternative Development and Initial Screening	Comparison of Specific Sites and Contaminate Control	Consolidation Settling Liner Compatibility Stabilization Treatability-Effluent, Runoff, Leachate
IV. Detailed Evaluation and Ranking	Assessment of Specific Sites and Criteria	Field Investigations for Surface, Geologic, Ecological/Sociologic Assessments
V. Alternative Selection		

RADs During Phase I. Two RADs are required during Phase I of the DMASS process.

1. Decision of No Contamination. An initial decision must be made as to the level of sediment contamination that will trigger the necessity to implement the DMASS. This RAD is referred to as the decision of no contamination or decision of sediment contamination in the DMF (Lee et al. 1985, Peddicord et al. 1986). If sufficient information is available and provides no substantive reason to believe contaminants are present based on the chemical analysis of a composite sediment sample, a decision for no further testing is made. In such cases, the selection of a disposal site is based on considerations other than potential contaminant impacts on the environment.

2. Decision for Further Testing versus Design in Lieu of Testing. If the available information is inadequate or provides a substantive reason to believe contaminants are present, then a decision for further testing or for design in lieu of testing is made. In either case, the emphasis is on selecting the disposal environment minimizing the potential for adverse impacts from the contaminated material. Limitations on available disposal sites should be considered. If only upland disposal sites are available then testing protocols selected for execution should emphasize contaminant migration pathways associated with upland sites. Likewise if design in lieu of extensive testing is implemented, control/treatment alternatives selected for evaluation should be suitable to address those migration pathways typical of the anticipated disposal environment.

RADs During Phase II. Six RADs are required during Phase II of the DMASS process.

1. Selection of Possible Disposal Sites. Disposal sites are classified into upland, nearshore, and open-water. At this level, concerns over impacts are limited to major readily apparent problems that would preclude use of a specific disposal site. For specific projects, an initial screening can be used to identify those disposal sites that are suitable. A decision is required on both factors to be used and criteria by which these factors are to be evaluated. The decision must also be concerned with whether to use absolute criteria, a relative comparison of sites, or both. The DMASS suggests factors such as availability, distance from dredging site, capacity, costs, and impact. A decision must also be made as to the number of sites to be retained for further evaluation.

2. Site Specific Pathways of Concern. General pathways of concern for each disposal environment (upland, nearshore, open-water) are identified in the DMASS (Lee et al. 1985, Peddicord et al. 1986). The significance of these pathways for generic sites are addressed through a decisionmaking framework based on sediment testing. Numerous RADs are included in this decisionmaking process and are incorporated by reference. The criteria used for these RADs are based on sediment characteristics. An additional RAD, to address the impact of site specific conditions, on these criteria is necessary. For example, suppose that testing of the sediment indicates that contaminants tend to leach from the dredged material at an unacceptable rate. Also suppose that the results of site characterization indicate that as a result of fortuitous geology this rate of leaching has no significant impact on the groundwater at the proposed disposal site. Thus, a RAD is necessary to preclude the implementation of unnecessary control/treatment alternatives.

3. Site Characterization. A basic premise of the DMASS is that sediment characteristics alone, as determined by implementation of the testing protocols outlined in the DMF (Lee et al. 1985, Peddicord et al. 1986), do not trigger the implementation of control/treatment alternatives. Specific site characteristics can either magnify or mitigate the need for restrictions. Thus an important part of the DMASS is a site characterization and assessment. The level of detail of a site characterization and assessment can range from brief desk top studies to expensive and time consuming field investigations. The DMASS process assumes that site characterization and assessment will be based on existing site information with limited additional field studies. Detailed field studies would not be conducted until the design phase. A RAD is necessary to set the level of detail of the site characterization and evaluation conducted in Phase II.

4. Decision of No Site Specific Restrictions. Phase II of the DMASS evaluates the interactions of the disposal site and the contaminated sediment. Ideally, disposal sites that do not require restrictions can be located. Thus, a decision will be required as to the need for site specific restrictions.

5. Decision for Continuing Evaluation. Although disposal sites that do not require restriction may be located, site specific characteristics may indicate that other disposal sites with restrictions are more desirable. Thus, a

decision is required on whether to continue with the DMASS process, even though a no-restriction disposal site has been identified.

6. Decision for More Testing. The confirmation of contaminant pathway, Phase II of DMASS, may be inconclusive, i.e., the decision maker may have insufficient information. In such cases, a decision is required on whether to require more extensive site or sediment characterization.

RADS During Phase III. Six RADs are required during Phase III of the DMASS process.

1. Selection of Evaluation Factors. The DMASS, as proposed, uses nine factors for evaluating control/treatment alternatives implemented to reduce contaminant migration from dredging activities. These factors are based on the judgement of the authors. It is likely that regional authorities will expand or reduce the number of factors to be evaluated based on those issues that are perceived to be important in a particular region.

2. Weighting of Evaluation Factors. The DMASS, as proposed, assigns an equal weight to all nine evaluation factors, i.e., the nine factors are considered to be equally important, i.e. cost is equal in importance to public acceptance. This may or may not reflect the attitude of the regional authorities. A RAD is necessary to determine the relative importance of selected evaluation factors. For example, consider the reliability factor. If reliability is given high importance then control/treatment alternatives will tend to incorporate field demonstrated technologies, whereas, if the reliability factor is given less weight then alternatives that incorporate proven or demonstrable technologies may be included.

3. Screening of Alternatives. The DMASS, as proposed, discusses, three possibilities for screening of alternatives. Decisions are necessary to select: whether to screen or not, the screening method, and factors to be used for screening.

4. Innovative Alternatives. The DMASS, as proposed, is oriented to the selection of field demonstrated technologies. Demonstratable and conceptual technologies are at a disadvantage in the evaluation and selection process. A RAD will be required to address this issue. A regional policy on the implementation of demonstrable and conceptual technologies will need to be developed.

5. Technology Based Control/Treatment Requirements. The DMASS, as proposed, uses an environmental effects based approach for the selection of appropriate control/treatment alternatives. Using this approach, a presumed requirement for restrictions based on sediment characteristics can be reduced or eliminated because of site specific conditions. An alternative approach is the use of minimum technology based design requirements. For example, if testing of a sediment indicates that contaminant leaching is a potential then a technology based design standard may require installation of a liner, regardless of mitigating disposal site conditions. A decision is necessary to address the technology based standards issue.

6. Evaluating Technical Effectiveness. Technical effectiveness addresses the contaminant release potential for control/treatment alternatives. Contaminant release will have site specific impacts. A decision must be made on appropriate procedures or models to use when evaluating these site specific contaminant release impacts.

RADs During Phase IV. Two RADs are required during Phase IV of the DMASS process.

1. Values for Factors. The evaluation factors, both quantitative and qualitative selected in Phase III must be quantified. A decision must be made on absolute or relative quantification. The previous decision concerning the weighting of factors must also be incorporated into the process.

2. Elimination of Alternatives. During the detailed evaluation process, some alternatives will be clearly inferior. A decision must be made on whether to eliminate alternatives based solely on inferiority and which ones, if any to eliminate. As an alternative, it may be desirable to evaluate fully all alternatives surviving the initial screening process.

RADs During Phase V. Two RADs are required during Phase V of the DMASS process.

1. Alternative Selections. The conclusion of the DMASS process is the selection of an appropriate dredged material disposal alternative. Thus, a decision must be made as to the best alternative for a specific alternative.

2. Backup Alternative. The selection of an alternative is based on the best information available at the time of selection. As project design proceeds, additional information may be developed that precludes implementation of the selected alternative. Therefore, it may be desirable to include one or more back-up alternatives in the alternative selection process.

Illustrative Case Study

Background

As an example of how the decisionmaking framework can be used, an example from Commencement Bay (Phillips et al. 1985) has been chosen. The dredge site is the Totem Ocean Trailer Express (TOTE) facility in the Blair Waterway at the Port of Tacoma. Information on the dredge site was taken from a series of soil testing reports and memoranda on test results (Hart-Crowser and Associates, Inc. 1982, 1983; Benlab Laboratories, Inc. 1983; Analytical Technologies, Inc. 1983; Washington Department of Ecology 1984). Information on potential disposal sites was taken from Phillips et al. (1985) and is summarized in Appendix F.

Close adherance to the framework is not possible since the actual sequence of actions in this example were not the same as has been proposed in this part, nor was the DMF (Lee et al. 1985) followed. Nevertheless, the situation provides a good example from which hypothetical illustrations can be developed.

Dredging at the case study site was necessary because of the plans to upgrade and expand the TOTE container facility at the Port of Tacoma. The site, shown on the map in Figure 9.32, is located along the northeast side of the Blair Waterway. The project size was 270,000 cu yd.

Presumption of Contaminant Pathway

Since the testing protocol established by Lee et al. (1985) was not available at the time of the sediment analysis for the site, assumptions were made based on the results that were available. Unfortunately there was some discrepancy in the results of laboratory analyses and a difference in opinion as to the degree to which the sediment was contaminated. The result of the testing and analysis process was to classify the upper portion of the sediment as a problem material and the lower portion as containing no contaminants of concern. The upper portion represented a relatively small portion of the sediment: 37,000 cu yd of the total 270,000-cu yd volume.

In general, the contaminants in the upper portion included organic compounds and metals, particularly copper, lead, and zinc. Of particular concern were PAHs found in the sediment. The organic compounds are assumed to be

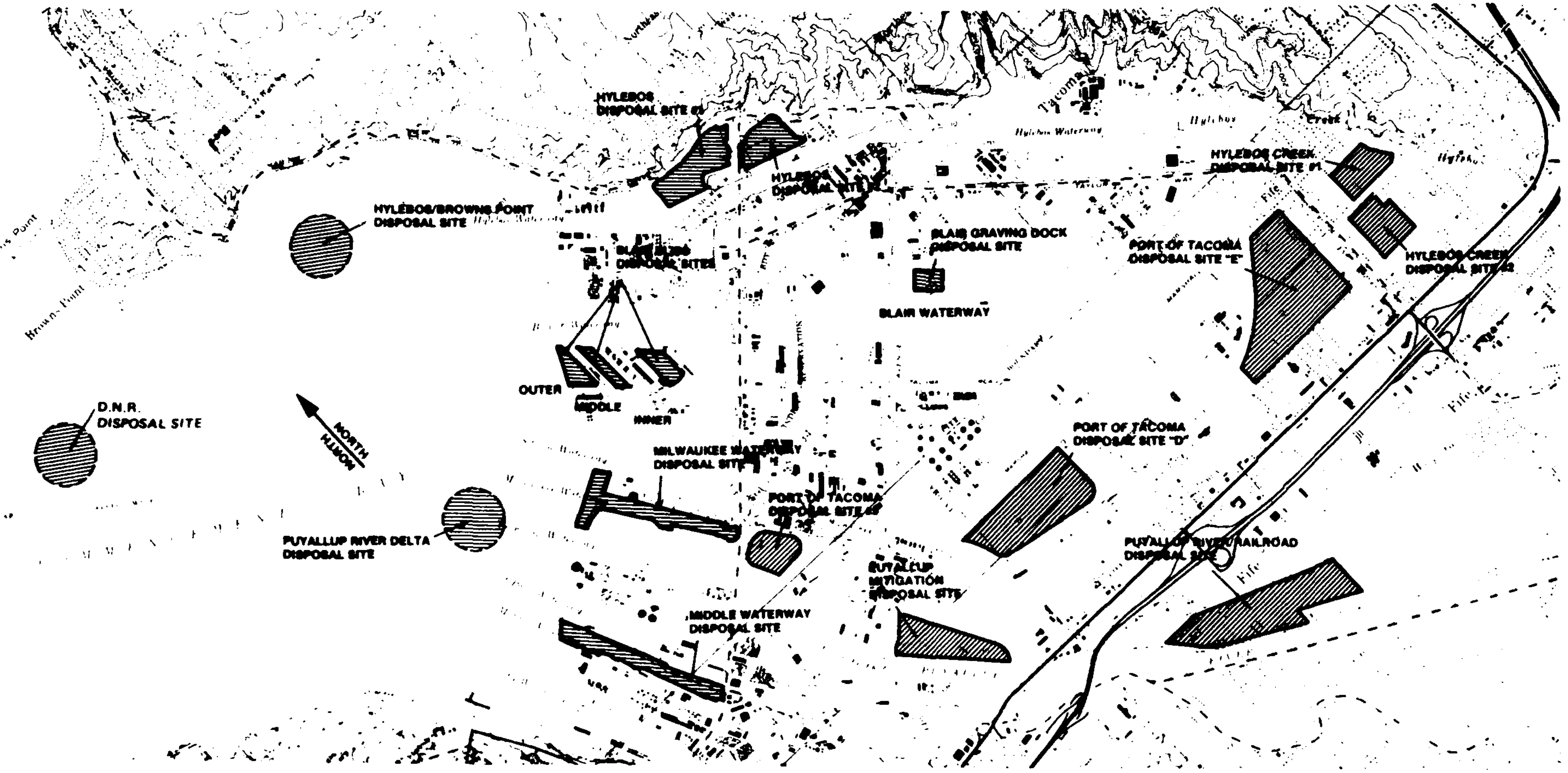

Figure 9.32. TOTE facility and potential disposal sites

tightly bound to the sediment and, if left relatively undisturbed, should pose no great threat. The metals, however, can pose considerable problems since they are readily soluble, particularly in a disposal environment where oxidation can occur. The results would be problems with contaminants in leachate and in effluent water created during the disposal process.

For the remainder of this case study, it was assumed that the sediment with the pollutants listed above (if it had been analyzed using the testing protocol) resulted in the following:

a. Possible restrictions needed because of impacts on the water column.
b. Possible restrictions needed because of benthic impacts.
c. Possible restrictions needed for upland/nearshore effluent water quality.
d. Possible restrictions needed for leachate quality.

It was assumed that plant and animal uptake and surface run-on would not pose threats.

Confirmation of Contaminant Pathway

Available Sites. A number of disposal sites are available in the proximity of Commencement Bay. Phillips et al. (1985) limited some potential sites on the basis of distance from the dredging area and capacity of the disposal area. For this case study, these limitations will be accepted and the remaining list of potential disposal sites will be used to illustrate the decision making process. The potential sites are listed in Table 9.19 along with pertinent information. In addition, Fig. 9.32 shows a map of the area with the potential disposal sites. More detailed descriptions of the sites are given in Appendix F.

Screening of Sites. The screening of sites can be done on both an absolute and a relative basis. Some preliminary screening of sites was done, and those sites were eliminated before being discussed in this case study. The preliminary screening was done on an absolute basis using proximity and capacity. Table 9.20 shows the criteria that were used in the screening.

The distance criteria were based on equipment limitations and cost considerations. Dredges would be able to pump typical Commencement Bay sediment about 2 miles on the level before a booster pump would be required. This distance is approximate and must be modified by elevation considerations. Thus, the hills to the north and south of Commencement Bay represent a limit to pipeline transport. The 12-mile distance criterion was selected as the

Table 9.19

Characteristics of Potential Disposal Sites for Illustrative Example

Site	Size	Capacity Million cu yds	Ownership (Zoning)*
Aquatic			
Puyallup River Delta	900 ft radius	unlimited?	State
DNR	900 ft radius	unlimited?	?
Hylebos/Brown	?	2.5	State
Upland			
Puyallup Mitigation	40 acres	1	? (S-10)
Port of Tacoma "D"	60 acres		Port of Tacoma
(+20 ft)**		0.1	(S-10)
(+35 ft)		1.45	
Puyallup River/RR	80 acres		UPRR†
(+20 ft)		1.3	(M-2)
(+35 ft)		3.3	
Port of Tacoma "E"	71 acres	1.7	Port of Tacoma (S-10)
Hylebos Creek 1 & 2	45 acres		Multiple
(+20 ft)		0.775	(A-1)
(+35 ft)		1.775	

(Continued)

NOTES:

* Zoning:
S-10: port industrial
S-11: industrial
M-2: light manufacturing
A-1: manufacturing

** Three of the upland sites can be filled to two different elevations (+20 and +35).

† UPRR = Union Pacific Railroad

Table 9.19 (Concluded)

Site	Size	Capacity Million cu yds	Ownership (Zoning)*
Nearshore			
Middle Waterway	27 acres	0.65	State
Milwaukee Waterway	30 acres	2.16	Port of Tacoma
Blair Waterway	12 acres	2.437	Port of Tacoma (S-10)
slips			
inner		0.6	
middle	8 acres	0.945	Port of Tacoma S-10
outer	7 acres	0.892	State (S-10)
Blair Graving Dock	8 acres	0.2	Port of Tacoma (S-10)
Hylebos Waterway 1	74 acres	1.274	City of Tacoma (S-11)
Hylebos Waterway 2	24 acres	0.3	Sound Refining Co. (S-11)

Table 9.20

Preliminary Screening of Potential Sites for Illustrative Example

Disposal Method	Screening Criteria	
Open Water	Distance:	within 12 miles of waterways
Upland	Distance:	within 2 miles of waterways
	Capacity*:	greater than 50,000 cu yd (sites below +20 ft MLLW)
		greater than 1,000,000 cu yd (sites at or above +20 ft MLLW)
	Other:	absence of permanent development
Nearshore	Distance:	within 12 miles of waterways
	Elevation:	-35 ft to +20 ft MLLW
	Capacity:	greater than 100,000 cu yd

* Sites could be filled to either +20 ft MLLW or +35 ft MLLW.

farthest distance that a two-barge mechanical dredging operation can continuously accommodate (i.e., the dredge will fill one barge while the second is proceeding to the disposal site, dumping, and returning). Beyond 12 miles, a three-barge operation would be necessary. In both cases (hydraulic and mechanical dredging), adding booster pumps or another barge increases costs.

The distance criteria also relate directly to the elevation criteria, especially for consideration of upland sites. Filling of upland sites to +20 ft MLLW and to +35 ft MLLW were considered. For small sites (less than 40 acres and with less than 1 million cu yd capacity), final site elevation would be +20 ft MLLW. Filling above that elevation would remove the parcel from railroad access and could cause land-use changes (e.g., change heavy industrial to light industrial use). Fill of one or more large sites to the maximum economical pumping height of +35 ft MLLW might provide bay-wide benefits to justify the tradeoff. For nearshore disposal, filling a site above +20 ft MLLW removes it from easy water access and reduces the site's potential for development.

Minimum site capacity was determined partially based on cost considerations. Although the TOTE facility is small, only large sites were considered, maintaining consistency with Phillips et al. (1985). Although actual costs must be determined on a case-by-case basis, a site with at least 100,000 cu yd capacity would be of sufficient size to amortize development costs for treatment facilities and site-preparation costs and would provide sufficient area (about 40 acres) to encourage settling of solids. It was felt that larger sites of at least 1 million cu yd capacity represent long-term multiple-use disposal opportunities rather than one-time uses. This opportunity for repeated use over time would imply a displacement, either potential or actual, of heavy industrial use of the site. Capacity for accepting at least 1 million cu yd of contaminated sediment has tangible economic inducements for long-range solutions to Commencement Bay Superfund and navigation issues.

In addition to the above considerations, only sites that had no large-scale permanent development or facilities in place were considered.

Once potential sites have been identified, screening can be done to further reduce the number of potential sites by eliminated possibilities that would likely not be good choices in the final analysis. Obviously this step would be inappropriate if only a few potential sites were being considered at this juncture, unless one or two were clearly inferior. For the case at hand, 16 sites are still candidates (three aquatic, five upland, and eight near-shore). A relative screening of these sites was performed by Phillips et al. (1985). A description of this process is repeated below. Two differences are apparent in the analysis that follows and the generic screening process presented earlier in this chapter. Different criteria are used and the scale of values used for the criteria are different (ranging from 0 to 2 rather than 1 to 4). These differences, however, should not have a significant impact on the results since the underlying approach is the same. The analysis done on the sites has been retained essentially as it was done since interested parties were contacted for their opinions and the analysis represents an excellent example of the appropriate amount of detail for a screening at this level.

The evaluation of the potential sites was based on available data and the professional judgements of authors of the Commencement Bay report. In addition, telephone and personal contacts were made with responsible officials with the Port of Tacoma, City of Tacoma, City of Fife, Pierce County, Puyallup Indian Tribe, State of Washington, and others. These contacts were not intended to be a comprehensive solicitation of concerns associated with dredging and disposal of contaminated sediment in Commencement Bay, but were instead intended to identify potential disposal sites and to obtain preliminary views on major concerns related to these sites. Not all landowners were contacted as to the availability of their lands, nor were assessments of the value of those lands made. The objective of this evaluation is to develop a reconnaissance level ranking of sites that could receive contaminated dredged material. Those sites that rank above others are not necessarily to be considered "recommended"; however, they show the best promise for more detailed evaluation leading to a recommended site. Table 9.21 shows a matrix of screening criterion values for the potential sites. A value of zero represents a negative assessment; one is neutral; and two corresponds to a positive evaluation. Bases for the assigned values are described in the following paragraphs.

For open-water disposal sites, ease of capping was used as an evaluation factor rather than cost of site preparation. Site preparation of open-water sites would simply be an extension of dredging; that is, underwater dikes could be constructed using clean sediment dredged during the course of navigation maintenance. For this factor, the Hylebos/Browns Point site ranks highest since it has the best potential for burial containment. The DNR site would have to employ the mounding technique in extreme depths. The Puyallup River delta is very unstable; capping and containment may be impossible over the long term. Only the DNR site is currently designated as approved for open-water disposal; however, depending on a variety of considerations, either or both of the other sites could be designated as well. Capacities are essentially unlimited at all sites. The Puyallup River delta is closest to the potential dredging sites; Hylebos/Browns Point is second. The DNR site is outside the most economical pumping distance for Commencement Bay sediment, but the site is acceptable for disposal from barges and hopper dredges. Because the DNR site has and is currently receiving dredged material on a periodic basis, additional adverse environmental impacts would be fewer. The instability of the Puyallup River delta suggests that unacceptable impacts on benthic resources would not occur, but that the same instability would render capping of contaminated sediments difficult. Little is known about the Hylebos/ Browns Point site, but it may be an important bottomfish habitat.

Upland disposal sites are highly varied within Commencement Bay area. Depending on the volume of contaminated sediment that requires removal and disposal, one or more upland sites may ultimately be determined to be

Table 9.21

Matrix of Site Screening Criteria Values for Illustrative Example

(0 = negative, 1 = neutral, 2 = positive)

	Criterion-Ranking					Composite
Site	Availability	Distance	Capacity	Cost*	Impacts to Habitat	Criterion Value**
Open Water						
Puyallup River Delta	1†	2	2	0††	1	6
DNR	2	0‡	2	0	2	6
Hylebos/Browns[δ] Point	1	2	2	1††	?	6+?
Upland						
Puyallup Mitigation (+35 ft)	0	2	2	2	?‡‡	6+?
POT "D"						
(+20 ft)	2	2	1	0	2	7
(+35 ft)	2	2	2	2	2	10
Puyallup River/ Railroad						
(+20 ft)	1	2	2	1	0	6
(+35 ft)	1	1	2	0	0	4
POT "E"						
(+35 ft)	2	1	2	2	2	9

(Continued)

NOTES:

* For open-water disposal, ease of capping was used in place of cost. Costs were based on site-preparation costs divided by cubic-yard capacity of site.

** Composite criterion values were based on equal weights for each of the five criteria.

† DNR would have to designate site as available.

†† Some site preparation might be required.

‡ Beyond pipeline pumping, acceptable for barge and hopper.

‡‡ Agency concerns anticipated.

δ Relocation of existing marina in inner slip required.

Table 9.21 (Concluded)

Site	Criterion-Ranking					Composite Criterion Value**
	Availability	Distance	Capacity	Cost*	Impacts to Habitat	
Hylebos Creek #1 & #2						
(+20 feet)	?	1	1	1	0‡‡	3+?
(+35 feet)	?	1	2	0	0‡‡	3+?
Nearshore						
Middle WW	0	1	1	2	1	5
Milwaukee WW	2	2	2	2	1	9
Blair WW Slips	2	2	2	1δ	1	8
Blair Graving Dock	2	1	1	2	1	7
Hylebos WW #1	2	1	2	2	0	7
Hylebos WW #2	2	1	0	0	0	3

necessary. In addition, individual dredgers may encounter small volumes of material that could be disposed of upland, but timing of dredging, need to fill the site for development, or other considerations may make use of a small site appropriate.

The capacities of the Port of Tacoma "D" and the Puyallup River/Railroad sites are large; the sites are within pumping distance from a variety of Commencement Bay dredging sites; and the sites are sufficiently large to permit onsite treatment facilities to be constructed. Because of the existence of the wetland meadow on Puyallup River/Railroad site, environmental impacts are rated low (high impact) in relation to the other sites being evaluated, and a more detailed examination of environmental effects is warranted. The Port of Tacoma "E" Site is considered a good candidate due to its location relative to much of the harbor area, but does not have capacity below +20 ft MLLW. The proposal for wetland restoration at the Puyallup mitigation site makes future use unlikely. Hylebos Creeks Nos. 1 and 2 have a good preparation cost-to-capacity ratio; however, use of these sites would displace ongoing agricultural activity. In addition, the sites' availabilities are unknown, and their mixed ownership would probably require the sites be acquired rather than be made available.

There are generic problems with nearshore disposal sites with regard to containment of contaminated sediments. Nevertheless, as further information is developed, techniques for placing and retaining contaminants in nearshore areas may be refined. Middle Waterway might be useful for partial fill using contaminated sediment, but it might be more useful dredged out and its navigational capability restored. The outer area is still used; relocation of adjacent landowners and users to other portions of the harbor could be expensive and difficult. Benefits do not appear to warrant the effort. The two Hylebos Waterway sites are probably available, but the cost of one is high in comparison to capacity, and both sites are wetlands with high resource value to Commencement Bay. Further evaluation at this stage does not seem warranted.

The Blair graving dock site has relatively limited capacity; however, its preparation costs are quite low. The site is more suitable for a one-time disposal and should be considered for such if the opportunity presents itself. The Blair Waterway slips are intended to be filled and developed in the future. They represent a large capacity, and preparation costs are reasonable. They are located centrally on the waterfront and would be able to accept sediment dredged from anywhere in Commencement Bay. Environmental impacts are relatively moderate, but mitigation might be required. The largest drawback to the slips is the existing marina in the inner slip that would need to be relocated. Likewise, Milwaukee Waterway presents an opportunity as the port intends to fill the waterway to accommodate Sea-Land and to develop their own container terminal capacity. Milwaukee Waterway has large capacity, is not presently being extensively used for navigation; and it has no adjacent users that would have to be relocated.

The last column in Table 9.21 shows the composite criterion values for each of the potential sites. The composite criterion values were developed by adding the values for the five criteria (equal weighting assumed). At this point, any number of factors may influence the number of sites chosen for further evaluation. Ranking the sites by the composite criterion and selecting a certain number for further evaluation is one possibility. Picking a number of sites above a certain rank is a second approach. For example, nine of the sites have composite criterion values of seven or above (including the two ranked as 6+?). It also may be desirable to retain at least one site from each type of disposal site (open water, upland, and nearshore).

It is important to remember, however, that relying solely on the composite criterion is inappropriate. It is merely an aid in the process; specific characteristics of each site must be addressed, as was done in the previous paragraphs.

Based on the analyses, the following sites were retained for further analysis in conjunction with specific technologies: Open water --- Hylebos/Browns Point; Upland --- Port of Tacoma "D", Puyallup River/Railroad (+20 ft), Port of Tacoma "E" (+35 ft); and Nearshore --- Milwaukee Waterway and Blair Waterway slips. The Hylebos/Browns Point site was retained because of the potential for more complete containment of sediment. It is also desirable to consider one open-water site, and this one edges out the other two. The Port of Tacoma "D" and Puyallup River/Railroad sites both had large capacities, which made them attractive. In addition, Port of Tacoma "E" received a high composite score, although it does not have capacity below +20 ft MLLW. The two nearshore sites were retained because of their overall attractiveness.

Site Evaluation. The next step in the DMASS flowchart (Fig. 9.3) is a more thorough evaluation of each of the six sites retained for further consideration. This case study from this point on will not present as much detail as would be required in an actual assessment, simply because no further analyses have been done on the Commencement Bay sites. During actual site assessment, however, this step should be an extensive assessment of characteristics that would affect transport and/or attenuation of the contaminant. For the purpose of this example, the following assumptions (some possibly unrealistic) were made concerning the characteristics of each site.

1. Hylebos/Brown Point - dispersion of pollutants would be a problem if an unrestricted dump were allowed; however, no problems with surge resuspension are expected. It is expected that benthic organisms will reinhabit the site following disposal.
2. Port of Tacoma "D" - geologic evaluation shows that no attenuation of leachate would occur and the plume would degrade the underlying aquifer. Effluent water would violate water quality criteria.
3. Puyallup River/Railroad - geologic evaluation reveals that the site will provide good leachate attenuation yielding no degradation of the underlying aquifer. Effluent water would violate water quality criteria.
4. Port of Tacoma "E" - geologic evaluation shows that no attenuation of leachate would occur. Effluent water would violate water quality criteria.

5/6. Milwaukee Waterway and Blair Waterway slips - in both cases convection would cause problems and contaminant levels would violate water quality standards. Ground-water flow patterns reveal very little exchange between the surface and subsurface water bodies.

Dredge/Transport Selection. For each potential site that has been identified, compatible dredging and transport techniques must be selected.

For the Hylebos/Browns Point disposal site, the flowchart shown in Figure 9.18 should be followed. Characterization of the sediment and analysis of the disposal site have demonstrated that the water column would need to be isolated during disposal. Therefore, some sort of conduit or downpipe would need to be employed. Consideration might also be given to an innovative technique, such as solidification of the sediment. Presumably a solidification process would require the sediment to be slurried. Although such a technique is untried, it will be retained in the discussion.

Analysis of the bottom conditions at the disposal site has determined that there is no need to control the surge resulting from the disposal.

Since the disposal conduit can only accommodate a slurried sediment and since solidification also requires a slurry, restrictions must be placed on the dredge/transport process. The following four options are compatible: (1) hydraulically dredge and pipe sediment; (2) mechanically dredge, slurry the sediment, and pipe slurry; (3) mechanically dredge, barge, and then slurry the sediment before disposal; and (4) hydraulically dredge and barge the slurry.

Because of the nature of the sediment and the characteristics of the site, restrictions are also necessary at the dredge site. First, because the contaminants are easily diffused into the water column, restrictions are needed to limit this action. In addition, because of the physical nature of the site, the issue of maneuverability limits dredging options to mechanical means. Hence, available dredging options are closed clamshell, closed bucket, clamshell with silt curtain, or bucket with silt curtain.

Checking the compatibility of these options with the options remaining after imposition of disposal-site restrictions reveals that two of the options must be eliminated (those using hydraulic dredging). Hence, for open-water disposal 16 options remain; closed clamshell, closed bucket, clamshell/silt curtain, and bucket/silt curtain, followed by one of four transport options: (1) slurry, pipe, and conduit down; (2) barge, slurry, and conduit down; (3) slurry, solidify, barge, and dump; and (4) slurry, pipe, solidify, and dump.

All five upland and nearshore potential sites are considered together since there are only minor differences in how each site would affect dredge/transport options. The progression through the flowchart in Figure 9.18 involves only the lower portion of the diagram. In addition to piping and barging sediment, truck and rail transport are also options. Obviously, proximity to a road or a rail line is an important consideration. Also in some cases, combinations of transport options are possible (such as barge then truck or pipe), although transferring from one mode to another would increase the cost. Table 9.22 lists possible transport means for each of the five sites.

Transport combinations have been eliminated from Table 9.20 since at least three direct transport means are possible for each site. The

Table 9.22

Possible Transport to Upland/Nearshore Sites for Illustrative Example

Site	Type of Transport-Feasibility*			
	Barge	Truck	Pipe	Rail
Port of Tacoma "D"		X	X	0
Puyallup River/Railroad	X	X	X	0
Port of Tacoma "E"		X	X	0
Milwaukee Waterway	X	0	0	0
Blair Waterway	X	0	0	0

---

* Key to entries:
X = feasible means
0 = feasible but eliminated because another means clearly dominated for the site.

availability of a transport means was based on the proximity to both the dredging site and disposal site. It was assumed that conveyors could easily be used to move sediment over a distance of 1/8 mile. Therefore, for example, rail transport is feasible if a rail line is within 1/8 mile of both end points. Similar statements can be made for truck and barge transport. Costs were not considered in Table 9.22; it only considers feasibility. At this stage, consideration of options such as truck and rail transport may seem absurd when compared to piping. However, when considering the need for mechanical dredging and when looking ahead to the possible reduced treatment costs for concentrated material, it may be advantageous to keep the sediment in as solid a state as possible (i.e., avoid piping). When costs are considered, the piping option may be inferior since the increased cost of slurrying sediment and the increased cost of treating larger quantities of water may outweigh the savings of pumping and piping.

At this point, some of the options in Table 9.22 can (and should) be eliminated since other options clearly dominate. At least one option should be retained for each site. For the two nearshore sites, barging is the obvious choice to retain since truck and rail transport are bound to be more expensive (and more cumbersome) and piping would seem inconsistent with mechanical dredging. Rail transport was eliminated for the other sites because it does not appear to have an advantage over trucking.

After elimination of these dominated transport options, 36 dredge/transport/site possibilities still exist; closed clamshell, closed bucket, clamshell/silt curtain, and bucket/silt curtain for each of the options labeled with an X in Table 9.22.

Pathways of Concern. From the previous discussion, it is clear that restrictions are necessary for a number of reasons. If one of the sites had been suitable for unrestricted disposal, it could be selected without proceeding further through the DMASS flowchart (Fig. 9.3). It is also possible that further information is needed, either in terms of disposal site or dredged material characteristics. Even if a site allowing unrestricted disposal were identified, it might be advantageous to continue through the flowchart, saving the unrestricted disposal alternative for comparison with other alternatives, based on all of the evaluation criteria.

The next phase in the framework is to select and screen technologies capable of addressing the pathways of concern. For the potential sites, pathways are repeated below:

a. Hylebos/Browns Point. Two pathways have been identified: water column and effects on benthic organisms. The water column has already been addressed with the downpipe.

b. Port of Tacoma Sites "D" and "E." Two pathways for each site have been identified, leachate contamination of ground water and effluent contamination of receiving water bodies.

c. Puyallup River/Railroad. The only pathway of concern is contamination of the receiving water by effluent concentrations.

d. Milwaukee and Blair Waterways. Both sites need to have controls to prevent excessive diffusion.

Alternative Development and Initial Screening

Any number of technologies and technology schemes are available for dredging/transportation/disposal of contaminated sediment. These were detailed in Parts II through VI and summarized earlier in this part. To provide a preliminary assessment of the applicability of these technologies to Commencement Bay, the appropriate criteria were applied to the technologies to screen out those that are not likely to be viable and/or efficient options.

Select Potential Technologies. Selection of potential technologies for the project involves a general knowledge of how technologies and combinations of technologies will address the contaminants of concern: in this case, soluble heavy metals and organics that tend to stay bound to the sediment. The selection is also done knowing the types of disposal sites that have been retained for further consideration. In this case, all three types, open water, upland and nearshore, are still candidates. All possible containment and treatment technologies that are applicable to the disposal of sediment from the TOTE dredging project were considered. Some were eliminated without formally being evaluated in terms of the NCP criteria, simply because their inappropriateness was apparent at a glance. For example, volitalization of contaminants was not a problem; therefore, no means to address volitalization were considered.

Those technologies that were addressed can be grouped into (1) site controls, (2) effluent/supernatant treatment, and (3) leachate treatment. Site controls included liners, covers, underdrains, dikes, and stabilization.

Treatment practices are diagramed in Fig. 9.33 as they were considered by Phillips et al. (1985). Leachate treatment was approached in a simple manner and was either considered (and treated offsite after underdrain collection) or not considered.

Reasonable technology schemes for upland, nearshore, and open-water sites are shown in Tables 9.23, 9.24 and 9.25, respectively. The various schemes will not be detailed here and should be somewhat self-explanatory. Upland disposal scheme number 11, for example, would result in a lined site with underdrains to collect leachate, which would be discharged to a local sewer for offsite treatment. In addition, any effluent or supernatant water would be treated by plain sedimentation, chemical clarification, and filtration before being discharged to a receiving stream.

Tables 9.23, 9.24, and 9.25 also list values for the NCP screening criteria for each of the schemes. These values are crude approximations (particularly for this case study). Estimated costs are subjective ballpark values based on estimates from Phillips et al. (1985). The values for impact and accepted engineering practice are also subjective assessments, based on one person's general knowledge of how the schemes would behave for these criteria. Values for the impact criterion were estimated on the basis of how the scheme would address all pathways of concern.

Schemes were eliminated based on values given the criteria for a scheme. Any scheme with a cost that exceeded another by an order of magnitude was eliminated. On this basis, open-water disposal schemes 5, 6, and 7 were dropped. It was assumed that the cost of solidification was far too great to allow further consideration. The reliability of this technology is also unknown, resulting in a low ranking for accepted engineering practice. In addition to the cost criterion, all schemes with high impact values and low values for accepted engineering practice were eliminated. Schemes that were retained are identified in the last columns of the three tables.

Formulation of Alternatives. Alternatives were next formulated based on the potential sites and schemes that were retained for further consideration. For nearshore disposal, there are 36 alternatives (18 possible schemes for each of two sites), and for open-water disposal, there are three. Because of the differences in geologic characteristics among the upland sites, not all schemes are appropriate for all sites. Those schemes without a liner were considered appropriate only for the Puyallup River/Railroad Site because of

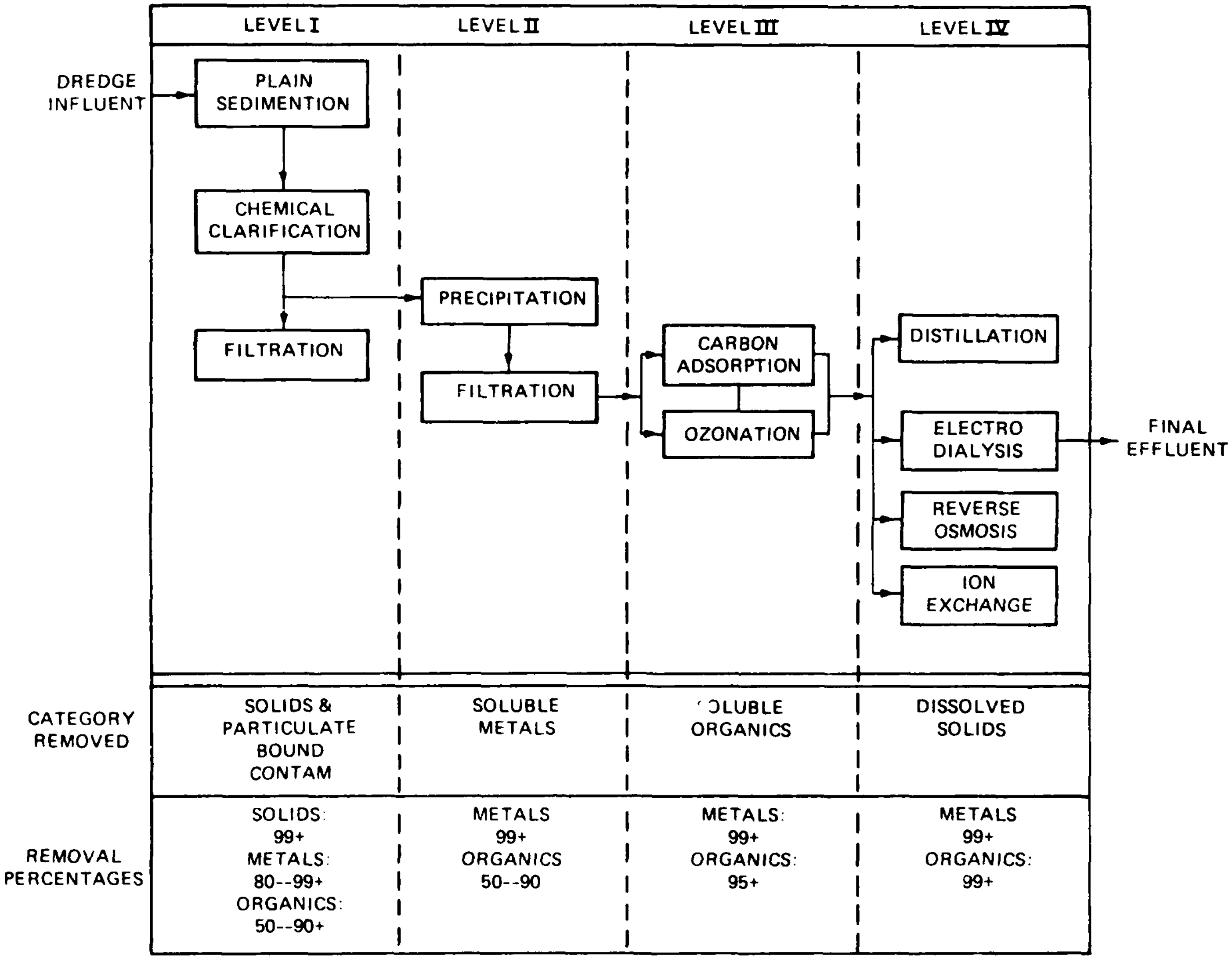

Figure 9.33. Treatment processes showing estimated removal efficiencies

Table 9.23

Alternative Upland Disposal Site Restrictions

and Criteria for Illustrative Example

Technology Scheme Number	Site Controls			Effluent/ Supernatant Treatment					OffSite Leachate Treat.	Criterion-Ranking			Retained
	Liner	Cover	Underdrain	Plain Sed.	Chem. Clar.	Chem. Precip.	Filtration	Carb. Adsorp		Est. Cost, $M	Impact	Acc. Eng. Practice	
1	X			X						0.7	HIGH	HIGH	
2	X			X	X					0.8	MED	HIGH	X
3	X			X		X				0.8	MED	HIGH	X
4	X			X	X		X			0.9	MED	HIGH	X
5	X			X	X		X	X		1.0	MED	HIGH	X
6	X			X		X	X			0.9	MED	HIGH	X
7	X			X		X	X	X		1.0	MED	HIGH	X
8	X		X						X	1.5	HIGH	HIGH	
9	X		X	X	X				X	1.6	MED	HIGH	X
10	X		X	X		X			X	1.6	MED	HIGH	X
11	X		X	X	X		X		X	1.7	LOW	HIGH	X
12	X		X	X	X		X	X	X	1.8	LOW	HIGH	X
13	X		X	X		X	X		X	1.7	LOW	HIGH	X
14	X		X	X		X	X	X	X	1.8	LOW	HIGH	X
15	X		X	X					X	1.4	LOW	HIGH	X
16		X		X						0.7	HIGH	HIGH	
17		X		X	X					0.8	MED	HIGH	X
18		X		X		X				0.8	MED	HIGH	X
19		X		X	X		X			0.9	MED	HIGH	X
20		X		X	X		X	X		1.0	MED	HIGH	X
21		X		X		X	X			0.8	MED	HIGH	X
22		X		X		X	X	X		1.0	MED	HIGH	X
23	X	X		X						1.5	HIGH	HIGH	
24	X	X		X	X					1.6	MED	HIGH	X
25	X	X		X		X				1.5	MED	HIGH	X
26	X	X		X	X		X			1.7	LOW	HIGH	X
27	X	X		X	X		X	X		1.8	LOW	HIGH	X
28	X	X		X		X	X			1.7	LOW	HIGH	X
29	X	X		X		X	X	X		1.8	LOW	HIGH	X
30				X						0.1	HIGH	HIGH	
31				X	X					0.2	HIGH	HIGH	
32				X		X				0.2	HIGH	HIGH	
33				X	X		X			0.3	HIGH	HIGH	
34				X	X		X	X		0.4	HIGH	HIGH	
35				X		X	X			0.3	HIGH	HIGH	
36				X		X	X	X		0.4	HIGH	HIGH	

Table 9.24

Alternative Nearshore Disposal Site Restrictions

and Criteria for Illustrative Example

Technology Scheme Number	Site Controls		Supernatant Treatment					Criterion-Ranking			
	Cover	Stabilization	Plain Sed.	Chem. Clar	Chem. Prec.	Filtration	Carb. Ads.	Est. Cost, $M	Impact	Acc. Eng. Practice	Retained
1			X					0.1	HIGH	HIGH	
2			X	X				0.2	HIGH	HIGH	
3			X		X			0.2	HIGH	HIGH	
4			X	X		X		0.3	HIGH	HIGH	
5			X	X		X	X	0.4	HIGH	HIGH	
6			X		X	X		0.3	HIGH	HIGH	
7			X		X	X	X	0.4	HIGH	HIGH	
8	X		X					0.8	HIGH	HIGH	
9	X		X	X				0.9	MED	HIGH	X
10	X		X		X			0.9	MED	HIGH	X
11	X		X	X		X		1.0	LOW	HIGH	X
12	X		X	X		X	X	1.1	LOW	HIGH	X
13	X		X		X	X		1.0	LOW	HIGH	X
14	X		X		X	X	X	1.1	LOW	HIGH	X
15		X	X					0.5	HIGH	MED	
16		X	X	X				0.6	MED	MED	X
17		X	X		X			0.7	MED	MED	X
18		X	X	X		X		0.8	LOW	MED	X
19		X	X	X		X	X	0.9	LOW	MED	X
20		X	X		X	X		0.8	LOW	MED	X
21		X	X		X	X	X	0.9	LOW	MED	X
22	X	X	X					1.2	HIGH	HIGH	
23	X	X	X	X				1.3	MED	HIGH	X

(Continued)

Table 9.24 (Concluded)

Technology Scheme Number	Site Controls		Supernatant Treatment					Criterion-Ranking			
	Cover	Stabilization	Plain Sed.	Chem. Clar	Chem. Prec.	Filtration	Carb. Ads.	Est. Cost ($M)	Impact	Acc. Eng. Practice	Retained
24	X	X	X		X			1.3	MED	HIGH	X
25	X	X	X	X		X		1.4	LOW	HIGH	X
26	X	X	X	X		X	X	1.5	LOW	HIGH	X
27	X	X	X		X	X		1.4	LOW	HIGH	X
28	X	X	X		X	X	X	1.5	LOW	HIGH	X

Table 9.25

Alternative Open-Water Disposal Site Restrictions and Criteria for Illustrative Example

Technology Scheme Number	Technology				Criterion-Ranking			Retained
	Down-Pipe	Dike	Cap	Solidification	Est. Cost,$M	Impact	Acc. Eng. Practice	
1	X				0.5	HIGH	MED	
2	X	X			0.7	MED	MED	X
3	X		X		0.75	LOW	MED	X
4	X	X	X		0.9	LOW	MED	X
5		X		X	8.0	MED	LOW	
6			X	X	7.5	LOW	LOW	
7				X	7.0	MED	LOW	

the presence of a natural clay liner. Table 9.26 shows the appropriate combinations, resulting in 63 alternatives.

When all three types of disposal sites are considered there are 84 alternatives.

Screening of Alternatives. It was decided that the final evaluation should include alternatives for each type of disposal site and, further, that each type of site have three alternatives for more detailed evaluation. The screening process, therefore, followed the flowchart shown in Fig. 9.21. This process requires a ranking of all alternatives by cost for each type of site and then evaluating other criteria to see if they are acceptable. Each alternative in each ranked list is evaluated until three are acceptable.

At this stage the full list of nine criteria was used to evaluate the alternatives. For this case study, assumed values will be used for the criteria. In an actual application, a more thorough analysis of the criteria would be performed, particularly for cost and environmental impact. Traditional cost-estimating techniques would be used given the level of detail that is available at this stage. Environmental impact would be assessed by stepping through the flowcharts shown in Figs. 9.22, 9.24, 9.25, and 9.29, which represent the identified contaminant pathways.

The first step in the progression through the flowchart in Figure 9.17 is to formulate all potential alternatives. These can be obtained from Tables 9.23, 9.24, 9.25, and 9.26. Determining the cost for each potential alternative would involve cost-estimating techniques. This step has not been done here; rather, values were assumed as being somewhat close to those used in Tables 9.22, 9.24, and 9.25. These values are shown in Tables 9.27 and 9.28 for upland and nearshore sites, respectively. Only partial listings of alternatives (those with lower costs) are shown in the tables. No table for open-water disposal is shown since only three alternatives were available before the screening. Therefore, this entire step was bypassed for open-water disposal, and all three alternatives were retained for detailed evaluation. In effect, the uppermost path in Fig. 9.15 was followed.

Once ranks are determined for the potential alternatives, values for the remaining schemes are determined. Tables 9.27 and 9.28 merely note whether the schemes were acceptable or not. Once three alternatives have been determined as acceptable (according to all criteria), the process stops and the three alternatives are saved for detailed evaluation.

Table 9.26

Restriction/Site Combinations for Upland Disposal for Illustrative Example

	Disposal Site-Alternative Scheme*		
Scheme	P.O.T.D.	P.O.T.E.	PR/RR
2	X	X	X
3	X	X	X
4	X	X	X
5	X	X	X
6	X	X	X
7	X	X	X
9	X	X	X
10	X	X	X
11	X	X	X
12	X	X	X
13	X	X	X
14	X	X	X
15	X	X	X
17			X
18			X
19			X
20			X
21			X
22			X
24	X	X	X
25	X	X	X
26	X	X	X
27	X	X	X
28	X	X	X
29	X	X	X

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* Key: P.O.T. D - Port of Tacoma, Site D
P.O.T. E - Port of Tacoma, Site E
PR/RR - Puyallup River/Railroad Site

Table 9.27

Screening Criteria Values for Upland Disposal Alternatives for Illustrative Example

(ranked according to increasing cost)

Rank	Alternative		Cost, $M	Criterion-Ranking**								Acceptable
	Site*	Scheme		Eng. Imp.	Reliab.	Impl. & AV.	Tech. Eff.	Safety	O&M$	Reg. Req.	Pub. Acc	
1	PR/RR	17	0.73	N	A	A	A	A	A	A	A	
2	PR/RR	2	0.74	N	A	A	N	A	A	A	A	
3	POT.D	2	0.75	N	A	A	A	A	A	A	A	
4	POT.E	2	0.75	N	A	A	A	A	A	N	A	
5	PR/RR	21	0.81	A	A	A	A	A	A	A	A	YES
6	POT.D	3	0.82	N	A	A	A	A	A	A	N	
7	PR/RR	3	0.83	N	A	A	A	A	A	A	A	
8	POT.E	3	0.84	N	A	A	A	A	A	N	A	
9	PR/RR	18	0.85	A	A	A	A	A	A	A	A	YES
10	PR/RR	19	0.91	A	A	A	A	A	A	A	A	YES
11	PR/RR	6	0.91									
12	POT.D	6	0.91									
13	POT.E	6	0.93									
14	POT.E	4	0.93									
15	POT.D	4	0.94									
16	PR/RR	4	0.95									

* POT.D & E = Port of Tacoma Sites "D" & "E"
PR/RR = Puyallup River/Railroad Site

** A = acceptable
N = not acceptable

Table 9.28

Screening Criteria Values for Nearshore Disposal Alternatives for Illustrative Example

(ranked according to increasing cost)

Rank	Alternative		Cost, $M	Criterion-Ranking**								Acceptable
	Site*	Scheme		Eng. Imp.	Reliab.	Impl. & AV.	Tech. Eff.	Safety	O&M$	Reg. Req.	Pub. Acc	
1	BL.	16	0.59	N	N	A	N	A	A	A	A	
2	MIL.	16	0.60	N	N	A	N	A	A	A	A	
3	BL.	17	0.69	N	N	A	N	A	A	A	A	
4	MIL.	17	0.70	N	N	A	N	A	A	A	A	
5	BL.	18	0.83	A	A	A	A	A	A	A	A	yes
6	MIL.	18	0.84	A	N	A	A	A	A	A	A	yes
7	BL.	20	0.87	A	A	A	A	A	A	A	A	yes
8	MIL.	20	0.88									
9	BL.	10	0.90									
10	BL.	19	0.90									
11	BL.	19	0.91									
12	BL.	9	0.91									
13	MIL.	9	0.92									
14	MIL.	10	0.93									
15	BL.	21	0.93									
16	MIL.	21	0.94									

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* BL. = Blair Slips Disposal Site
MIL. = Milwaukee Waterway Disposal Site

** A = Acceptable, N = not acceptable

Table 9.29 lists the nine resulting alternatives remaining after applying the screening process.

Detailed Evaluation and Ranking

The next phase in the framework is a detailed evaluation of the nine alternatives identified in the previous section. Again, the case study example will not address the degree of detail that would normally be considered at this point. However, the process will be followed using hypothetical values.

Thorough Delineation of Alternatives. The nine alternatives listed in Table 9.29 represent only brief descriptions of schemes for addressing the dredging, transport, treatment and/or disposal of the dredged material. For example, Alternative F includes the use of a cover at the Puyallup River/ Railroad Site and incorporates plain sedimentation followed by chemical precipitation and filtration. However, few details beyond these general specifications have been made.

At this point in the process, considerably more detail is added for each alternative. For example, the cover portion of Alternative F could be designed in a number of different ways. Two basic options are depicted in Part IV of this report. In addition, a host of different synthetic liners could be used in place of the barrier layer of clay. Also, different thicknesses of the various layers are possible, resulting in an almost infinite number of designs, simply for the cover of the site.

The specification of the details for each alternative involve a mixture of experience and, possibly, design testing to narrow the choices to those that best meet the requirements at the lowest cost. For example, a synthetic barrier may be chosen over clay, based on knowledge of the type of material being disposed, or possibly on the availability of clay.

These sorts of decisions must be made at this point so that a detailed assessment of each alternative can be determined in terms of the nine evaluation criteria (cost, reliability, etc.). Parts IV, V, and VI of this report and a host of other references are available for guidance on the selection of design components and their effect on cost, reliability, effectiveness, etc.

The remainder of this section will provide more detail on the alternatives to give somewhat of an idea of the level of detail necessary for the next step in the process. Since there are many similarities among the schemes, each alternative will not be described. Instead, Table 9.29 will be

Table 9.29

Nine Alternatives Remaining After Screening Process for Illustrative Example

Alternative	Site	Scheme			
		Dredge	Transport	Disposal/Treat.	Site Control
A	Hylebos/Browns Point	Clamshell with silt curtain	Slurry at dredge site, pump to disposal area	Pump down via vertical conduit	Dike open side of depression before disposal
B	Hylebos/Browns Point	Same	Same	Same	Cap Sediment after disposal
C	Hylebos/Browns Point	Same	Same	Same	Dike open side before and cap after disposal
D	Puyallup River/ Railroad	Same	Barge to disposal site and convey from barge	Collect effluent and treat with plain sedimentation and chem. precipitation	Cover and contour site
E	Puyallup River/ Railroad	Same	Same	Collection effluent and treat with plain sed., chem. clar., and filtration	Same
F	Puyallup River/ Railroad	Same	Same	Collect effl. and treat with plain sed., chem. precipitation, and filtration	Same
G	Blair Slip	Same	Barge to disposal site and clamshell off barge	Silt curtain, collect effluent and treat with plain sed., chem, clar., and filtration	Dike outer end, stabilize upper layer of sediment
H	Milwaukee Waterway	Same	Same	Same	Same
I	Blair Slip	Same	Same	Silt curtain, collect effluent and treat with plain sed., chem. precip. and filtration	Same

used as a basis for the discussion, and detail will be provided on general technologies.

Dredge

All six alternatives utilize the same means of dredging. A clamshell bucket dredge operating from the barge was chosen because of the configuration of the site and the desire to dredge mechanically. The clamshell could easily discharge directly to the barge for transport to the disposal site or, in the case of the pipeline transport, directly to facility which would slurry and pump the sediment. A silt curtain would be used to control resuspension and possible contamination of the waterway. The silt curtain was chosen because of the relative ease of its use; the water at the site is relatively shallow; and the curtain would need to surround only part of the site since the shoreline provides another boundary.

Transport

For the open-water disposal alternatives (A, B, and C), the dredged material would be slurried at a facility located on the shore (or nearby barge) and pumped to the disposal site. The slurry mechanism would break up large clumps of sediment and mix approximately 10 parts water (pumped from the waterway) to 1 part sediment. The slurry would be screened to remove foreign objects before being pumped by a positive displacement pump capable of handling up to 10,000 gpm of slurry. The material would be pumped through a floating 8-in.-diameter pipeline to the disposal site.

For the upland disposal site, the barge would be towed to and moored along side the site in the Puyallup River. The clamshell crane would unload sediment to a conveyor belt allowing transport to the northeast corner of the disposal site. This corner was selected to allow further, more convenient use of the rest of the site for other projects.

The same mechanism would be used for nearshore disposal except that the clamshell would discharge directly to the subsurface site.

Disposal/Treatment

No treatment is provided for open-water disposal. However, because of the potential for dispersion during disposal, the slurry would be pumped down a 12-in. conduit to within 20 ft of the bottom. A positive displacement pump, also capable of pumping 10,000 gpm, would be used at the surface.

For both upland and nearshore disposal, any water draining from the sediment would be treated. Since the material will have been mechanically dredged, the volume of water requiring treatment would be small. Therefore, temporary portable treatment units would be used where possible. At the upland disposal site, the existence of a natural clay liner and excess space would allow construction of an in-ground sedimentation basin. The design would allow gravity drainage from the deposited material to the basin. Since the volume of water expected as effluent from the sediment is estimated at 10 million gallons, two batch sedimentation basins would be utilized. Each would allow for a depth of 3 ft and have a surface area of approximately 1/8 acre. One would allow sedimentation while the other would be drained to allow further treatment of the supernatant. Due to the space limitations at the nearshore disposal sites, a temporary, high-rate, rectangular sedimentation basin mounted on a barge would be utilized. Since the sediment would be placed directly into the site (below the low tide level), it would not yield as much effluent water. However, water over the site will become contaminated during disposal and should be treated following completion of the operation. This volume of water, however, would require a lesser degree of treatment since pollutant concentrations will be low.

Both upland and nearshore sites would utilize portable units for chemical clarification or chemical precipitation. Assuming a one-month period for disposal of the sediment the units would have to have a flow-rate capacity of 40 gpm.

Small sand filters, of the type described in Part IV, would be constructed at the upland sites; for the nearshore sites, similar filters would be built on the barge containing the earlier treatment processes.

Site Controls

For the open-water disposal alternatives, site controls include construction of a dike or a cover, or a combination of both. The dike would need to be placed before disposition of the contaminated sediment and would come from dredging of an uncontaminated site. Approximately 10,000 cu yd of material would be needed for the dike. The cover will consist of uncontaminated, dredged material to a depth of 4 ft. Approximately 10,000 - 15,000 cu yd would be necessary to ensure a proper cover. The uncontaminated lower layer of sediment to be dredged at the TOTE facility would be the obvious choice for the cover material since the means for dredging, transport, and disposal are all in place.

For the upland alternatives, the site would be excavated to a depth of 4-5 ft with the excavated clay used as a dike to contain the material. This excavation would be done in conjunction with construction of the settling basins. Approximately 1 acre would be necessary for a finished grade of 20 ft above the existing ground level. The cover for the completed fill area would consist of four layers: loam - 18 in,; gravel - 6 in.; clay - 12 in.; and gravel - 6 in. The site would be graded to ensure that water does not flow onto the site, does not pond, and flows easily from the site.

For the nearshore alternatives, only the portion of the site below the low tide line would be used for contaminated material. By keeping the contaminated dredged material in an anaerobic environment, the chance of dispersing the contaminant metals is greatly reduced. To ensure the adequacy of this plan, the area should be about 1-1/2 acres in the innermost portion of the site with a subsurface dike at the outer edge to contain the material. The necessary volume of uncontaminated material used for the dike would be approximately 5,000 cu yd. The upper 2-ft layer of the contaminated material would be stabilized using lime to reduce the risk of dispersion.

Assessment of Criteria Values. More detailed designations of the alternatives, as has just been described, allows a better assessment of the alternatives in terms of the evaluation criteria, particularly initial cost and operation and maintenance cost. Using the numerical ranks shown in Table 9.13 for the seven qualitative criteria, each alternative was evaluated. The results, along with a composite criterion, are shown in Table 9.30. The criteria were weighed equally in determining the composite criterion rank. Table 9.31 shows the costs associated with each alternative. For this case study, these costs are rough approximations of the costs associated with each alternative. Actual assessment of the costs of each alternative would involve a detailed determination based on the descriptions provided in the previous subsection.

Ranking of Alternatives. For each alternative, values for the two composite criteria are plotted in Fig. 9.34. From the plot, it can be seen that no one alternative stands out as being clearly dominant over the others. However, four alternatives (D, E, G and C) dominate the other five. This result, however, should be viewed in terms of the various assumptions that were used in the process leading up to this point. Although the multicriteria plot does not put relative weights on the two composite criteria, the display

Table 9.30

Qualitative Criteria Values for Nine Alternatives for Illustrative Example

Alternative	Qualitative Criterion-Ranking							Composite Criterion Value*
	Reliability	Implemen. Avail.	Tech. Effect	Environ. Concerns	Safety	Regulatory Require.	Public Accept.	
A	3	2	3	2	4	2	4	20
B	3	2	3	2	4	2	4	20
C	3	2	4	3	4	3	4	23
D	4	4	4	2	4	3	3	20
E	4	4	4	3	4	3	3	21
F	4	4	4	3	4	3	3	21
G	3	4	3	2	4	3	3	22
H	3	4	3	2	4	3	3	22
I	3	4	3	3	4	3	2	22

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* Assuming equal weights for the seven criteria.

Table 9.31

Estimated Costs for Nine Alternatives for Illustrative Example

Alternative	Initial Cost, $K	O&M Cost, $K/YR	PV Cost, $K*
A	560	20	760
B	540	20	740
C	590	20	790
D	465	10	565
E	505	10	605
F	525	10	625
G	535	15	685
H	530	15	710
I	585	15	735

* Present value (PV) cost calculated using interest rate of 10 percent and an infinite time period

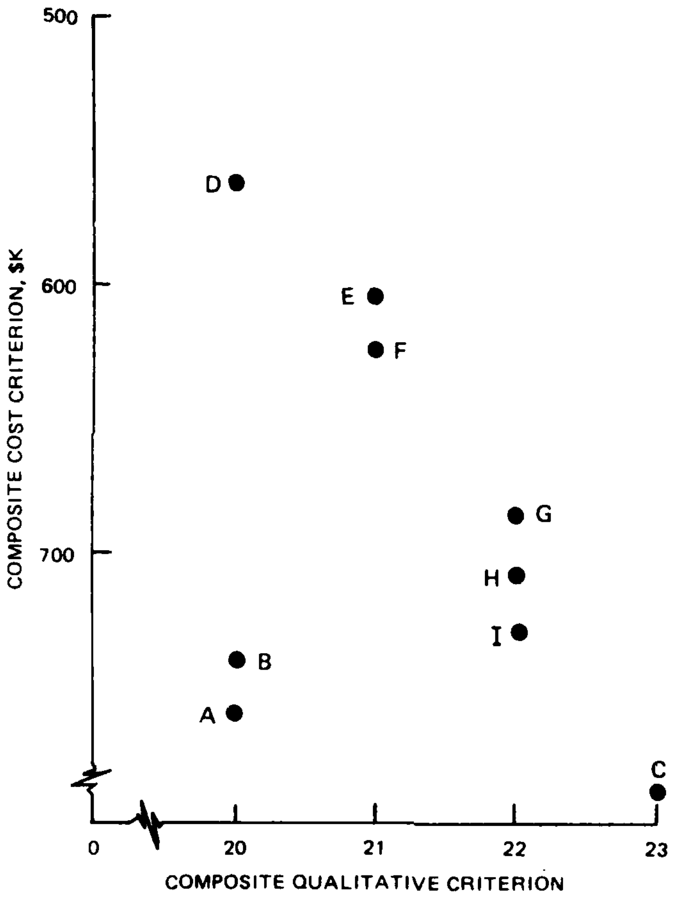


Figure 9.34. Multicriteria plot showing hypothetical values for nine alternatives

gives an illusion that they are treated equally. In addition, seven different criteria make up the composite qualitative criterion, while only two are used in the composite cost criterion. An example of how the results might change can be shown using one number: if the O&M costs for Alternative C were overestimated by $10,000 per year, the composite cost criterion (after amortization) would shift from $760,000 to $660,000. This shift would move point C in Fig. 9.34 to a point much higher, where Alternative C would dominate Alternative G and would appear very competitive with Alternatives D and E. Any number of seemingly minor changes such as this could have a significant impact on the final selection.

At this point results of the process must be combined with knowledge of subjective aspects associated with each alternative that may not have been adequately considered in the evaluation of the nine criteria. If costs were considered a major factor in the decision process, then the alternatives would be ranked D, E, G and C. If, however, the qualitative criteria were viewed as being more important, then the ranked order would be the exact opposite.

Other aspects that may come into play at this point include any of the following: political factors; expected near-term innovations in technology; personal or group biases; unexpected changes in criteria values (e.g., heavy public resistance during the selection process); or consideration of interaction with other dredging projects.

With regard to the four identified alternatives, several factors may influence the ranking of alternatives. The Port of Tacoma is eager to fill both the Milwaukee Waterway and the Blair Slips so that the area can be better utilized. The Port would like to complete the Milwaukee Waterway within the next two years. The desire on the part of the Port would favor use of either of these sites as long as the project were to commence in the specified time frame. There is considerable industrial activity around the Blair Slips, a factor that would need to be accounted for. In addition, the inner slip is being used by a fleet of shallow-draft ships.

Since there are bound to be many other dredging projects in the bay within the foreseeable future, it might be wise to plan and prepare a site capable of handling a large amount of dredged material. This approach would mean that staged construction could be planned and treatment facilities could be used for several projects. This consideration would favor Alternatives C (Hylebos/Browns Point) and G (Blair Slips). Although the Puyallup

River/Railroad Site is large, its full capacity might not be available because of the presence of a wetland and a former meandering river channel claimed by Puyallup Indians.

An agrument on the other side could also be made; since the TOTE project is so small, only a small disposal site should be used. This view would favor a portion of the Puyallup River/Railroad Site (Alternatives D and E) and one of the Blair Waterway Slips (Alternative G). The fact that the Blair Slips can be considered as a large capacity site or three smaller sites puts Alternative G in a good light. Staged use of the site would (1) allow for easy use for small dredging projects, (2) provide a large capacity, (3) possibly allow for better coordination with industrial activity, and (4) give time to relocate the ships currently using the inner slip.

Another consideration that did not unfold during evaluation of Alternative C (Blair Slips) was that the deposited dredged material could easily be covered by clean material dredged from the bottom layer of the TOTE site. This fact could easily warrant the use of a higher value for the environmental criterion and thereby increase the value for the composite quantitative criterion for that alternative.

Given all of these considerations and the results of the process, a likely ranking would be:

Ranking	Alternative
1	G
2	C
3	D
4	E

Alternatives D and E are not much different, and increased quality of effluent water for Alternative E would probably not justify the increase in cost.

Discussion of Case Study

It should be reemphasized that the amount of work that went into the preparation of this case study is far less than would be necessary to actually follow through the process for an actual project. Because the case study is merely an illustration, countless shortcuts were taken for the sake of expediency. Two facets emphasize this fact: very little detail was provided for the final alternatives, and almost no justification was provided throughout the process on why certain decisions were made. The time and resources available for preparing the case study were simply not sufficient to go further. In an actual application, increased level of detail and appropriate justification would be necessary and would go hand-in-hand throughout the process. In most cases, choices would be regional administrative decisions made by the appropriate local, regional, and/or state authorities.

Some of the values and numbers used in the case study may seem unreasonable. An attempt was made to provide realistic values wherever possible. However, the necessary backup calculations were not made, and often numbers (for example costs) were simply assumed. In other cases slightly unrealistic assumptions (e.g., the natural clay liner at the Puyallup River/Railroad Site) were made to allow adequate presentation of the process.

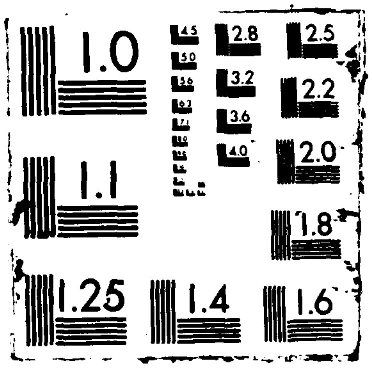
In summary, the case study is presented only to display the process involved in using the framework. Although the TOTE project was a real dredging problem, the decisions, numbers, and values used in the case study should not necessarily be regarded as having validity. The case study illustrates the decision making process.

As a follow up on the actual actions taken at the TOTE facility, the contaminated upper layer was removed and placed in a temporary, lined containment site, slightly upstream from the dredge site. The operation cost approximately $430,000. A decision on the ultimate fate of the temporarily stored material has yet to be made.

Summary of DMASS Framework

This part of the report presents a general procedure to assist in decisions regarding the dredging, transport, treatment, and/or disposal of contaminated dredged material. The process involves five phases: (1) presumption of contaminant pathway, (2) confirmation of contaminant pathway, (3) alternative development and screening, (4) detailed evaluation [illegible] ing, and (5) alternative selection. The first and last phases were [illegible] covered in great detail in this part; the presumption of contaminant [illegible] phase is thoroughly described in Lee et al. (1985), and the [illegible] tion phase involves the actual decisions on which project [illegible] final design. This final step is one that involves human [illegible] ing it difficult to establish set rules or pathways. The [illegible]

AD-A184 930 GUIDELINES FOR SELECTING CONTROL AND TREATMENT OPTIONS 6/8
FOR CONTAMINATED DREDGED MATERIAL(U) ARMY ENGINEER
WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR..
UNCLASSIFIED M J CULLINANE ET AL. SEP 86 F/G 24/3 NL


1.0
4.5
5.0
5.6
6.3
7.1
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

process leading up to the final decision is to provide as much meaningful information as possible, without muddling the issue with an overwhelming array of facts and data.

The three major phases covered in this part (confirmation of contaminant pathway, alternative development and screening, and detailed evaluation and ranking) represent a process which selectively screens potential disposal sites, screens available technologies, and combines sites and technology schemes to form alternatives that are further screened to a set that can be ranked for final selection. The intent of the process is to eliminate poor choices as soon as possible in the process while retaining options that are worthy of further consideration. By eliminating as many options early in the process, considerable resources can be saved later in the process when more detailed (and therefore more costly) evaluations are necessary.

The process presented in this part represents an ongoing effort to develop a logical and straightforward approach to a very complex problem. As more experience is gained in the area of the disposal of contaminated dredged material, modifications to the process may be warranted. In addition, exploration of other related issues, outlined in Part XI of this report, may help to enhance the overall process.

PART X: CONCEPTS FOR EVALUATING THE DESIGN WITHOUT TESTING OPTION

Background

The Decisionmaking Framework (Lee et al. 1985, Peddicord 1986) proposes a variety of tests for the determination of appropriate restrictions on the disposal of contaminated dredged material. The tests may be roughly divided into two categories: tests to determine sediment characteristics (usually bulk chemistry and simple bioassays) of the sediment to be dredged and tests to determine the potential for contaminant mobility. Whereas those for determining sediment characteristics are relatively inexpensive, tests for determining the potential for contaminant mobility are expensive, time consuming, and, in many cases, are not conducted using a standard test protocol.

An alternative to these extensive testing procedures is the concept of conservative design or design based on the sediment's bulk chemistry. Using this concept, the disposal site is designed to control the known characteristics of the dredged material (based on bulk chemistry) and to meet stringent restrictions for assumed unknown characteristics. The basis for this strategy is the idea that implementation of a control/treatment alternative designed from bulk sediment chemistry data may be more economical or more expedient than conducting the extensive testing protocols identified by the decisionmaking framework (Lee et al. 1985, Peddicord et al. 1986). Cost concerns and time constraints, as well as technical factors, influence the decision to substitute design in lieu of extensive testing.

Contaminant mobility testing may not be necessary under at least three scenarios:

a. Bulk chemistry results indicate that the material is acceptably clean and standard disposal site design criteria apply.

b. The intended future use of the disposal site imposes design restrictions more stringent than those that would otherwise be required. For example, if an upland disposal site is to be capped and sealed because the site is planned for future industrial use, plant and animal bioaccumulation testing could be avoided.

c. The use of the most environmentally protective design is more cost effective than incurring the cost of testing to demonstrate that a less restrictive design is appropriate.

There is currently no standard design for a contaminated dredged material disposal site. Conceptual designs are usually based on the addition of appropriate design features to conventional sites that address anticipated contaminant migration pathways. Since contaminant migration pathways determine appropriate restriction alternatives, disposal site characteristics are as important as sediment characteristics. Another approach is to begin with the most environmentally secure facility and delete design features until an appropriate level of restriction is attained. In either case, it is necessary to define both a conventional facility and an environmentally secure facility. A typical upland disposal site design is presented in Appendix D. Similar typical designs are not available for nearshore, restricted open-water, or environmentally secure facilities for any of the three types of disposal.

Design features incorporated into an environmentally secure facility depend as much on regulatory standards and public pressures as technical requirements. Thus, there is no universally accepted design for an environmentally secure facility for disposal of contaminated dredged material. In such cases, it is standard engineering practice to adapt design concepts from similar facilities. Unfortunately, there are no similar facilities for restricted open-water or nearshore disposal. For upland and possibly near shore sites, guidance can be obtained by reviewing the USEPA hazardous waste landfill regulations promulgated under the Resource Conservation and Recovery Act (40 CFR 264). These standards apply to facilities designed to contain hazardous wastes and are overly conservative for application to a typical contaminated dredged material. To provide a point of reference, however, a summary of these standards is presented in Appendix E. The technical require ments of these standards are not directly applicable to the disposal of contaminated dredged material, and in many cases the criteria may indeed be technically infeasible when applied to contaminated dredged material. However, the general concepts provided by these criteria can be used to identify design considerations applicable to the disposal of all contaminated materials. The concept presented in Figure 10.1 and described in Appendix E has been proposed as a secure contaminated dredged material disposal facility meeting these requirements. However, this design is clearly excessive for most dredged material disposal site combinations. This type of facility would be appropriate for disposal of highly contaminated sediments in environmentally

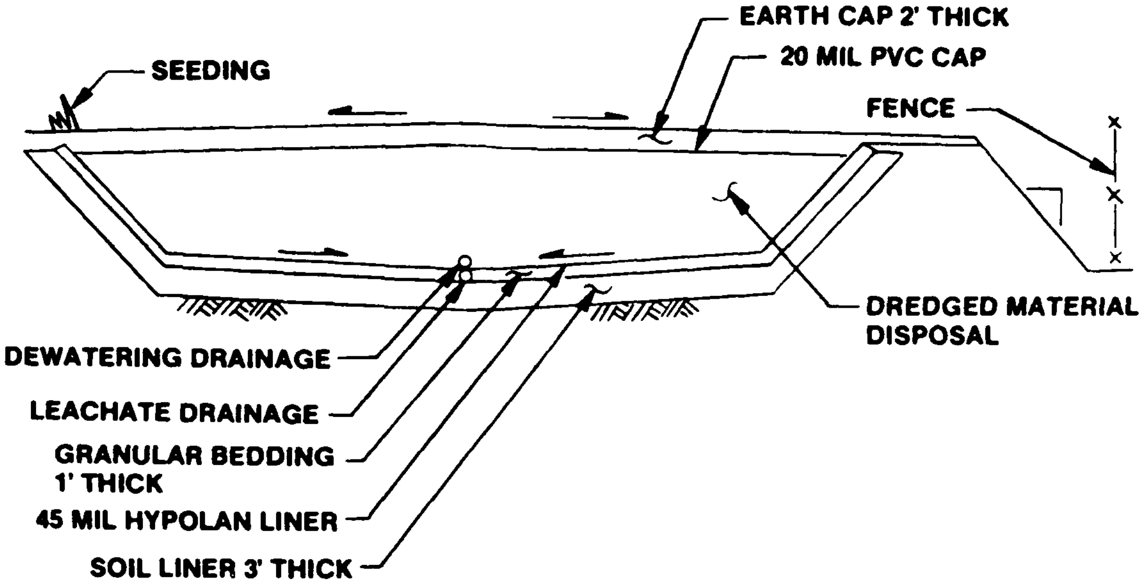


Figure 10.1. Proposed concept for a secure disposal facility for contaminated sediments

sensitive areas. Such dredged material-disposal site combinations would only be chosen as a last resort.

Design versus Extensive Testing

Design Strategy

Since there are no standard designs for contaminated dredged material disposal facilities, it is obvious that there are also no guidelines for what constitutes an overdesigned facility. Indeed, the entire concept of overdesign may be somewhat subjective because of the miriad and often conflicting concerns of the various resource management and regulatory agencies involved in the decision making process. Thus, the concept of facility overdesign may be subject to a variety of interpretations. The bottom line is the definition of an acceptable and approvable plan for disposal of the contaminated dredged material.

The planning level design of a contaminated dredged material disposal facility usually incorporates a variety of structural features designed to isolate the contaminated dredged material from the environment and a monitoring program to assess the environmental impacts of the disposal facility. The testing protocols defined in the Decisionmaking Framework (Lee et al. 1985, Peddicord et al. 1986) are designed to minimize the number of site restrictions while ensuring that implemented measures have a high probability of meeting environmental goals. The concept of design in lieu of extensive testing, on the otherhand, is generally based on less data and may have more environmental risk. To compensate for the possibility of increased risk, such concepts usually include more intensive monitoring programs and contingent remedial action plans that are triggered by specific contaminant releases as determined by the monitoring plan. Thus, the design in lieu of extensive testing proposal includes three major elements:

a. Design features (including a management plan).

b. Monitoring plan.

c. Remedial action plan.

Design features. Appendix D, design of a typical conventional dredged material disposal facility, and Appendix E, design of an environmentally secure dredged material disposal facility, offer the two extremes available for disposal of contaminated dredged material in the upland and nearshore environment. Design features incorporated in the typical contaminated dredged material disposal facility would probably be somewhere between these two extremes. The decision to include any particular design feature depends on the characteristics of the dredged material and disposal site.

Monitoring Plan. An integral part of any strategy, as described above, is a monitoring program that will determine the effectiveness of the control/treatment strategies and the impact of the disposal site on the surrounding environment. Monitoring includes the physical inspection of the disposal site as well as implementation of techniques for evaluating contaminant releases via any of the migration pathways associated with a specific site. Requirements for monitoring are discussed in Appendix E.

Remedial Action Plan. The remedial action plan is a contingency plan that is executed if disposal facility design results in unacceptable environmental consequences. Execution of the remedial action plan is triggered by interpretation of data collected during execution of the site monitoring program. Remedial actions will be similar to those for hazardous waste sites (USEPA 1985). Whereas remedial actions associated with the release of hazardous substances are planned after the fact, remedial actions developed for execution at dredged material disposal sites are preplanned activities. USEPA (1985) provides detailed guidance on remedial action planning.

The remedial action plan consists of a series of activities that will be implemented if certain events occur. These activities may range from increased monitoring to the removal of the dredged material. The contents of the remedial action plan will be extremely site specific. Table 10.1 provides a list of general remedial action technologies applicable for site restoration (USEPA 1985). Most of the technologies are presented in Parts II through VI of this report.

Extensive Testing Strategy

The Decisionmaking Framework (Lee et al. 1985, Peddicord et al. 1986) incorporates the use of extensive contaminant mobility testing protocols to evaluate the potential impact of the contaminated dredged material on the surrounding environment. A description of many of these protocols is included in Part VII and Appendix A of this report. Unfortunately, many of these proposed protocols are still in the verification stage and have not been finalized. In other cases, appropriate protocols have not been developed or selected.

In general, the contaminant mobility protocols are costly and time consuming. An estimate of the cost and time required to conduct each of the contaminant mobility testing protocols is presented in Table 10.1. Costs are presented in 1984 dollars. General assumptions made to calculate costs were that the equipment and facilities to conduct the test are available. Therefore, equipment costs were not included. In addition, each sediment sample was considered to be tested in four replicates to ensure some degree of precision. Cost to conduct the test will vary from one part of the nation to another. Chemical analysis costs will also vary across the nation. Cost varies with the number of samples and the number of parameters determined. In most cases, a fewer number of composited sediment samples can be evaluated to give an indication of potential contaminant mobility from sediment to be dredged. In addition, if the sediment is analyzed for fewer contaminants, especially organic compounds, the cost of chemical analysis will be reduced. Table 10.1 clearly illustrates the significant costs associated with chemical analysis of samples. These costs are generated from the testing of only one sediment sample. Additional sediment samples will increase costs proportionally, rapidly escalating the total cost of contaminant mobility testing.

Table 10.1

Relative Time and Cost Estimates for Conducting Test Protocols

Test Protocol	Time Months	Cost/Test Run,[1] $	Cost of Chemical Analysis,[2] $	Total Cost,[3] $
Sediment Characterization:				
1. Bulk Chemistry	2	1,000-2,000	8,000-12,000	8,100-12,200
2. Physical Characteristics	1	1,000-2,000	-	1,000-2,000
Site Characterization:				
1. Surface Investigations	6	10,000-150,000	-	10,000-150,000
2. Geologic Investigations	6	20,000-200,000	-	20,000-200,000
3. Ecological/Environmental Assessment	6	75,000-125,000	-	75,000-125,000
Contaminant Release:				
1. Effluent Quality	2	100-500	6,000-9,000	6,100-9,500
2. Surface Runoff	6	4,000-6,000	15,000-22,500	19,000-28,500
3. Leachate (Batch)[4]	6	30,000-40,000	70,000-90,000	100,000-130,000
4. Leachate (Continuous Flow)[4]	6	30,000-40,000	70,000-90,000	100,000-130,000
5. Plant Uptake[5]	4	4,000-6,000	12,000-18,000	16,000-24,000
6. Animal Uptake[6]	4	3,000-5,000	12,000-18,000	15,000-23,000
7. Mixing Zone (Chemical Criteria)	2	100-500	6,000-9,000	6,100-9,500
8. Mixing Zone (Toxicity Criteria)	3	1,000-5,000		1,000-5,000
9. Benthic Bioassay and Bioaccumulation[7]	5	1,000-5,000	16,000-24,000	17,000-29,000
Control/Treatment Design:				
1. Consolidation	2	4,000-6,000	-	4,000-6,000
2. Settling	3	4,000-6,000	-	4,000-6,000
3. Chemical Clarification	4	11,000-15,000	-	11,000-15,000
4. Linear Compatibility	12	75,000-100,000	-	75,000-100,000
5. Stabilization	6	20,000-30,000	30,000-40,000	50,000-70,000
6. Treatability Studies	12	10,000-50,000	10,000-50,000	20,000-100,000

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[1] One sediment sample.

[2] Estimated cost of PCBs, pesticides, 10 metals, and suspended solids per analyzed sample ranged from $1,000-$1,500.

[3] Does not include cost of equipment or facilities or sample collection and transport to lab.

[4] Leaching test and serial batch tests currently under development. Routine test cost will be lower.

[5] Plant bioassay of 45-day exposure.

[6] Earthworm bioassay of 28-day exposure.

[7] Four species were used.

The size of the dredging project and the homogeneity of the sediment are the controlling factors in determining the cost benefits of the design in lieu of extensive testing strategy. If the sediment in a dredging project is homogeneous, only one suite of tests would be required to determine the potential for contaminant mobility, regardless of project size. Thus, it can be assumed that the costs of conducting the testing protocols for a 100,000 cu yd project would be the same as for a 1,000,000 cu yd project. It is evident then that the smaller the project, assuming homogeneous materials, the greater the cost factor for extensive testing. Also if a project has several different types of dredged material with different types and degrees of contamination then the extensive testing protocols would have to be conducted on each type of sediment. Thus, if the dredged materials cannot be assumed to be homogeneous, more tests will be required and the greater the cost factor for testing.

In addition to the costs of recommended contaminant mobility protocols, it must be recognized that many of the suggested procedures are still in the developmental stages. Furthermore, the extensive testing protocols are time consuming and may delay project completion.

Selection Strategy

Figure 10.2 presents a general flow chart of the steps involved in the implementation of the conservative design strategy. The implementation process is similar to that presented in Part IX with the following exceptions:

a. The migration pathway analysis is based on bulk chemistry results rather than detailed contaminant mobility testing.

b. Closer coordination with regulatory agencies is required, with the regulatory agencies actively participating in the alternative development and evaluation process.

c. The alternative package includes a detailed remedial action plan.

d. Monitoring will be more intensive.

The decision to actually implement the design in lieu of extensive testing alternative should be based on the twin concerns of costs and environmental risks as measured by regulatory acceptance. Costs are generally quantifiable whereas regulatory acceptance will vary from project to project and may be based on a variety of intangible factors. Therefore, the strategy presented in Figure 10.2 emphasizes the use of costs as an initial screening

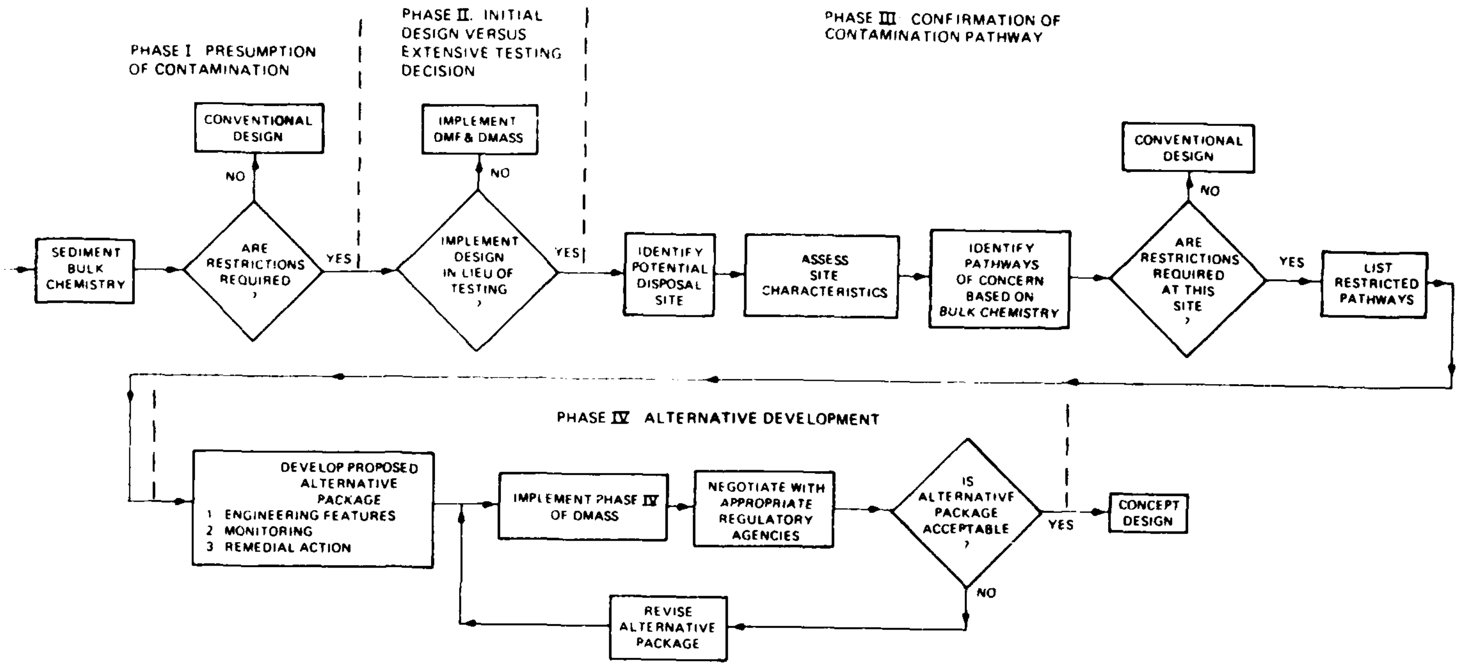

Figure 10.2. Flowchart describing implementation of the design in lieu of extensive testing strategy

tool to evaluate the feasibility of implementing the design in lieu of extensive testing option.

The four-phase strategy presented in Figure 10.2 includes: presumption of contamination, initial design versus extensive testing decision, confirmation of a contaminant pathway, and alternative development and selection. Each of these phases is discussed below.

Phase I Presumption of Contamination

Phase I of the selection strategy, presumption of contamination, is similar to Phase I of the DMASS presented in Part IX. However, the presumption of contamination is based on the results of bulk chemistry rather than the contaminant mobility testing described in the DMF (Lee et al. 1985). It is assumed that the concentrations of contaminants represented by the results of bulk chemistry testing will represent the worst case, i.e. if all contamination as measured by the bulk chemistry were released via the various migration pathways. Thus, bulk chemistry values would be used in lieu of results of mobility testing protocols to determine potential release of contaminants. This concept could be modified slightly if it were decided to perform some of the less expensive test protocols, e.g., modified elutriate.

Phase II Initial Design Versus Extensive Testing Decision

Since the costs for conducting the contaminant mobility test protocols can be extremely high, it may be cost effective to implement or overdesign the control option to ensure isolation of the contaminated dredged material instead of performing the testing protocols; i.e., construction of a liner system may be less costly than conducting the leachate testing protocol or capping a site with clean material to prevent contamination of plants and animals and associated food-webs may be more cost effective than conducting the plant and animal uptake test protocols.

The initial decision to proceed with the design versus extensive contaminant mobility testing will be made based on the relative costs of each.

The costs for conducting one complete round of contaminant mobility testing protocols on one homogeneous sediment can be greater than $600,000. Furthermore, several of the proposed testing protocols are still under development and the exact costs are impossible to predict. In addition, depending on the specific site conditions and the control/treatment strategy used, all of the testing protocols might not be required.

The costs for the entire design in lieu of testing option must include the cost for construction of the control/treatment alternative, the costs for extensive monitoring, and the potential remedial action should the control/treatment alternative fail. The project planner must make an initial guess as to the control/treatment alternatives that would be approved by regulatory agencies without conducting contaminant mobility testing protocols. Preliminary discussions with regulatory agencies may be desirable during this phase.

Once the costs for the extensive testing and the design without extensive testing options have been determined, a simple cost comparison can be used to determine the appropriate course of action. Unfortunately, due to the site-specific nature of the costs to implement a control/treatment strategy, the factors involved in ground-water monitoring that can cause costs to vary by orders of magnitude, and the possibility of a future remedial action, it is difficult to accurately estimate screening level costs during Phase II.

However, using material and construction cost data presented earlier in this report, Fig. 10.3 and 10.4 were developed to provide a comparison of the costs of engineering features to limit contaminant migration and the cost of contaminant mobility testing. Figure 10.3 presents information for small projects (less than 100,000 cu yd) while Figure 10.4 shows information for large projects (greater than or equal to 100,000 cu yd). Clearly, for large projects it will almost always be cost effective to conduct extensive testing in an effort to eliminate control measures. For smaller projects, however, the design in lieu of testing option may be cost effective. It should be stressed that Fig. 10.3 and 10.4 are presented for illustrative purposes only and do not reflect actual costs for any project.

The result of Phase II is a decision to proceed with the design in lieu of extensive testing or implementation of the DMF (Lee et al. 1985).

Phase III Confirmation of Contaminant Pathway

Phase III corresponds to phase II of the DMASS presented in Part IX of this report. However, the migration pathway is based on the bulk chemistry data rather than contaminant mobility testing. Phase III results in a list of restricted pathways and associated contaminants of concern.

Phase IV Alternative Development and Selection

Phase IV includes elements of phases III, IV and V from the DMASS (Part IX of this report) as well as the provision for extensive discussions

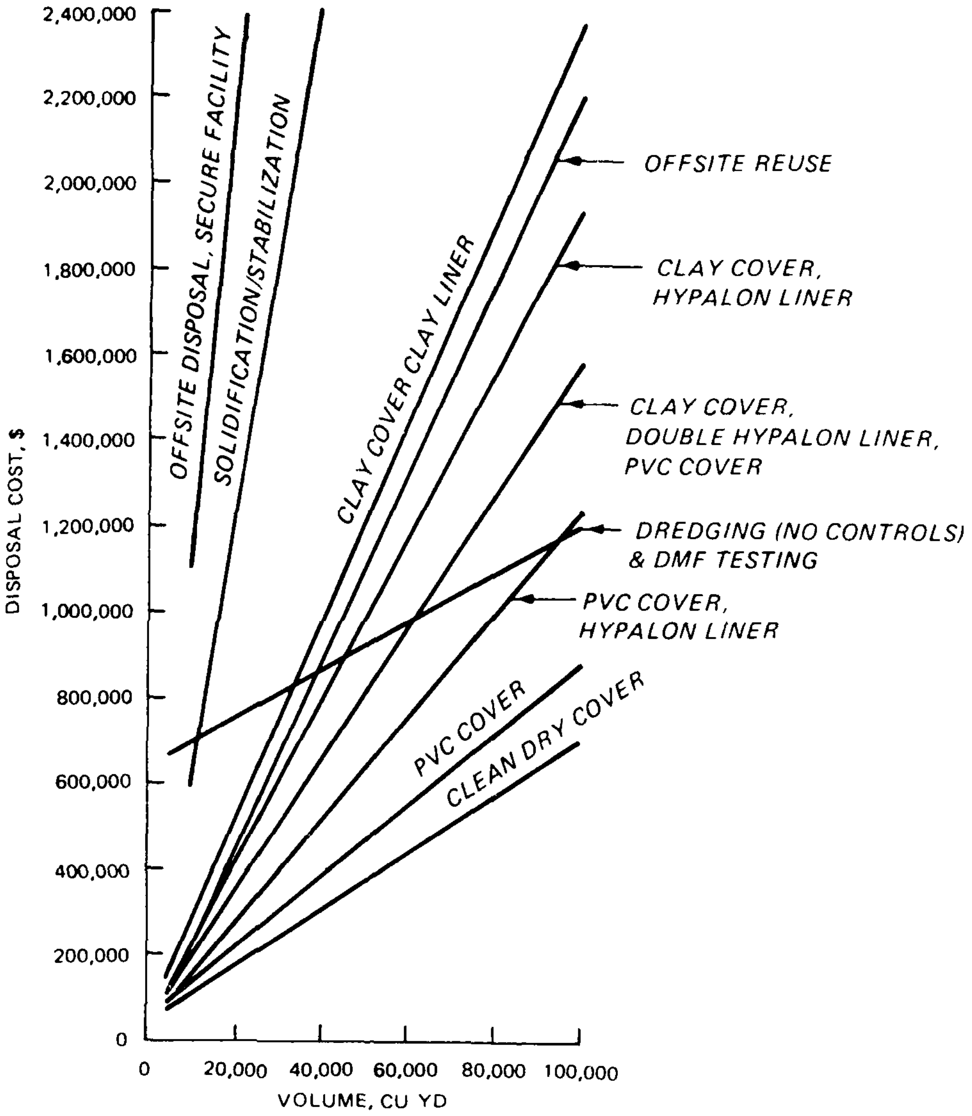

Figure 10.3. Comparison of the costs of restrictions versus the cost of extensive testing for small projects (<100,000 cu yd)

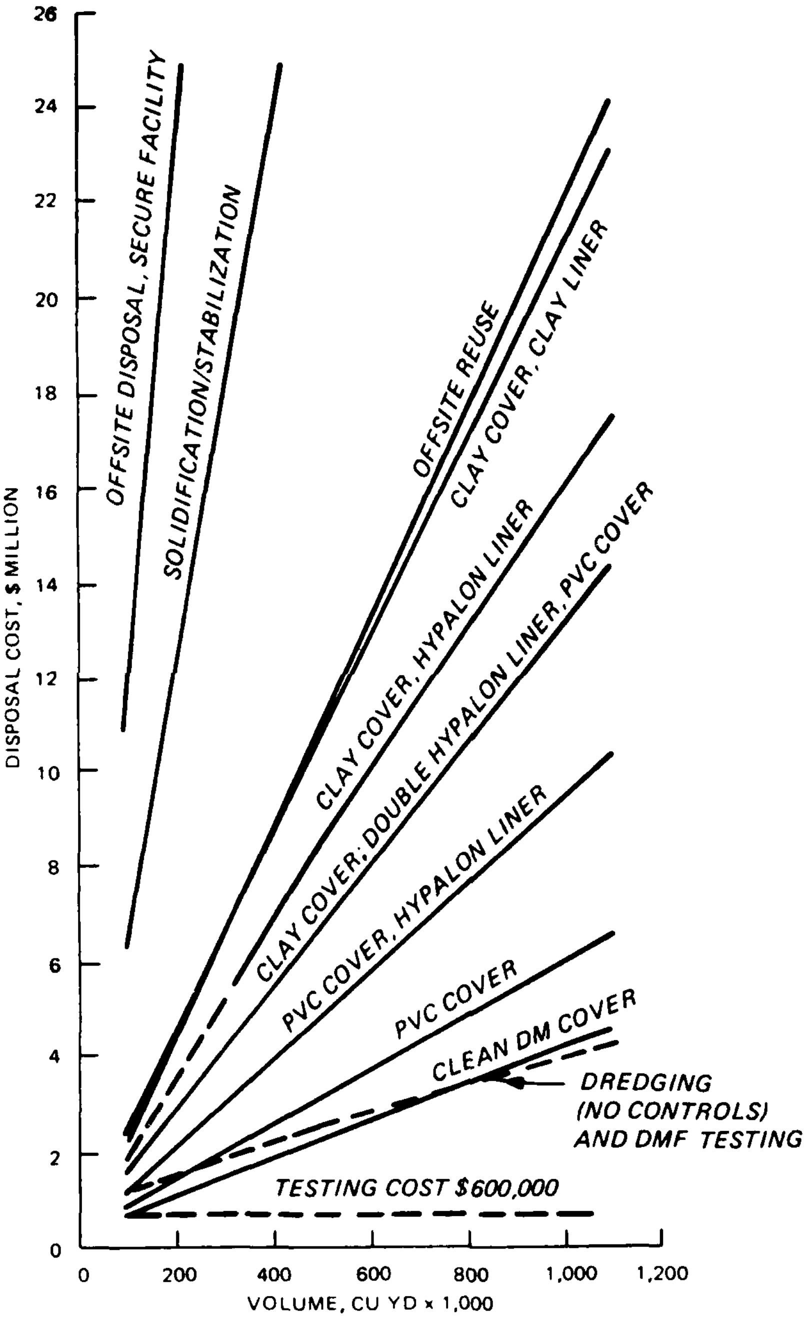

Figure 10.4. Comparison of the costs of restrictions versus the cost of extensive testing for large projects (≥100,000 cu yd)

and negotiations with regulatory and resource management agencies to select the desired control/treatment-monitoring-remedial action alternative.

The implementation of the design without extensive testing option will probably be a complicated process because of the reluctance of regulatory agencies to accept disposal facilities incorporating fewer design features than the RCRA alternative (Appendix E). Typically, regulatory resistance to design in lieu of extensive testing is met by agreements to extensively monitor migration pathways during active dredging/transport/disposal activities, extensive long-term monitoring of the disposal sites, and the promise to execute remedial action measures if necessary. This approach trades high initial capital costs associated with control/treatment for increased future operating costs and the potential for future capital costs to execute the remedial action plan.

The exact nature and details of the control/treatment-monitoring-remedial action alternative are usually determined through intense negotiations. These negotiations serve to narrow the number of alternatives that must be evaluated and define the level of detail of the required evaluations; however, it is still necessary to perform the detailed alternative evaluation (Phase IV) of the DMASS. The only difference is that bulk chemistry information is substituted for the results of contaminant mobility testing.

The results of the detailed analysis are used as input to regulatory agencies for use in their decisionmaking process. The detailed evaluation also aids the planner in evaluating the risks associated with the design in lieu of extensive testing option and the probability that the remedial action plan will have to be executed.

Obviously, the appropriate control/treatment-monitoring-remedial action package will be highly site specific, and development of a generic package is not feasible. Furthermore, any final alternative may result as much from nontechnical as from technical considerations. The selection process may be highly qualitative.

The final product of Phase IV is an approvable control/treatment-monitoring-remedial action package sufficiently detailed for initiation of concept design.

Summary

The design in lieu of extensive testing strategy employs control/treatment alternatives that are expected to sufficiently isolate contaminated dredged material from the surrounding environment. These control/treatment alternatives can take a variety of forms including liners, surface caps, etc. Design is based on bulk chemistry data. Economically, it is desirable to limit the number of restrictive design features. In order to provide sufficient reliability, the design in lieu of testing strategy incorporates extensive monitoring and contingent remedial action plans. The decision to use the design in lieu of testing strategy will be dependent on the cost and time for implementation requirements associated with the design in lieu of extensive testing strategy versus those associated with implementing the DMF and DMASS.

PART XI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Dredging and dredged material disposal have been extensively evaluated and researched in recent years, and the literature is abundant with reports of laboratory and field studies, literature reviews, and concepts for handling dredging and disposal operations. Most of this literature deals with relatively clean sediment. Disposal of contaminated sediment has received less attention, but recently has come to the forefront of consideration and study because of problems and questions that have surfaced in protecting the environment from the effects of contaminated dredged material disposal and in selecting, engineering, and operating disposal sites for contaminated dredged material. Other concerns have arisen from controlling contaminants that may be released at the dredging site or that may be released during transport from the dredging site to the disposal area.

Management, control, and treatment technologies have been oriented to the control of suspended sediment. While control of suspended sediment must be an integral part of any strategy for control of contaminants, control/treatment of contaminated dredged material generally must go beyond control of suspended sediment.

Long-term release of contaminants via various pathways from disposal/ sites cannot be ignored. Techniques for predicting these releases are under development and more information is needed to assess environmental effects and the need for controls and to provide design data for treatment processes.

Control technologies are available and have been proposed for containment and/or treatment of sediment and site waters expected at a dredged material disposal site. Beyond removal of suspended sediment from disposal area overflow, few technologies have been demonstrated for contaminated dredged material. Strategies for implementation of controls for a dredging scenario have not been adequately developed.

Design procedures for site water treatment technologies at upland and nearshore disposal sites are available and proven. Bench-scale tests for determining design parameters for treatment of site waters and leachate are essentially the same as those in the water treatment and wastewater treatment industry and can be applied to treatment processes at disposal areas.

Nearshore sites that involve saline waters present unusual, but not insurmountable, design problems. Control measures for lining sites and covering sites are not easily adaptable to the conditions at a confined disposal facility. Placement of liners, particularly at nearshore sites, has not been sufficiently demonstrated. Dewatering a confined disposal facility containing contaminated dredged material will require special equipment, possibly treatment of site water, and a management plan for controlling contaminant releases during the short term. Dewatering a nearshore site for placement of a cover will require development of management schemes and techniques that have been field demonstrated for only a few cases.

Design procedures for control measures at open water disposal sites are not well developed. In particular, designs for submerged diffusers and downpipes in deep open-water sites have not been thoroughly developed and their implementation has not been documented.

Selection of control and treatment technologies depends on a number of factors, including: the pathways affected (type of material, degree of contamination, characteristics of disposal site); the impact of the technology (level of treatment, degree of control, reliability etc); the evaluation of criteria (cost, reliability, risk, etc), and the emphasis of decisionmakers. Guidelines and procedures for evaluating and selecting control or treatment alternatives have been presented. The DMASS is based on the concept of eliminating poor options via a series of screening processes. The screening approach is intended to eliminate poor dredge/transport/control options from further consideration without excluding any viable alternatives. The process allows considerable flexibility in that decisionmakers (and/or local/ regional officials) can select the desired criteria for use at different stages in the process; they can choose acceptable levels for criteria values, and they can select different paths through the DMASS flowchart based on project-specific characteristics.

The DMASS does not make decisions, but it provides a logical framework for eliminating poor alternatives and comparing those good alternatives that remain for detailed evaluation. Because of site specificity and the relative merits of different control techniques, no single alternative is likely to dominate all others and emerge as the best alternative. Decisionmakers must look at the relative merits and trade-offs of the alternatives, along with nonquantifiable aspects, in order to make a decision.

Economics of control alternatives are inadequately documented and highly variable. The cost of testing protocols for determining environmental effects and for selecting design parameters can represent a significant expenditure. For disposal of small quantities of contaminated sediment, it may be less expensive to forego most of the tests and provide state-of-the-art controls to protect potentially affected pathways.

Selection of control/treatment alternatives for very highly contaminated dredged material can rely on technologies developed and being implemented for Superfund projects with the assurance of major costs. Technologies for disposal of relatively clean dredged material may be selected from a number of proven and demonstrated methods. The most difficult decisionmaking process is the one addressed by this study: selection of technologies for contaminated sediment that requires more control than clean dredged material, but does not warrant state-of-the-art controls for a hazardous material. Until more experience and data are available for application of some of these control and treatment alternatives, the decisionmaking process must remain somewhat flexible.

Although the decisionmaking process must be flexible until a satisfactory technology data base is available, uncertainty in the process must be minimized. The process must have some measure of consistency and predictability. This can be accomplished by codifying to the extent possible, the regional administrative decisions (RAD's) identified in Part IX. Many of these RAD's are qualitative and procedural which result in difficult and hard to defend decisions on the part of regulatory and resource management agencies. However, only through codification of requirements and criteria can projects be expected to progress in a timely and orderly fashion.

Recommendations

Technology Development

One of the principal recommendations resulting from this study is that promising technologies for control or treatment of contaminated sediment be demonstrated on a pilot scale or, for selected technologies, on a prototype basis in the Puget Sound area. These demonstrations should be planned, monitored, and evaluated with emphasis on defining the reliability, technical effectiveness, economics of the technology, and other appropriate criteria.

Candidate technologies or alternatives for demonstration include the following:

(1) Open-water disposal

(a) The technical feasibility of using downpipes and submerged diffusers in deep water should be investigated.

(b) Concepts for treating contaminated dredged material followed by unconfined open water disposal should be developed and evaluated.

(c) Techniques for accurate placement of confinement dikes and caps in deep water should be evaluated.

(2) Upland disposal

(a) Combinations of technologies designed, operated, and managed to contain, minimize, or collect site waters generated as surface runoff, leachate, or interstitial drainage should be evaluated. Technologies as part of this system include covers, surface water controls, liners, and leachate collection. An integral part of the control system would be management of the facility while dredged material is being placed in the site.

(b) Treatment of site waters by higher treatment levels, particularly for organics removal should be evaluated.

(c) Stabilization/solidification of a small volume of highly contaminated dredged material and strategies for placement of the material within a site with long-term monitoring for evaluation.

(d) Separation of the coarse-grained fraction of hydraulically transported material by hydrocyclones or other technology followed by treatment of the remaining more contaminated fine-grained fraction.

(e) Isolation of highly contaminated sediment within a disposal area by surrounding it with cleaner dredged material.

(3) Nearshore disposal

(a) Lining a nearshore site with a synthetic liner or a soil liner to contain and/or collect leachate.

(b) Management of a nearshore site to maintain highly contaminated material in an anaerobic reduced state with a program to monitor test results over the long term.

(c) Treatment systems for contaminated saline waters

(4) Transport

(a) Development of containment plans and specification of equipment for capturing/containing release of contaminants from ruptured pipelines or pumping stations in the Puget Sound area.

(b) Development of strategies/plans or standard operating procedures for barge and truck transport of contaminated dredged material in the Puget Sound area.

(5) Dredging operations. Controls for dredging operations have been technically demonstrated in other areas. If a particular project requires control at this level for environmental or public acceptance reasons, then a prototype application of these technologies may be justified.

Analytical Techniques

The DMASS was developed specifically for the Puget Sound area. The DMASS concept may be adapted to other areas where it would be beneficial in selecting control and treatment alternatives for contaminated dredged material. In order to fully implement DMASS, additional analytical techniques must be developed and/or adapted to the decisionmaking process.

(1) Contaminant migration. Prediction of contaminant migration from disposal sites requires further research to provide the data necessary to plan, design, and evaluate control/treatment alternatives. Of particular concern are protocols for assessing the groundwater and air migration pathways. Development of leaching protocols for assessing the potential for contaminant migration from upland and near shore disposal sites is a priority.

(2) Computerized procedures. Computer assisted procedures for analyzing site specific contaminant migration potential and related environmental impacts should be developed. Development of programs to analyze the contaminant migration impacts on ground water and surface water at upland and near shore sites is a priority in this area. These programs should be coupled with the contaminant migration protocols of the DMF (Lee et al. 1985, Peddicord et al. 1986).

(3) Cost estimating. The cost of dredging and disposal of contaminated sediment is a major uncertainty in the decisionmaking process. Development of a unit cost based methodology for estimating the cost of projects involving contaminated dredged material would simplify the decisionmaking process.

(4) Evaluation factor assessment. The choice and use of evaluation factors have a significant effect on the outcome of the decisionmaking process. This aspect of the decisionmaking process is usually left to local, regional, and/or state officials who are responsible for the final decision. Many of the factors are evaluated in qualitative terms. Additional research is needed to develop techniques for identifying and quantifying important criteria on a project specific basis by which these factors can be evaluated.

(5) Systems analysis. System analysis techniques and the use of small computers might be of great help in the decisionmaking process itself. Computer programs are used routinely to provide information on different aspects of a problem (e.g. groundwater flow regimes or dispersion during open-water disposal). However, computerized routines can also assist greatly in the process of making decisions. Systems analysis techniques, including knowledge-based (expert) systems, could be used to help formulate alternatives and screen out poor choices simultaneously. In addition, programs currently exist to assist in weighting the importance of different criteria. Such approaches could be integrated into the overall framework.

Disposal Site Management

The coordinate use of one disposal site for several dredging projects has a number of advantages. Unlike certain hazardous wastes, different types of contaminated dredged material are generally compatible. Therefore, there is very little risk in disposal of sediments from different dredging projects in one site. Such an approach would have several benefits. The regulatory/public acceptance process would be eased when compared with that for several small sites. In addition, considerable cost savings would result because of economics of scale.

(1) Near term disposal operations. Sites selected to receive dredged materials from several projects should be evaluated to develop appropriate management techniques during active disposal operations. All aspects of active disposal operations should be investigated including environmental impact, cost, and socio-political considerations.

(2) Long term disposal operations. The long term impact of contaminated dredged material requires additional research.

(3) Beneficial use. Techniques for the beneficial use of contaminated dredged material should be investigated.

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APPENDIX A

DREDGED MATERIAL LABORATORY PROCEDURES

APPENDIX A: DREDGED MATERIAL LABORATORY PROCEDURES

PART I: MODIFIED ELUTRIATE TEST*

The modified elutriate test should be conducted and appropriate chemical analyses should be performed as soon as possible after sample collection. The volume of elutriate sample needed for chemical analyses will depend on the number and types of analyses to be conducted (Plumb 1981**). Both dissolved and total concentrations of contaminants must be determined. The volume required for each analysis, the number of parameters measured, and the desired analytical replication will influence the total elutriate sample volume required. A 4-ℓ cylinder is normally used for the test, and the supernatant volume available for sample extraction will vary from approximately 500 to 1,000 ml, depending on the sediment properties, settling times, and initial concentration of the slurry. It may be necessary to composite several extracted samples or use large-diameter cylinders to obtain the total required volume.

Apparatus

The following items are required:

a. Laboratory mixer, preferably with Teflon shaft and blades.

b. Several 4-ℓ graduated cylinders. Larger cylinders may be used if large sample volumes are required. Nalgene cylinders are acceptable for testing involving analysis of metals and nutrients. Glass cylinders are required for testing involving analysis of organics.

c. Assorted glassware for sample extraction and handling.

d. Compressed air source with deionized water trap and tubing for bubble aeration of slurry.

e. Vacuum or pressure filtration equipment, including vacuum pump or compressed air source and appropriate filter holder capable of accommodating 47-, 105-, or 155-mm-diam filters.

f. Presoaked filters with 0.45-μm pore-size diameter.

g. Plastic sample bottles, 500-ml capacity for storage of water and liquid-phase samples for metal and nutrient analyses.

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* Material in this appendix was extracted from DRAFT EM 1110-2- "Confined Dredged Material Disposal."

** References cited in this appendix are included in Part XII of the main text.

h. Wide-mouth 1-gal-capacity glass jars with Teflon-lined screw-type lids for sample mixing. These jars should also be used as sample containers when samples are to be analyzed for pesticide materials.

Prior to use, all glassware, filtration equipment, and filters should be thoroughly cleaned. Wash all glassware with detergent; rinse five times with tap water; place in a clean 10-percent (or stronger) HCl acid bath for a minimum of 4 hr; rinse five times with tap water; and then rinse five times with distilled or deionized water. Soak filters for a minimum of 2 hr in a 5-M HCl bath and then rinse 10 times with distilled water. It is also a good practice to discard the first 50 ml of water or liquid phase filtered. Wash all glassware to be used in preparation and analysis of pesticide residues using the eight-step procedure given USEPA (1980a).

Test procedure

The step-by-step procedure for conducting a modified elutriate test, as shown in Figure A.1, is given in the following paragraphs.

Step 1 - Slurry preparation. The sediment and dredging site water should be mixed to approximately equal the expected average field inflow concentration. If estimates of the average field inflow concentration cannot be made based on past data, a slurry concentration of 150 g/ℓ (dry-weight basis) should be used. Predetermine the concentration of the well-mixed sediment in grams per liter (dry-weight basis) by oven drying a small subsample of known volume. Each 4-ℓ cylinder to be filled will require a mixed slurry volume of 3-3/4 ℓ. The volumes of sediment and dredging site water to be mixed for a 3-3/4-ℓ slurry volume can be calculated using the following expressions:

$$V_{sediment} = 3.75 \frac{C_{slurry}}{C_{sediment}}$$

$$V_{water} = 3.75 - V_{sediment}$$

where

$V_{sediment}$ = volume of sediment, liters

3.75 = volume of slurry for 4-ℓ cylinder, liters

C_{slurry} = desired concentration of slurry, grams per liter (dry-weight basis)

$C_{sediment}$ = predetermined concentration of sediment, grams per liter (dry-weight basis)

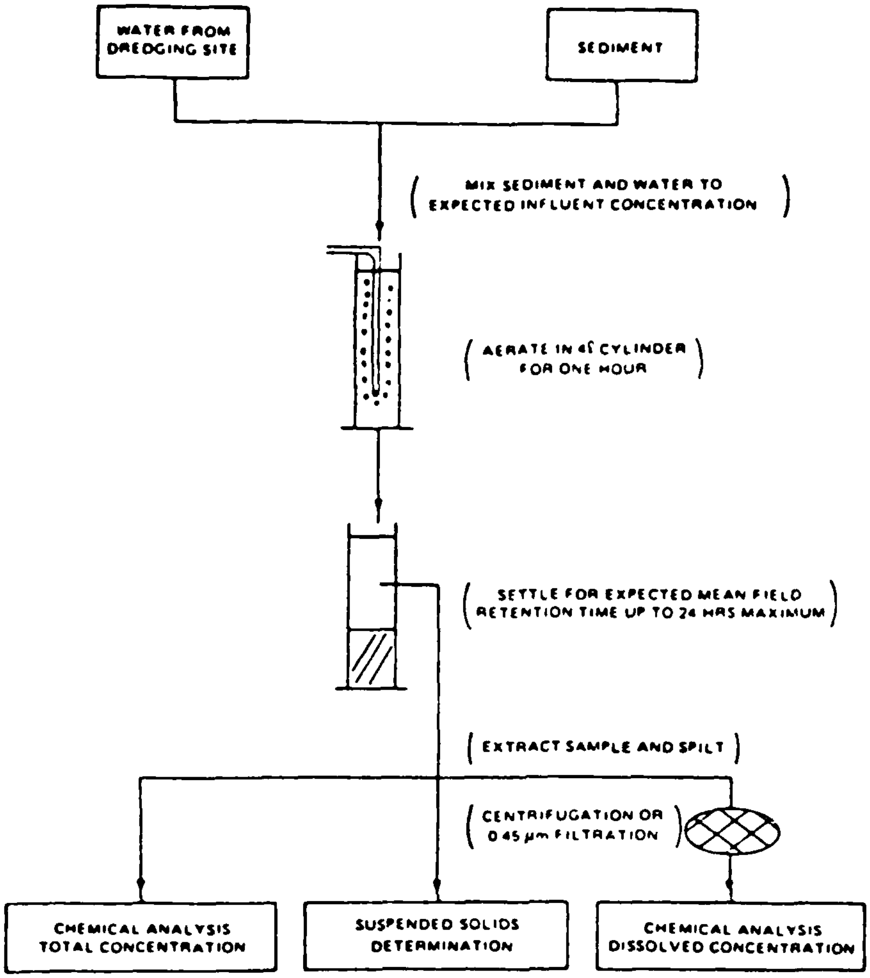

Figure A.1. Modified elutriate test procedure

V_{water} = volume of dredging site water, liters

Step 2 - Mixing. Mix the 3-3/4 ℓ of slurry by placing appropriate volumes of sediment and dredging site water in 1-gal glass jars and mixing for 5 min with a laboratory mixer. The slurry should be mixed to a uniform consistency with no unmixed agglomerations of sediment.

Step 3 - Aeration. Bubble aeration is used to ensure oxidizing conditions in the supernatant water during the subsequent settling phase. Pour the mixed slurry into a 4-ℓ graduated cylinder. Attach glass tubing to the aeration source and insert tubing to the bottom of the cylinder. The tubing can be held in place by insertion through a predrilled No. 4 stopper placed in the top of the cylinder. Compressed air should be passed through a deionized water trap, through the tubing, and bubbled through the slurry. The flow rate should be adjusted to agitate the mixture vigorously, and bubbling should be continued for 1 hr.

Step 4 - Settling. Remove the tubing and allow the aerated slurry to undergo quiescent settling for a time period equal to the anticipated field mean retention time up to a maximum of 24 hr. If the field mean retention time is not known, allow settling for 24 hr. Guidance for estimating the field mean retention is given in Technical Note EEDP-04-3 (Palermo 1985).

Step 5 - Sample extraction. After the settling period, an interface will usually be evident between the supernatant water with low concentration of suspended solids and the more concentrated settled material. Samples of the supernatant water should be extracted from the cylinder at a point midway between the water surface and the interface using syringe and tubing. Care should be taken not to resuspend settled material.

Step 6 - Sample preservation and analysis. The sample should be analyzed as soon as possible after extraction to determine the total suspended solids and the dissolved and total concentrations of selected constituents. The fraction of a constituent in the total suspended solids can then be calculated. Filtration using 0.45-μm filters should be used to obtain subsamples for analysis of dissolved concentrations. Samples to be analyzed for dissolved pesticides or PCB must be free of particles but should not be filtered, due to the tendency for these materials to adsorb on the filter. However, particulate matter can be removed before analysis by high-speed centrifugation at 10,000 times gravity using Teflon, glass, or aluminum centrifuge tubes (Fulk et al. 1975). The total suspended solids concentration can also be determined by filtration (0.45 μm). The fraction of a constituent in the total suspended solids is calculated as follows:

$$F_{SS} = (1 \times 10^6) \frac{C_{total} - C_{diss.}}{SS}$$

where

F_{SS} = fraction of constituent in the total suspended solids, milligrams per kilogram of suspended solids

C_{total} = total concentration of constituent, milligram per liter of sample

$C_{diss.}$ = dissolved concentration of constituent, milligrams per liter of sample

SS = total suspended solids concentration, milligrams per liter of sample

Subsamples for analyses of total concentrations should undergo appropriate digestion prior to analysis. All digestion and chemical analyses should be performed using accepted procedures (American Public Health Association 1985; USEPA 1980a; and USEPA 1979).

Samples to be analyzed for pesticides or PCB should immediately undergo solvent extraction. The extract may then be held in clean uncontaminating containers for periods up to three or four weeks at -15 to -20° C before further analyses are performed.

Samples for metals analysis should be preserved immediately by lowering the pH to <2 with 3 to 5 ml nitric acid per liter (USEPA 1979). High purity acid, either purchased commercially or prepared in a subboiling unit, must be used.

Nutrient analyses should be conducted as soon as possible. Acidification with H_2SO_4 to pH <2 and storage at 4° C will allow the sample to be held for maximum of 24 hr for ammonia nitrogen, Kjeldahl nitrogen, and nitrate nitrogen analyses (USEPA 1979). Storage at 4° C will allow holding of samples to be analyzed for dissolved orthophosphate and total dissolved phosphorus for up to 24 hr. Subsamples to be analyzed for cyanide should be preserved with 2 ml of 10 N sodium hydroxide per liter of sample (pH >12) (USEPA 1979).

PART II: STANDARD ELUTRIATE TEST*

The elutriate test is a simplified simulation of the dredging and disposal process wherein predetermined amounts of dredging site water and sediment are mixed together to approximate a dredged material slurry. The elutriate in the supernatant resulting from the vigorous 30-min shaking of one part sediment from the dredging site with four parts water (vol/vol) collected from the dredging site followed by a 1-hr settling time and appropriate centrifugation and 0.45 μ filtration. Thus, it will be necessary to collect both water and sediment samples to perform the elutriate test. When evaluating a dredging operation, the sediment should be collected at the dredging site and the water should be collected at the dredging and the disposal site. To evaluate a fill material activity, samples should be collected from the source of the fill material and the water should be collected from the disposal site.

Water sample collection. Collection should be made with an appropriate noncontaminating water sampling device. Either discrete samplers such as Kemmerer or Van Dorn samplers or continuous collectors such as submersible pumps may be used. The volume of water required will depend on the number of analyses to be performed. For each sample to be subjected to elutriate testing, it is suggested that a minimum of 4 ℓ be collected at the disposal site and 8 ℓ be collected at the dredging site to evaluate a dredging operation and/or 12 ℓ be collected at the disposal site to evaluate a fill material disposal operation. This will provide 4 ℓ of water for analyses and sufficient water to prepare triplicate 3-ℓ elutriates. (Each elutriate should yield 2.0 to 2.2 ℓ of standard elutriate for analysis.) If the samples are to be analyzed for trace organics or a large number of constituents, a proportionately larger initial sample should be collected.

Samples must be stored in glass containers if trace organic analyses are to be performed. Generally, either plastic or glass containers may be used for other parameters. The samples should be maintained at 4°C until analyzed but never frozen. The storage period should be as short as possible to

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* The procedure for the Standard Elutriate Test was extracted from TR EPA/CE-81-1 "Procedures for Handling and Chemical Analysis of Sediment and Water Samples."

minimize changes in the characteristics of the water. Disposal site water should be analyzed or split and preserved immediately. The remainder of the water should be used in the elutriate test, which should be processed within 1 week of collection.

Sediment sample collection. Samples should be taken from the fill or the dredging site with a grab or a corer. Approximately 3ℓ of sediment or fill material would provide sufficient sample to prepare triplicate 3-ℓ elutriates. Again, if the resultant standard elutriates are to be analyzed for trace organics or a large number of constituents, a proportionately larger initial sample should be collected.

Samples may be stored in plastic bags, jars, or glass containers. However, if trace organic analyses are to be performed, glass containers with Teflon-lined lids are required. A special precaution that must be taken with sediment samples is to ensure that the containers are completely filled with sample and that air bubbles are not trapped in the container. This step is necessary to minimize sample oxidation that could influence elutriate test results.

The samples should be stored immediately at 4°C. They must not be frozen or dried prior to use. The storage period should be as short as possible to minimize changes in the characteristics of the sediment. It is recommended that samples be processed within 1 week of collection.

Apparatus. The following apparatus are required to perform the elutriate test. Prior to use, all glassware, filtration equipment, and filters should be washed with 5 to 10 percent (or stronger) hydrochloric acid (HCl) and then rinsed thoroughly with deionized water. The necessary apparatus include:

a. Acid-rinsed plastic bottles for collection of water samples.

b. Plastic jars or bags ("Whirl-Pak," plastic freezer containers, etc.) for collecting dredged or fill material samples.

c. Laboratory shaker capable of shaking 2-ℓ flasks at approximately 100 excursions/minute. Box type or wrist-action shakers are acceptable.

d. Several 1-ℓ graduated cylinders.

e. Large (15 cm) powder funnels.

f. Several 2-ℓ, large-mouth graduated Erlenmeyer flasks.

g. Vacuum or pressure filtration equipment, including vacuum pump or compressed air source, and an appropriate filter holder capable of accommodating 47-, 105-, or 155-mm-diameter filers.

h. Membrane filters with a 0.45-μ pore-size diameter. The filters should be soaked in 5 M HCl for at least 2 hr prior to use.

i. Centrifuge capable of handling size 1- or 0.5-ℓ centrifuge bottles at 3000 to 5000 rpm. International Model K or Sorval Super Speed are acceptable models.

j. Wide-mouth, 1-gal capacity glass jars with Teflon-lined screw-top lids for use as sample containers when samples are to be analyzed for trace organics. (It may be necessary to purchase jars and Teflon sheets separately; in this case, the Telfon lid liners may be prepared by the laboratory personnel.)

Test procedure. The stepwise test procedure is given below:

a. Subsample a minimum volume of 1 ℓ each of dredging site and disposal site water. If it is known in advance that a large number of measurements are to be performed, the size of each subsample should be increased to meet the anticipated needs.

b. Filter an appropriate portion of the disposal site water through an acid-soaked 0.45-μ pore-size membrane filter that has been prerinsed with approximately 100 ml of disposal site water. The filtrate from that rinsing procedure should be discarded.

c. Analyze the filtered disposal site sample as soon as possible. If necessary, the samples may be stored at 4°C after splitting and the appropriate preservatives have been added. Filtered water samples may also be frozen with no apparent destruction of sample integrity.

d. Repeat steps a, b, and c with dredging site water. This step is omitted with a fill material sample.

e. Subsample approximately 1 ℓ of sediment from the well-mixed original sample. Mix the sediments and unfiltered dredging site water in a volumetric sediment-to-water ratio of 1:4 at room temperature (22 ± 2°C). This is best done by the method of volumetric displacement. One hundred milliliters of unfiltered dredging site water is placed into a graduated Erlenmeyer flask. The sediment subsample is then carefully added via a powder funnel to obtain a total volume of 300 ml. (A 200-ml volume of sediment will now be in the flask.) The flask is then filled to the 1000-ml mark with unfiltered dredging site water, which produces a slurry with a final ratio of one volume sediment to four volumes water.

This method should provide 700 to 800 ml of water for analysis. If the analyses to be run require a larger volume of water, the initial volumes used to prepare the elutriate slurry may be proportionately increased as long as the solid-to-liquid ratio remains constant (e.g. mix 400 ml sediment and 1600 ml unfiltered dredging site water). Alternately, several 1-ℓ sediment/dredging site water slurries may be prepared as outlined above, and the filtrates combined to provide sufficient water for analysis. The procedure continues as follows:

f. (1) Cap the flask tightly with a noncontaminating stopper and shake vigorously on an automatic shaker at about 100 excursions per minute for 30 min. A polyfilm-covered rubber stopper is acceptable for minimum contamination.

(2) During the mixing step given above, the oxygen demand of the dredged material may cause the dissolved oxygen concentration in the elutriate to be reduced to zero. This change can alter the release of chemical contaminants from dredged material to the disposal site water and reduce the reproducibility of the elutriate test. If it is known that anoxic conditions (zero dissolved oxygen) will not occur at the disposal site or if reproducibility of the elutriate test is a potential problem, the mixing may be accomplished by using a compressed air-mixing* procedure instead of the mechanical mixing described in Step f (1). After preparation of the elutriate slurry, an air-diffuser tube is inserted almost to the bottom of the flask. Compressed air should be passed through a deionized water trap and then through the diffuser tube and the slurry. The flow rate should be adjusted to agitate the mixture vigorously for 30 min. In addition, the flasks should be stirred manually at 10-min intervals to ensure complete mixing.

g. After 30 min of shaking or mixing with air, allow the suspension to settle for 1 hr.

h. After settling, carefully decant the supernatant into appropriate centrifuge bottles and then centrifuge. The time and revolutions per minute during centrifugation should be selected to reduce the suspended solids concentration substantially and, therefore, shorten the final filtration process. After centrifugation, vacuum or pressure filter approximately 100 ml of sample through a 0.45-μ membrane filter and discard the filtrate. Filter the remainder of the sample to give a clear final solution (the standard elutriate) and store at 4°C in a clean noncontaminating container in the dark. The filtration process is intended for use when the standard elutriate is to be analyzed for conventional chemical contaminants. When the elutriate is to be analyzed for organic contaminants and PCBs, filtration should not be used since organic concentrations can be reduced by sorption. Centrifugation should be used to remove particulate matter when the standard elutriate is to be analyzed for specific organics.

i. Analyze the standard elutriate as soon as possible. If necessary, the samples may be stored at 4°C after splitting and the appropriate preservatives have been added.

j. Prepare and analyze the elutriate in triplicate. The average of the three replicates should be reported as the concentration of the standard elutriate.

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* This procedure can cause the loss of highly volatile chemical constituents. If volatile materials are of concern, compressed air mixing should not be used.

PART III: SETTLING TEST PROCEDURES

1. Testing Equipment and Procedures

a. Test Objective. The objective of running settling tests on sediment to be dredged is to define, on a batch basis, its settling behavior in a large-scale continuous flow dredged material containment area. The tests provide numerical values for the design criteria which can be projected to the size and design of the containment area.

b. Settling Column. The settling column shown in Fig. A.2 should be used for dredged material settling tests (Montgomery 1978). The column is constructed of 8-in. plexiglass tubing and can be sectioned for easier handling and cleaning. Shop drawings of the column with bills of materials are available from the WES Environmental Laboratory.*

c. Samples. Samples used to perform settling tests should consist of fine-grained (<No. 40 sieve) material. If coarse-grained (>No. 40 sieve) material present in the sample is less than 10 percent (dry-weight basis), separation is not required prior to sedimentation testing. A composite of several sediment samples may be used to perform the tests if this is thought to be more representative of the dredged material. Approximately 15 gal of sediment is usually required for the tests.

d. Pilot Test. A pilot test conducted in a small graduated cylinder (1 ℓ is satisfactory) is a useful method for determining if flocculent or zone processes will govern the initial settling. The pilot test should be run at a slurry concentration of approximately 150 g/ℓ. If an interface forms within the first few hours of the test, the slurry mass is exhibiting zone settling, and the fall of the interface versus time should be recorded. The curve will appear as shown in Figure A-3. The break in the curve will define the concentration at which compression settling begins. Only lower concentrations should be used for the zone settling test series in the 8-in. column. If no break in the curve is evident, the material began settling in the compression zone, and the pilot test should be repeated at a lower slurry concentration. It should be emphasized that use of a small cylinder as in the pilot test is not acceptable for use in design. Wall effects for columns of small diameter

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* Address requests to the attention of WESEP-E.

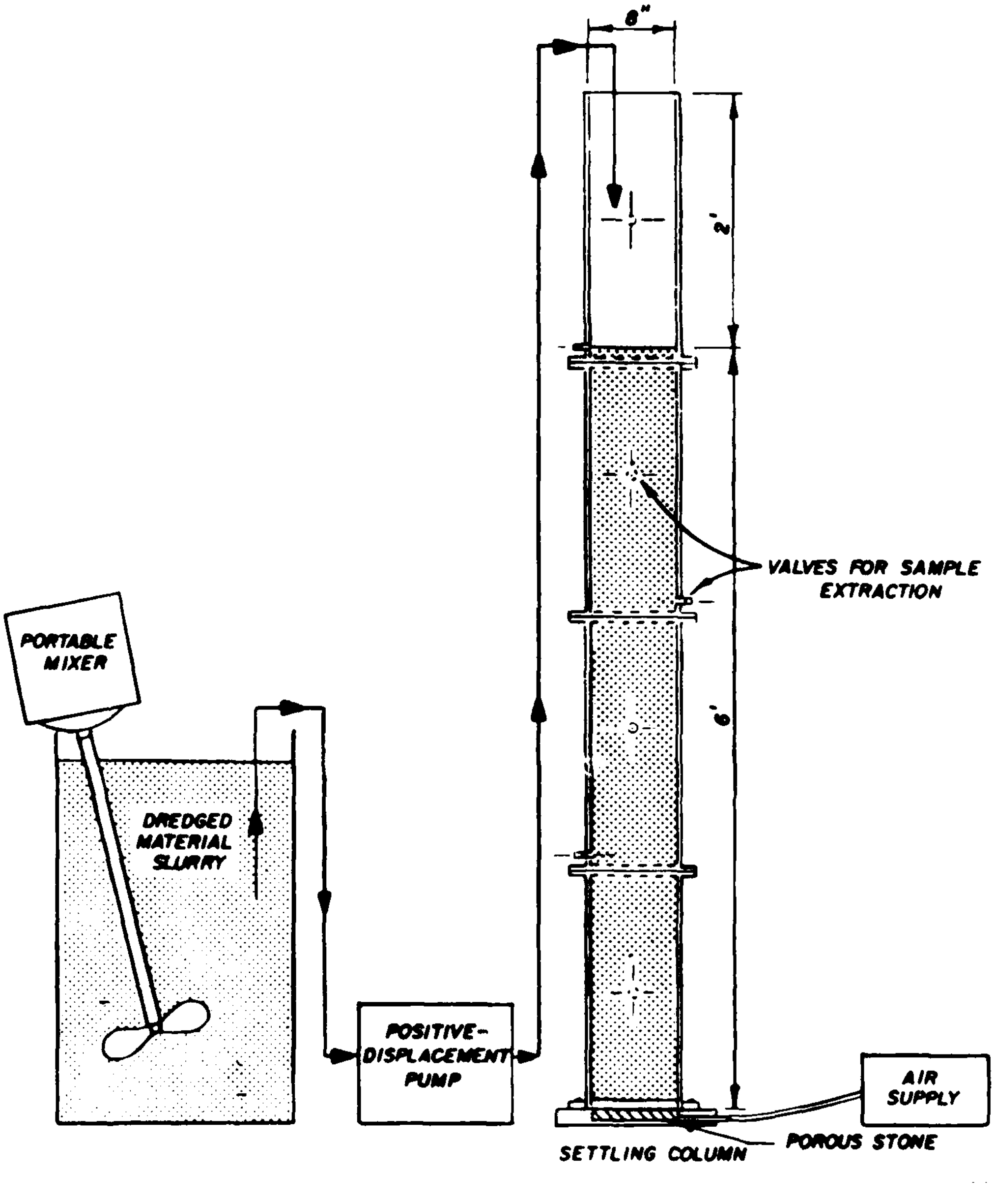

Figure A.2. Schematic of apparatus for settling tests

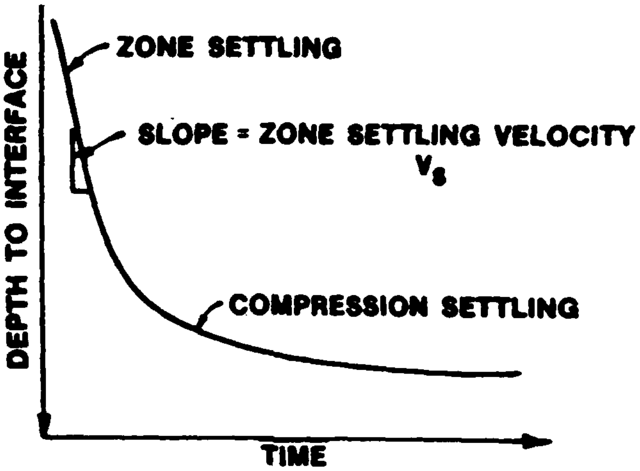

Figure A-3. Conceptual plot of interface depth versus time

affect zone settling velocities, and data obtained using small-diameter columns will not accurately reflect field behavior. If no interface is observed in the pilot test within the first few hours, the slurry mass is exhibiting flocculent settling. In this case, the pilot test should be continued until an interface is observed between the turbid water above and more concentrated settled solids below. The concentration of the settled solids (computed assuming zero concentration of solids above) is an indication of the concentration at which the material exhibits compression settling.

e. Required Number of Column Loadings for Tests. Three types of settling tests may be needed to fully define the settling properties of the dredged material. However, in many cases, the 8-in. settling column used for the settling tests need only be loaded with slurry once. A compression settling test is needed to define the volume that will be occupied in the disposal area by a newly deposited dredged material layer. Also a flocculent settling test for either the slurry mass or for the supernatant water above any interface is required to predict effluent suspended solids concentrations. Both of these tests should be conducted at a slurry concentration equal to the expected influent concentration, therefore only one loading of the test column would be required to collect data for both purposes. A series of zone settling tests is required to define the minimum required surface area needed for effective zone settling. For the zone settling test series, the pilot test will define the highest concentration that should be used for the series. If the column is initially loaded for this condition, the same material in the column can be used for the remaining tests by draining appropriate volumes of slurry (remixed following a test by agitating with compressed air) and replacing the drained slurry with an equal volume of water of appropriate salinity.

2. Settling Tests

a. Flocculent settling test.

(1) The flocculent settling test consists of measuring the concentration of suspended solids at various depths and time intervals in a settling column. If an interface forms near the top of the settling column during the first day of the test, sedimentation of the material below the interface is governed by zone settling. In that case, the flocculent test procedure should be continued only for that portion of the column above the interface.

(2) Information required to design a containment area in which flocculent settling governs can be obtained using the following procedure:

(a) A settling column such as shown in Fig. A.2 is used. The slurry depth used in the test column should approximate the effective settling depth of the proposed containment area. A practical limit on depth of test is 6 ft. The column should be at least 8 in. in diameter with sample ports at 0.5-ft intervals (minimum). The column should have provisions for slurry agitation with compressed air from the bottom to keep the slurry mixed during the column-filling period.

(b) Mix the sediment slurry to the desired suspended solids concentration selected to represent the concentration of the dredged material influent C_1. The slurry should be mixed in a container with sufficient volume to fill the test column. Field studies indicate that, for maintenance dredging the fine-grained material, concentration will average about 150 g/ℓ. This should be the concentration used in the test if better data are not available.

(c) Pump or pour the slurry into the test column using compressed air to maintain a uniform concentration during the filling period.

(d) When the slurry is completely mixed in the column, cut off the compressed air and immediately draw off samples at each sample port and determine their suspended solids concentration. Use the average of these values as the initial slurry concentration at the start of the test. The test is considered initiated when the initial samples are drawn.

(e) If an interface has not formed on the first day, flocculent settling is occurring in the entire slurry mass. Allow the slurry to settle and withdraw samples from each sampling port at regular time intervals to determine the suspended solids concentrations. Substantial reductions of suspended solids will occur during the early part of the test, but reductions will lessen at longer retention times. Therefore, the intervals can be extended as the test progresses. Recommended sampling intervals are: 1, 2, 4, 6, 12, 24, 48, 96 hr, etc., till the end of the test. As a rule, a 50-ml sample from each port should be taken. Continue the test until an interface of solids can be seen near the bottom of the column and the suspended solids concentration in the fluid above the interface is <1 g/ℓ. Test data are tabulated and used to plot a concentration profile diagram as shown in Fig. A-4.

(f) If an interface forms the first day, zone settling is occurring in the slurry below the interface, and flocculent settling is occurring in the supernatant water. For this case, samples should be extracted from all side ports above the falling interface. The first of these samples should be extracted immediately after the interface has fallen sufficiently below the uppermost port to allow extraction. This sample can usually be extracted within a few hours after initiation of the test, depending on the initial slurry concentration and the spacing of ports. Record the time of extraction and port height for each port sample taken. As the interface continues to fall, extract samples from all ports above the interface at regular time intervals. As an alternative, samples can be taken above the interface at the desired depths using a pipette or syringe and tubing. As before, a suggested sequence of sampling intervals would be 1, 2, 4, 6, 12, 24, 48, 96 hr, etc. The samples should continue to be taken until the suspended solids concentration of the extracted samples shows no decrease. For this case the suspended solids in the samples should be less then 1 g/ℓ, and filtration will be required to determine the concentrations. Tabulate the data and plot a concentration profile diagram as shown in Fig. A-4. In computing the percentages remaining R for this case, the concentration of the first port sample taken above the falling interface is considered the initial concentration SSo.

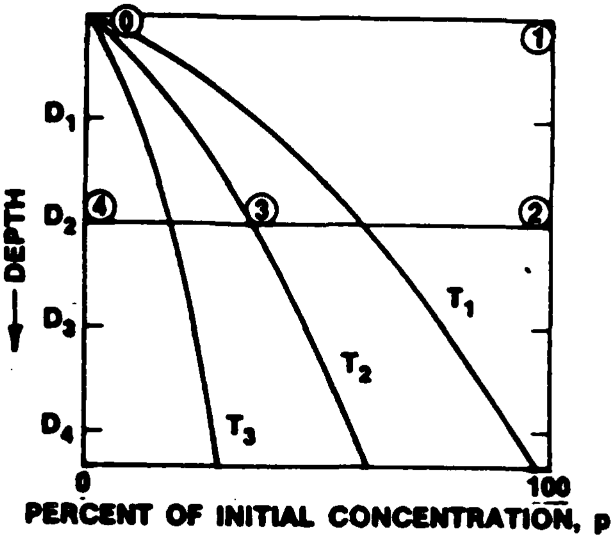

Figure A-4. Conceptual concentration profile diagram

b. <u>Zone settling test</u>.

(1) The zone settling test consists of placing a slurry in a sedimentation column and reading and recording the fall of the liquid-solids interface with time. These data are plotted as depth to interface versus time. The slope of the constant settling zone of the curve is the zone settling velocity, which is a function of the initial test slurry concentration. A series of these tests are required if the material exhibits an interface within the first day. The range of slurry concentrations used in the series should vary from a low of approximately 50 g/ℓ to a high concentration at which the slurry exhibits compression settling (determined by the pilot settling test).

(2) Information required to design a containment area in which zone settling governs can be obtained by using the following procedure:

(a) A settling column such as shown in Fig. A.2 is used. It is important that the column diameter be sufficient to reduce the wall effect and that the test be performed with a test slurry depth near that expected in the field. Therefore, a 1-ℓ graduated cylinder should never be used to perform a zone settling test for sediment slurries representing dredging disposal activities.

(b) Mix the slurry to the desired concentration and pump or pour it into the test column. Air may not be necessary to keep the slurry mixed if the filling time is less than 1 min.

(c) Record the depth to the solid-liquid interface as a function of time. Readings must be taken at regular intervals to gain data for plotting the depth to interface versus time curve as shown in Fig. A-3. It is important to take enough readings to clearly define this curve for each test.

(d) Continue the readings until sufficient data are available to define the maximum point of curvature of the depth to interface versus time plot for each test. Tests may require from 1 to 3 days to complete.

(e) Perform a minimum of four tests. Data from these tests are required to develop the zone settling velocity versus concentration curve as shown in Fig. A-5.

c. Compression Settling Test.

(1) A compression settling test must be run to obtain data for estimating the volume required for initial storage of the dredged material. For slurries exhibiting zone settling, the compression settling data can be obtained from one of the series of zone settling tests with interface height versus time recorded. The only difference is that the test is continued for a period of 15 days so that a relationship of concentration versus time in the compression settling range as shown in Fig. A-6 is obtained. For slurries exhibiting flocculent settling behavior, the test used to obtain flocculent settling data can be used for the compression settling test if an interface is formed after the first few days of the test. If not, an additional test is required with the slurry concentration for the test sufficiently high to initially induce compression settling. This concentration can be determined by the pilot test.

(2) The following steps are used to develop the concentration versus time plot:

(a) Tabulate the interface height H for various times of observation during the 15-day test period.

(b) Calculate concentrations for various interface heights as follows:

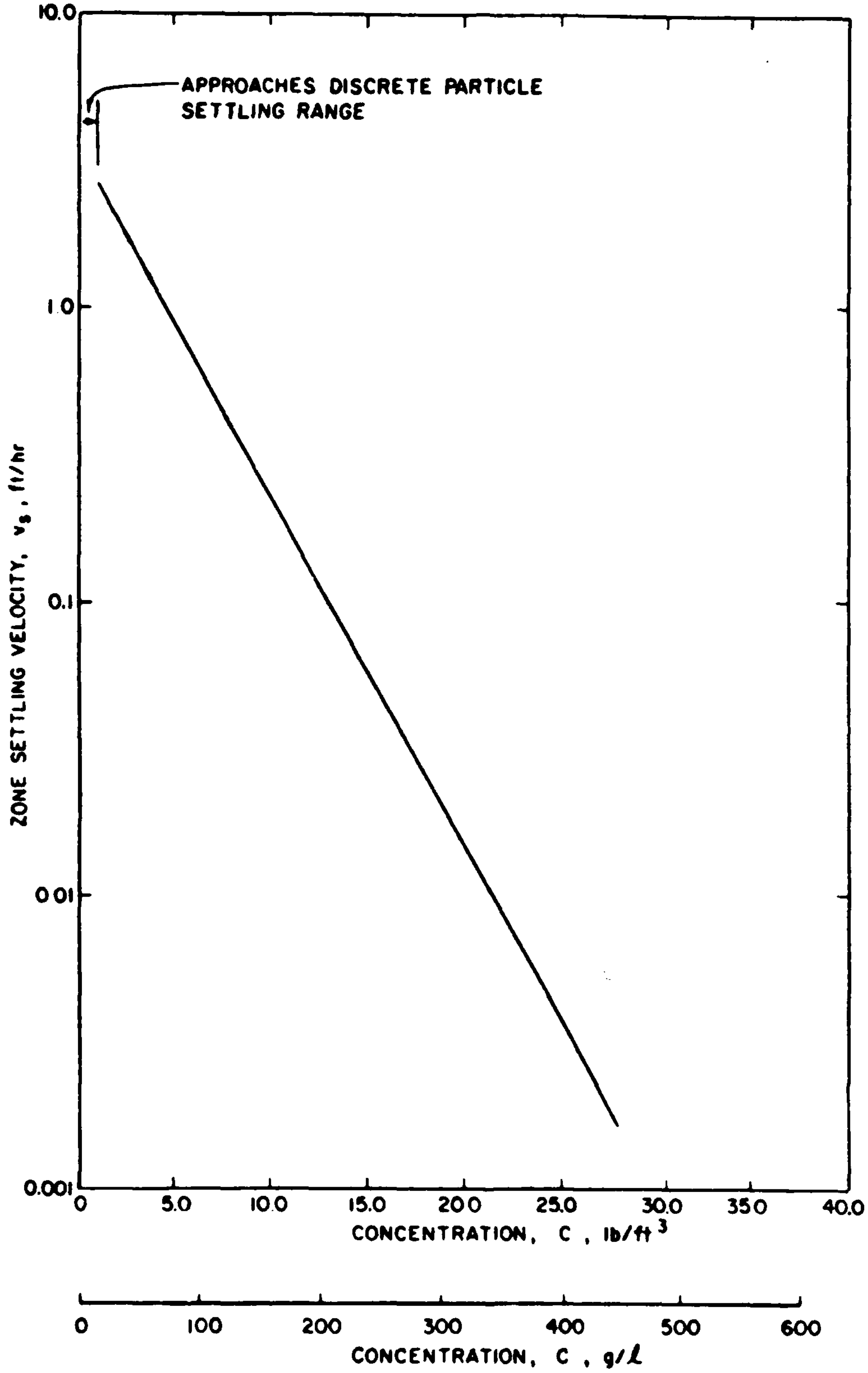

Figure A-5. Conceptual plot of zone settling velocity versus concentration

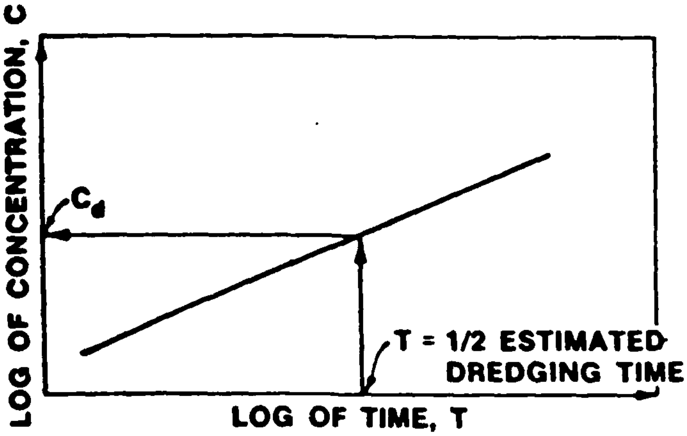

Figure A-6. Conceptual time versus concentration plot

$$C = \frac{C_i H_i}{H}$$

where C = slurry concentration at time T, g/ℓ

C_i = initial slurry concentration, g/ℓ

H_i = initial slurry height, ft

H = height of interface at time T, ft

Assume zero solids in the water above the interface to simplify calculations.

(c) Plot concentration versus time on log-log paper as shown in Fig. A-6.

(d) Draw a straight line through the data points. This line should be drawn through the points representing the compression settling or consolidation zone as shown in Fig. A-6.

PART IV: JAR TEST PROCEDURES FOR CHEMICAL CLARIFICATION

1. General.

Jar tests have been used to evaluate the effectiveness of various coagulents and flocculants under a variety of operating conditions for water treatment. The procedures and evaluation process have been adapted to dredged material. However, conducting jar tests and interpreting the results to determine design parameters are not simple tasks because there are many variables that can affect the tests. Only experience can assist in applying the following jar test procedures to a specific project. Additional information is available on equipment requirements and the importance of flocculant type, flocculant concentration, flocculant addition methods, temperature, mixing and test equipment, and intensity and duration of mixing on the jar tests results.

2. Selection of test conditions.

a. Mixing intensity and duration. Prior to testing, the mixing intensity and duration for the jar tests should be selected based on project conditions. Assuming mechanical mixing will not be used in the treatment system, the amount of mixing should be based on the available head between the two containment areas, that is, the difference between the water surfaces of the two areas that can be maintained throughout the project. The depth of the secondary area must be sufficient to provide 2 to 3 ft of storage and 2 to 3 ft of ponding for good settling. Preferably, 2 to 3 ft of head should be available for mixing. The object is to convert the head into mixing energy in the culvert(s) joining the two containment areas. The amount of head loss is a function of flow rate, culvert diameter, and length.

(1) The designer may calculate a mixing value Gt based on the head loss, mixing intensity, and duration for the existing or designed culvert according to the following procedure for pipe flow (Streeter 1971). Assuming a submerged inlet and outlet and corrugated metal pipe,

$$H = \left(1.5 + \frac{Lf}{D}\right)\frac{v^2}{2g}$$

where

H = head loss, ft

L = culvert length, ft

f = friction factor

= $185\ n^2/D^{1/3}$ (n = Manning's coefficient, 0.025 for corrugated metal pipes)

D = culvert diameter, ft

v = maximum velocity through culvert, ft/sec

= $4\ Q_{max}/\pi D^2$

Q_{max} = maximum flow rate, units

g = gravity, 32.2 ft/sec^2

The mean velocity gradient G can be calculated as follows (Jones, Williams, and Moore 1978):

$$G = \frac{\gamma_s f \bar{v}^3}{2gD\mu_s}$$

where

γ_s = specific weight, 62.4 lb/ft^3

$\bar{v}$ = average velocity, ft/sec

μ_s = absolute viscosity, 2.36×10^{-5} lb-sec/ft^2 at 60°F

The duration t of the mixing is determined by

$$t = \frac{L}{\bar{v}}$$

The net mixing Gt is the product of the mean velocity gradient (intensity) and the duration. The mixing increases with increases in head loss, culvert length, and duration and with decreases in culvert diameter. Long, multiple, small-diameter corrugated culverts provide the best mixing conditions. Good mixing requires a Gt of about 30,000, though a Gt of about 8,000 provides adequate mixing.

(2) An alternative to using long, small-diameter corrugated culverts to effectively convert the available head into mixing would be to install static mixers in the culverts. Static mixers are fixed obstructions that, when placed in a culvert, efficiently increase the turbulence produced by the flow. The mixers increase the head loss without using smaller diameter or longer culverts. When using these devices, care must be taken to accurately determine the head loss to ensure that good mixing is provided while not exceeding the available head.

(3) After determining G and t for field conditions, use the same G and t for rapid mixing conditions in the laboratory jar test. If the G is greater than the G available on the jar test apparatus, mix at maximum speed and increase the duration to obtain the same Gt. The relationship between G and revolutions per minute of a jar test apparatus is shown in Fig. A.7.

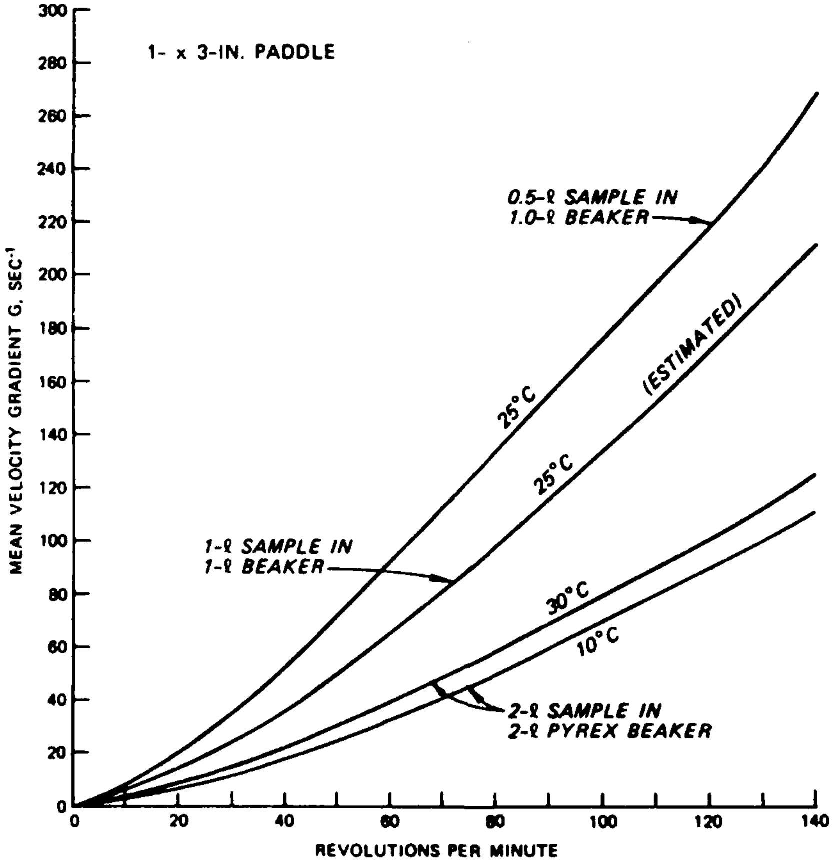

Figure A.7. Velocity gradient G calibration curves for jar test apparatus

For slow mixing, mix at 20 rpm ($G = 10\ sec^{-1}$) for 300 sec to simulate the exit loss conditions as the water dissipates its kinetic energy upon entering the secondary cell.

b. Suspension concentration. The next step is to predict the average solids concentrations and turbidity of the suspension to be treated at the primary weir. This can be estimated from past records of dredging at the site, flocculent settling tests, or from nomographs developed by Walski and Schroeder (1978). Two nomographs were developed: one for freshwater clays that undergo flocculent settling and the other for freshwater silts and saltwater sediments that undergo zone settling. The nomographs relate the flow rate, effective weir length, and ponding depth (depth of water above interface of settled material at the weir) to the suspended solids concentration of water discharged over the weir. These relationships are considered valid for well-designed primary containment areas that are properly sized for the efficient retention of suspended solids by gravity sedimentation.

c. Settling time for flocculated material. The next variable to establish is settling time. Flocculated (chemically treated) material settles at a rate of about 0.25 ft/min (Jones, Williams, and Moore 1978). The required ponding depth for good settling is about 2 to 3 ft; therefore, a minimum of 10 min is needed for settling. Also, due to basin inefficiencies, some of the water will reach the secondary weir in 10 to 20 percent of the theoretical detention time. For secondary containment areas, this may be as short as 10 to 20 min, though the mean detention time may be about 50 min. Based on this information, the settling time in the jar test should be set at 10 min. The effect of settling time on suspended solids removal can be evaluated in the jar test procedures.

d. Selection of polymers for testing. The final consideration before starting the jar tests is the selection of polymers to be tested. To simplify the operation of feeding and dispersing the polymer at the project, a low viscosity liquid polymer should be used. Some polymers effective on dredged material are:

Betz	1180
	1190
Calgon	M-503
Hercofloc	815
	849
	863
	876
Magnifloc	573C
	577C
Nalco	7103
	7132

Polymer manufacturers may be able to suggest others. The manufacturers can also recommend maximum polymer-feed concentrations. Polymer selected for testing should be nontoxic, nonhazardous, and unreactive. Polymer manufacturers can provide detailed information on the properties of their products. Also, the US Environmental Protection Agency has approved many polymers for use on potable water at specified dosages. Very little of an applied dosage is expected to be discharged from the containment area since the polymer adsorbs on the solids and settles in the containment area. Therefore, polymers should not be detrimental to the quality of the receiving waters. Polymers do not increase the long-term release of contaminants or nutrients from treated dredged material. Consequently, there appears to be no reason to consider polymer-treated uncontaminated dredged material as a hazardous substance requiring special considerations.

3. Suspension preparation. Dredged material that is discharged over the weir is composed of only the finest fraction of the sediment. In many cases, this material has been suspended and mixed in the primary containment area for several days while the coarser material settled. Therefore, to obtain representative suspensions for testing, the following procedure is recommended:

a. Thoroughly mix each sediment sample to ensure homogeneity. Then, blend together equal portions of each sample to form a representative composite of the sediment. Grain-size analysis and soil classification may be performed on this material to characterize the mixture and to compare it with previous characterizations of the sediment.

b. If the sediment mixture contains more than 10 percent (dry-weight basis) coarse-grained (>No. 200 sieve) material, the material should be sieved though a standard U. S. series No. 200 sieve. The fines can be washed through the sieve using water from the bottom of the water column at the dredging site. If this water is unavailable, tap water may be used in its place, but the salinity of the suspension of fines (<No. 200 sieve) must be adjusted to the naturally occurring salinity of the bottom waters at the project site.

c. Prepare a supply of 2.0 g/ℓ suspensions by diluting a well-mixed portion of the slurry of fines with water from the dredging site or with tap water adjusted with salt to the same salinity. Suspensions at other concentrations would be prepared in the same manner.

4. Jar test procedures.

a. Having established the test variables, the designer is ready to start the laboratory jar test procedures. Care must be exercised in the tests to ensure that each sample is handled uniformly. The tests must be performed in a standard manner to evaluate the results. The following variables must be controlled: identical test equipment and setup; suspension preparation; sample temperature; polymer-feed concentration and age; polymer dosage; sample premix time and intensity; polymer addition method; duration and intensity of rapid mixing; duration and intensity of slow mixing; settling time; sampling method; and laboratory analyses of samples.

b. All of the following procedures described in this section are not necessary for every project. The required tests are dependent on the purpose of the study, and some tests can be eliminated based on past experience of treating dredged material under similar circumstances.

c. Selection of polymer. The laboratory jar test procedures are as follows:

(1) Fill a 1- or 2-ℓ beaker with a 2.0 g/ℓ suspension of fine-grained dredged material.

(2) Mix at 100 rpm and incrementally add polymer at a dosing of 2 mg/ℓ until flocs appear. Note total dosage applied. (Use a polymer-feed concentration of 2 g/ℓ or 2 mg/ml.)

(3) Fill six 1- or 2-ℓ beakers with a 2.0 g/ℓ suspension of dredged material and measure the suspended solids concentration and turbidity of the suspension.

(4) Mix at 100 rpm for 1 min and then rapidly add the desired polymer dosage to each beaker. Use a range of polymer dosages from 0 mg/ℓ to about twice the dosage determined in step (2).

(5) Immediately adjust the mixing to the desired G for rapid mixing as determined earlier. Mix for the desired duration t also determined earlier.

(6) Reduce the mixer speed to a G of 10 $\sec^{-1}$ and slow mix for 300 sec.

(7) Turn off mixer and allow the mixture to settle for 10 min.

(8) Withdraw samples from the 700-ml level of 1-ℓ beakers and from the 1400-ml level of 2-ℓ beakers.

(9) Measure the suspended solids concentration and turbidity of the samples. Also record any significant observations such as nature, size, and settling characteristics of the flocs; time of floc formation; and any peculiarities.

(10) Repeat steps (3) through (9) as needed to adequately define the effects of dosage on clarification.

(11) Repeat steps (1) through (10) for the other polymers. A dosage of 10 mg/ℓ should reduce the solids concentrations by 95 percent if the polymer is effective. Examine enough polymers to find at least two effective polymers.

(12) Select the most cost-effective polymer that can be easily fed and dispersed.

d. Selection of polymer-feed concentration. After selecting the polymer, the effects of polymer-feed concentration and polymer-solution age on the removals can be evaluated. Some polymers require great dilution and aging following dilution to maximize their effectiveness. This test is not required if adequate dilution water and solution aging are provided in the design to meet the manufacturer's recommendations. Often, to simplify the treatment system design, these recommendations are not met. The test is performed as follows:

(1) Prepare six fresh solutions of the selected polymer ranging in concentration from about 1 to 40 g/ℓ.

(2) Fill six beakers as in step (3) of the jar test procedure.

(3) Mix at 100 rpm for 1 min and then rapidly add the polymer solutions at the effective dosage established earlier and in the same manner.

(4) Continue to follow the procedures outlined in steps (5) through (9) of the jar test procedure.

(5) Allow two solutions to age as desired (between 1 hr and 1 day) and repeat steps (2) through (4).

e. Determination of required dosage. The dosage requirements of the selected polymer for the anticipated average solids concentration of the primary effluent suspension to be treated at the primary weir should be evaluated. This concentration was determined previously from past records, flocculant settling tests or from nomographs (Schroeder and Walski 1978). The procedure is as follows:

(1) Fill six beakers with suspensions at the desired concentration of the fine-grained fraction of dredged material. Measure the suspended solids concentration and turbidity of the suspension.

(2) Mix at 100 rpm for 1 min and then rapidly add the desired polymer dosage to each beaker. The range of dosages should be proportional to the solids concentration.

(3) Continue to follow the procedures outlined in steps (5) through (10) of the jar test procedure.

Other suspensions with different solids concentrations may be examined in the same manner to determine the possible range of dosages required for the project and the possible range of effluent quality obtainable under conditions of variable primary effluent solids concentration to be treated.

f. Effects of mixing. Other mixing conditions can be examined to determine the impact of low flow conditions and to evaluate whether the mixing is adequate. The effects of increasing the mixing by a Gt of 5,000 and 10,000 and of decreasing flow rate by 50, 75, and 90 percent on the polymer dosage requirements can be evaluated as follows:

(1) Calculate the new mixing intensity and duration.

(2) Fill six beakers with a suspension at the anticipated average solids concentration.

(3) Mix at 100 rpm for 1 min and then rapidly add the desired polymer dosage to each beaker. Select a range of dosages surrounding the optimum dosage determined in the last set of experiments on the same suspension.

(4) Immediately adjust the mixing to the G value calculated in step 1 for rapid mixing and mix for the calculated duration t.

(5) Follow the procedures outlined in steps (6) through (9) of the jar test procedure.

g. Effects of settling time. The effects of settling time on effluent quality can be examined as follows:

(1) Determine the range of settling time of interest bearing in mind that the secondary basin will be hydraulically inefficient and the settling conditions will not be quiescent.

(2) Follow procedures outlined in steps (3) through (9) of the jar test procedure but adjust the settling time and sampling schedule to cover the range determined above.

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APPENDIX B

APPROVED TEST PROCEDURES FOR THE CLEAN WATER ACT*

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* SOURCE: "Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act," Federal Register, Vol 49, No. 209, Friday, October 26, 1984.

Table B1. List of Approved Biological Test Procedures

Parameter and units	Method [1]	EPA [2]	Reference (Method Number or Page)		
			Standard Methods 15th Ed.	ASTM	USGS
Bacteria.					
1. Coliform (fecal) number per 100 ml	MPN, 5 tube, 3 dilution; or, membrane filter (MF) [4], single step	p. 132	980C		B-0050-77
		p. 124	909C		
2. Coliform (fecal) in presence of chlorine number per 100 ml	MPN, 5 tube, 3 dilution	p.132	908C		
3. Coliform (total, number per 100 ml	MPN, 5 tube, 3 dilution; or, MF [4] single step or two step	p. 114	908A		B-0025-77.
		p. 108	909A		
4. Coliform (total) in presence of chlorine, number per 100 ml	MPN, 5 tube, dilution; or MF [4] with enrichment	p. 114	908A		
		p. 111	909 (A+A.5c)		
5. Fecal streptococci, number per 100 ml	MPN, 5 tube, 3 dilution; MF [4]; or, plate count	p. 139	910A		B0055-77.[5]
		p. 136	910B		
		p. 143	910C		

Table IA Notes

[1] The method must be specified when results are reported.

[2] "Microbiological Methods for Monitoring the Environment, Water and Wates, 1978", EPA-600/8-78-017, U.S. Environmental Protection Agency.

[3] Greeson, P.E., *et al.*, Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples, "U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 5, Chapter A4, Laboratory Analysis, 1977

[4] 0.45 um membrane filter or other pore size certified by the manufacturer to fully retain organisms to be cultivated, and free of extractables which could interfere with their growth and development.

[5] Approved only if dissolution of the KF Streptococcus Agar (Section 5.1, USGS Method 8-0055-77) is made in a boiling water bath to avoid scorching of the medium.

Table B2. List of Approved Inorganic Test Procedures

Parameter, units, and method	Reference (method No. or page)				
	EPA 1979	Standard methods 15th Ed.	ASTM	USGS [1]	Other
1. Acidity, as $CaCO_3$, mg/L: Electrometric end point or phenolphthalein end point.	305.1	402(4.d)	D1067-70(E)		
2. Alkalinity, as $CaCO_3$, mg/L: Electrometric or colorimetric:					
Titration to pH 4.5, manual	310.1	403	D1067(B)	I-1030-78	P. 548 [5]
Or automated	310.2			I-2030-78	
3. Aluminum—Total [3] mg/L: Digestion [3] followed by:					
AA direct aspiration	202.1	303C		I-3051-78	
AA furnace	202.2	304			
Inductively coupled plasma					Method 200.7 [4]
Or colorimetric (Enochrome cyanine R)		306B			
4. Ammonia (as N), mg/L: Manual distillation [6] (at pH 9.5):					
Followed by	350.2	417A			
Nesslerization	350.2	417B	D1426-79(A)	I-3520-78	P. 553 [5]
Titration	350.2	417D			
Electrode	350.3		D1426-79(D)		
Automated phenate, or	350.1	417F	D1426-79(C)	I-4523-78	
Automated electrode					[6]
5. Antimony—Total [3], mg/L: Digestion [3] followed by:					
AA direct aspiration	204.1	303A			
AA furnace, or	204.2	304			
Inductively coupled plasma					Method 200.7 [4]
6. Arsenic—Total [3], mg/L:					
Digestion [3] followed by	206.5				
Hydride	206.3	303E	D2972-78(B)	I-3062-78	
AA furnace	206.2	304			
Inductively coupled plasma					Method 200.7 [4]
Or, colorimetric (SDDC)	206.4	307B	D2972-78(A)	I-3060-78	
7. Barium—Total [3], mg/L: Digestion [3] followed by:					
AA direct aspiration	208.1	303C		I-3084-78	
AA furnace, or	208.2	304			
Inductively coupled plasma					Method 200.7 [4]
8. Beryllium—Total [3], mg/L: Digestion [3] followed by:					
AA direct aspiration	210.1	303C	D3645-78	I-3095-78	
AA furnace	210.2	304			

Table B2. (Continued)

Parameter, units, and method	Reference (method No. or page)				
	EPA 1979	Standard methods 15th Ed	ASTM	USGS[1]	Other
Inductively coupled plasma					Method 200.7.[4]
Or colorimetric (aluminon)		309B			
9 Biochemical oxygen demand (BOD_5), mg/L					
Winkler (Azide modification)	405.1	507		I-1578-78	P. 17.[9]
Or electrode method					P. 548.[8]
10 Boron—Total, mg/L					
Colorimetric (curcumin) or	212.3	404A		I-3112-78	
Inductively coupled plasma					Method 200.7.[4]
11 Bromide, mg/L. Titrimetric	320.1		D1246-77(C)	I-1125-78	P. S44.[2,6]
12 Cadmium—Total[2], mg/L. Digestion[3] followed by					
AA direct aspiration	213.2	303A or 303B	D3557-78 (A or B)	I-3135-78 or I-3136-78	Pg. 557.[8]
AA furnace	213.2	304			P. 37.[9]
Inductively coupled plasma					Method 200.7.[4]
Voltametry[5] or			D3557-78(C)		
Colorimetric (Dithizone)		310B			
13 Calcium—Total[2] mg/L. Digestion[3] followed by					
Atomic absorption	215.1	303A	D511-77(C)	I3152-78	
Inductively coupled plasma					Method 200.7.[4]
Or EDTA titration	215.2	311C	D511-77(B)		
14 Carbonaceous Biochemical oxygen demand ($CBOD_5$), mg/L. Winkler (Azide modification) or electrode method with nitrification inhibitor		507(5.e.6)			
15 Chemical oxygen demand (COD), mg/L					
Titrimetric colorimetric	410.1	508A	D1252-78	I-3560-78	P. 550[8] and
Manual or	410.2			I-3562-78	P. 17[9] and
	410.3			I-3561-78	([10])
Automated	410.4				
Spectrophotometric					([11])
16 Chloride, mg/L					
Titrimetric (silver nitrate) or		407A	D512-67(B)	I-1183-78	
Mercuric nitrate	325.3	407B	D512-67(A)	I-1184-78	P. 554.[8]
Colorimetric (ferricyanide) manual or			D512-67(C)	I-1187-78	
Automated	325.1 or 325.2	407D		I-2187-78	
17 Chlorine—Total residual, mg/L					
Titrimetric-amperometric[12]	330.1	408C	D1253-76(A)		
Starch end point	330.2	408B			
Iodometric or	330.3	408A	D1253-76(B)		
DPD-FAS	330.4	408D			
Spectrophotometric, DPD, or	330.5	408E			
Electrode					([13])
18 Chromium VI dissolved, mg/L. 0.45 micron filtration with					
Extraction and atomic absorption, or	218.4	303B		I-1232-78	
Colorimetric (Diphenylcarbazide)				I-1230-78	
19 Chromium—Total[2], mg/L					
Digestion[3] (optional extraction) followed by	218.3				
AA direct aspiration	218.1	303A or 303B	D1687-77(D)	I-3236-78	P. 557.[8]
AA furnace	218.2	304			
Inductively coupled plasma					Method 200.7.[4]
Or colorimetric (Diphenylcarbazide)		312A	D1687-77(A)		
20 Cobalt—Total[2] mg/L. Digestion[3] followed by					
AA direct aspiration	219.1	303A or 303B	D3558-77 (A or B)	I-3240-78 or I-3239-78	P. 37.[9]
AA furnace, or	219.2	304			
Inductively coupled plasma					Method 200.7.[4]
21 Color, platinum Cobalt units or dominant wavelength hue luminance, purity:					
Colorimetric, ADMI	110.1	204D			([14])
Platinum cobalt, or	110.2	204A		I-1250-78	
Spectrophotometric	110.3	204B			
22 Copper—Total[2], mg/L. Digestion[3] followed by					
AA direct aspiration	220.1	303A or 303B	D1688-77 (D or E)	I-3271-78 or I-3270-78	P. 557[8] and P. 37[9]
AA furnace	220.2	304			
Inductively coupled plasma					Method 200.7.[4]
Colorimetric (Neocuproine)		313B	D1688-77(A)		
Bicinchoninate					([15])
23 Cyanide—Total, mg/L					
Manual distillation with $MgCl_2$	335.2	412D			
Followed by titrimetric	335.2	412B			P. 22.[9]
Manual or	335.2	412C	D2036-75(A)		
Automated[16] spectrophotometric	335.3	412D	D2036-75(A)	I-3300-78	
24 Cyanide amenable to chlorination, mg/L. Manual distillation with $MgCl_2$. Followed by titrimetric manual or automated[16] spectrophotometric	335.1	412F	D2036-75(B)		
25 Fluoride—Total, mg/L					
Manual distillation[6]		413A			
Followed by manual or	340.2	413B	D1179-72(B)		
Automated electrode				I-4327-78	
SPADNS	340.1	413C	D1179-72(A)		
Or automated complexone	340.3	413E			
26 Gold—Total[2] mg/L. Digestion[3] followed by					
AA direct aspiration	231.1	303A			
Or AA furnace	231.2	304			
27 Hardness—Total as $CaCO_3$, mg/L					
Automated colorimetric	130.1				
EDTA titration	130.2	314B	D1126-67(B)	I-1338-78	
Inductively coupled plasma					Method 200.7.[4]
Or atomic absorption (sum	215.1 +	303A		I-3153-78 +	
of Ca and Mg as their respective carbonates)	242.1			I-3448-78	

Table B2. (Continued)

Parameter, units, and method	Reference (method No. or page)				
	EPA 1979	Standard methods 15th Ed.	ASTM	USGS[1]	Other
28. Hydrogen ion (pH), pH units:					
Electrometric	150.1	423	D1293-78(A) or D1293-78(B).	I-1586-78	
Measurements; or automated electrode					(14)
29. Indium—Total[3], mg/L: Digestion[3] followed by:					
AA direct aspiration	235.1	303A			
Or AA furnace	235.2	304			
30. Iron—Total[3], mg/L:					
Digestion[3] followed by		303A or 303B	D1068-77		
AA direct aspiration	236.1	303B	(C or D)	I-3381-78	P. 557.[9]
AA furnace	236.2	304			
Inductively coupled plasma					Method 200.7.[4]
Or colorimetric (Phenanthroline)		315B	D1068-77(A)		(17)
31. Kjeldahl nitrogen—Total (as N), mg/L:					
Digestion and distillation	351.3	420A or B			P. 552.[9]
Followed by titration	351.3	417D	D3590-77		
Nesslerization or	351.3	417B			
Electrode	351.3	417E		I-4551-78	
Automated phenate	351.1			I-4552-78	
Semi-automated block digestor	351.2				
Or potentiometric	351.4				
32. Lead—Total[3], mg/L: Digestion[3] followed by:					
AA direct aspiration	239.1	303A or 303B	D3559-78 (A or B)	I-3399-78	P. 557[9]
AA furnace	239.2	304			
Inductively coupled plasma					Method 200.7[4]
Voltametry[9] or			D3559-78(C)		
Colorimetric (Dithizone)		316B			
33. Magnesium—Total[3], mg/L: Digestion[3] followed by:					
Atomic absorption	242.1	303A	D511-77(B)	I-3447-78	P. 557[9]
Inductively coupled plasma					Method 200.7[4]
Or gravimetric		318B	D511-77(A)		
34. Maganese—Total[3], mg/L: Digestion[3] followed by:					
AA direct aspiration	243.1	303A or 303B	D858-77 (B or C)	I-3454-78	P. 557[9]
AA furnace	243.2	304			
Inductively coupled plasma					Method 200.7[4]
Or colorimetric (Persulfate)		319B	D858-77(A)		P. 564[9]
Periodate					18.
35. Mercury—Total[3], mg/L:					
Cold vapor, manual or	245.1	303F	D3223-79	I-3462-78	P. 559[9]
Automated	245.2				
36. Molybdenum—Total[5], mg/L: Digestion[3] followed by:					
AA direct aspiration	246.1	303C		I-3490-78	
AA furnace, or	246.2	304			
Inductively coupled plasma					Method 200.7[4]
37. Nickel—Total[3], mg/L: Digestion[3] followed by:					
AA direct aspiration	249.1	303A or 303B	D1886-77 (C or D)	I-3499-78	
AA furnace	249.2	304			
Inductively coupled plasma					Method 200.7[4]
Or colorimetric (Heptoxime)		321B			
38. Nitrate (as N), mg/L:					
Brucine sulfate, or	352.1		D992-71		P. 554[9]
Nitrate-nitrite N minus Nitrite N	See parameters 39 and 40.	See parameters 39 and 40.	See parameters 39 and 40.	See parameters 39 and 40.	P. 28[9]
39. Nitrate-nitrite (as N), mg/L:					
Cadmium reduction, manual	353.3	418C	D3867-79(B)		
Or automated; or	353.2	418F	D3867-79(A)	I-4545-78	
Automated hydrazine	353.1				
40. Nitrite (as N), mg/L:					
Spectrophotometric, manual or	354.1	419	D1254-67		19.
Automated (Diazotization)				I-4540-78	
41. Oil and grease—Total recoverable, mg/L: Gravimetric (extraction).	413.1	503A			
42. Organic carbon—Total (TOC), mg/L: Combustion or oxidation.	415.1	505	D2579-78(A) or D2579-78(B)		P. 551[9] and P. 4[10]
43. Organic nitrogen (as N), mg/L: Total Kjeldahl N minus ammonia N.	See parameters 31 and 4	420A	D3590-77 minus D1426-79(A)	See parameters 31 and 4	PP. 552-53[9]
44. Orthophosphate (as P), mg/L: Ascorbic acid method, automated	365.1	424G		I-4601-78	P. 561[9]
Or manual single reagent or	365.2	424F	D515-78(A)		
Manual two reagent	365.3				
45. Osmium—Total[3], mg/L: Digestion[3] followed by:					
AA direct aspiration, or	252.1	303C			
AA furnace	252.2	304			
46. Oxygen, dissolved, mg/L:					
Winkler (Azide modification)	360.2	421B	D1589-60(A)	I-1575-78	P. 550[9]
Or electrode	360.1	421F		I-1576-78	
47. Palladium—Total[3], mg/L: Digestion[3] followed by:					
AA direct aspiration	253.1				P. S27[11]
Or AA furnace	253.2				P. S28[11]
48. Phenols, mg/L:					
Manual distillation	420.1		D1783-70 (A or B)		26.
Followed by manual	420.1				26.
Or automated[12] colorimetric (4AAP)	420.2				
49. Phosphorus (elemental), mg/L: Gas-liquid chromatography					21.

Table B2. (Continued)

Parameter, units, and method	Reference (method No. or page)				
	EPA 1979	Standard methods 15th Ed.	ASTM	USGS [1]	Other
50. Phosphorus—Total, mg/L:					
Persulfate digestion	365.2	424C (III)			P. 561.[8]
Followed by manual or	365.2 or 365.3	424F	D515-78(A)		
Automated ascorbic acid	365.1	424G		I-4600-78	
Reduction; or semi-automated block digestor	365.4			I-4603-78	
51. Platinum—Total [3], mg/L: Digestion [3] followed by:					
AA direct aspiration	255.1	303A			
Or AA furnace	255.2	304			
52. Potassium—Total [3], mg/L: Digestion [3] followed by:					
Atomic absorption	258.1	303A		I-3630-78	P. 560.[8]
Inductively coupled plasma					Method 200.7.[4]
Or flame photometric		322B	D1428-64(A)		
53. Residue—total, mg/L: Gravimetric, 103–105°C	160.3	209A		I-3750-78	
54. Residue—filterable, mg/L: Gravimetric, 180°C	160.1	209B		I-1750-78	
55. Residue—nonfilterable, (TSS), mg/L: Gravimetric, 103–105°C post washing of residue.	160.2	209D		I-3765-78	
56. Residue—settleable, mg/L: Volumetric (Imhoff cone) or gravimetric.	160.5	209F			
57. Residue—volatile, mg/L: Gravimetric, 550°C	160.4	209E		I-3753-78	
58. Rhodium—Total [3], mg/L: Digestion [3] followed by:					
AA direct aspiration	265.1	303A			
Or AA furnace	267.2	304			
59. Ruthenium—Total [3], mg/L: Digestion [3] followed by:					
AA direct aspiration	267.1	303A			
Or AA furnace	267.2	304			
60. Selenium—Total [3] mg/L: Digestion [3] followed by:					
AA furnance	270.2	304			
Inductively coupled plasma					Method 200.7.[4]
Or hydride	270.3	303E	D3859-79	I-3667-78	
61. Silica—Dissolved, mg/L: 0.45 micron filtration:					
Followed by manual or	370.1	425C	D859-68(B)	I-1700-78	
Automated colorimetric (Molybdosilicate), or				I-2700-78	
Inductively coupled plasma					Method 200.7.[4]
62. Silver—Total [13] mg/L: Digestion [3] followed by:					
AA direct aspiration	272.1	303A or 303B		I-3720-78	P. 557 [8] and p. 37.[9]
AA furnace, or	272.1	304			
Inductively coupled plasma					Method 200.7.[4]
63. Sodium—Total [3], mg/L: Digestion [3] followed by:					
Atomic absorption	273.1	303A		I-3735-78	P. 561.[8]
Inductively coupled plasma					Method 200.7.[4]
Or flame photometric			D1428-64(A)		
64. Specific conductance, mhos/cm: Wheatstone bridge.	120.1	205	D1125-77(A)	I-1780-78	P. 547.[8]
65. Sulfate (as SO_4), mg/L:					
Automated methylthymol blue	375.2			I-2822-78	
Gravimetric, or	375.3	426A or 426B	D516-68(A)		PP. 562-63.[8]
Turbidimetric	375.4	426C	D516-68(B)		
66. Sulfide (as S), mg/L:					
Titrimetric (iodine) or	376.1	427D		I-3840-78	
Colorimetric (methylene blue)	376.2	427C			
67. Sulfite (as SO_3), mg/L: Titrimetric (iodine iodate)	377.1	428F	D1339-78(C)		
68. Surfactants, mg/L: Colorimetric (methylene blue)	425.1	512A	D2330-68(A)		
69. Temperature, °C: Thermometric	170.1	212			([12]).
70. Thallium—Total,[3] mg/L: Digestion [3] followed by:					
AA direct aspiration	279.1	303A			
AA furnace, or	279.2	304			
Inductively coupled plasma					Method 200.7.[4]
71. Tin—Total,[3] mg/L: Digestion [3] followed by:					
AA direct aspiration or	282.1	303A		I-3850-78	
AA furnace	282.2	304			
72. Titanium—Total,[3] mg/L: Digestion [3] followed by:					
AA direct aspiration or	283.1	303C			
AA furnace	283.2	304			
73. Turbidity, NTU: Nephelometric	180.1	214A	D1889-71	I-3860-78	
74. Vanadium—Total,[3] mg/L: Digestion [3] followed by:					
AA direct aspiration	286.1	303C			
AA furnace	286.2	304			
Inductively coupled plasma					Method 200.7.[4]
Or colorimetric (Gallic acid)			D3373-75		
75. Zinc—Total,[3] mg/L: Digestion [3] followed by:					
AA direct aspirationb	289.1	303A or 303B	D1691-77(D)	I-3900-78	P. 557.[8]
AA furnace	289.2	304	D1691-77(C)		P. 37.[9]
Inductively coupled plasma					Method 200.7.[4]
Or colorimetric (Zincon)					[14].

Table B2. (Continued)

Table IB Notes

[1] "Methods for Analysis of Inorganic Substances in Water and Fluvial Sediments," U.S. Department of the Interior, U.S. Geological Survey, Open-File Report 78-679, or "Methods for Determination of Inorganic Substances in Water and Fluvial Sediments," N.W. Skougstad, *et al.* U.S. Geological Survey, *Techniques of Water-Resources Investigation*, Book 5, Chapter A1 1979

[2] "Official Methods of Analysis of the Association of Official Analytical Chemists" methods manual, 13th ed. (1980)

[3] For the determination of total metals the sample is not filtered before processing. A digestion procedure is required to solubilize suspended material and to destroy possible organic metal complexes. Two digestion procedures are given in "Methods for Chemical Analysis of Water and Wastes, 1979." One (§ 4.1.3), is a vigorous digestion using nitric acid. A less vigorous digestion using nitric and hydrochloric acids (§ 4.1.4) is preferred, however, the analyst should be cautioned that this mild digestion may not suffice for all sample types. Particularly, if a colorimetric procedure is to be employed, it is necessary to ensure that all organo-metallic bonds be broken so that the metal is in a reactive state. In those situations, the vigorous digestion is to be preferred making certain that at no time does the sample go to dryness. Samples containing large amounts of organic materials would also benefit by this vigorous digestion. Use of the graphite furnace technique, inductively coupled plasma, as well as determinations for certain elements such as arsenic, the noble metals, mercury, selenium, and titanium require a modified digestion and *in all cases the method write-up should be consulted for specific instructions and/or cautions*

Note: If the digestion procedure for direct aspiration or graphite furnace atomic absorption analysis included in one of the other approved references is different than the above, the EPA procedure must be used

Dissolved metals are defined as those constituents which will pass through a 0.45 micron membrane filter. Following filtration of the sample, the referenced procedure for total metals must be followed. Sample digestion of the filtrate for dissolved metals, or digestion of the original sample solution for total metals may be omitted for AA (direct aspiration or graphite furnace) and ICP analyses provided the sample has a low COD and the filtrate meets the following criteria

(a) Is visibly transparent

(b) Has no perceptible odor, and

(c) Is free of particulate or suspended matter following acidification

[4] The full text of Method 200.7, "Inductively Coupled Plasma Atomic Emission Spectrometric Method for Trace Element Analysis of Water and Wastes," is given at Appendix C of this Part 136

[5] Manual distillation is not required if comparability data on representative effluent samples are on company file to show that this preliminary distillation step is not necessary; however, manual distillation will be required to resolve any controversies.

[6] Ammonia, Automated Electrode Method, Industrial Method Number 379-75WE, dated February 19, 1976, Technicon AutoAnalyzer II, Technicon Industrial Systems, Tarrytown, New York 10591

[7] *Carbonaceous biochemical oxygen demand* ($CBOD_5$) must not be confused with the traditional BOD_5 test which measures "total BOD". The addition of the nitrification inhibitor is not a procedural option, but must be included to report the $CBOD_5$ parameter. A discharger whose permit requires reporting the traditional $CBOD_5$ may not use a nitrification inhibitor in the procedure for reporting the results. *Only when a discharger's permit specifically states $CBOD_5$ is required* can the permittee report data obtained using the nitrification inhibitor

[8] *American National Standard on Photographic Processing Effluents*, Apr. 2, 1975. Available from ANSI, 1430 Broadway, New York, NY 10018

[9] The use of normal and differential pulse voltage ramps to increase sensitivity and resolution is acceptable

[10] Chemical Oxygen Demand, Method 8000, Hach Handbook of Water Analysis, 1979, Hach Chemical Company, P.O. Box 389, Loveland, Colorado 80537

[11] COD Method, Oceanography International Corporation, 512 West Loop, P.O. Box 2980, College Station, Texas 77840

[12] The back titration method will be used to resolve controversy

[13] National Council of the Paper Industry for Air and Stream Improvement, Inc., Technical Bulletin 253, December 1971

[14] Copper, Bicinchoninate Method, Method 8506, Hach Handbook of Water Analysis, 1979, Hach Chemical Company, P.O. Box 389, Loveland, Colorado 80537

[15] After the manual distillation is completed, the auto-analyzer manifolds in EPA Methods 335.03 (Cyanide) or 420.2 (phenols) are simplified by connecting the re-sample line directly to the sampler. When using the manifold setup shown in Method 335, the buffer 6.2 should be replaced with the buffer 7.6 found in Method 335.2

[16] Hydrogen Ion (pH) Automated Electrode Method, Industrial Method Number 378-75WA, October 1976, Technicon Auto-Analyzer II, Technicon Industrial Systems, Tarrytown, New York 10591

[17] Iron, 1,10-Phenanthroline Method, Method 8008, 1980, Hach Chemical Company, P.O. Box 389, Loveland, Colorado 80537

[18] Manganese, Periodate Oxidation Method, Method 8034, Hach Handbook of Wastewater Analysis, 1979, pages 2-113 and 2-117, Hach Chemical Company, Loveland, Colorado 80537

[19] Nitrogen, Nitrite, Method 8507, Hach Chemical Company, P.O. Box 389, Loveland, Colorado 80537

[20] Goerlitz, D., Brown, E., "Methods for Analysis of Organic Substances in Water," U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 5, Chapter A3, p. 4 (1972)

[21] R.F. Addison and R.G. Ackman, "Direct Determination of Elemental Phosphorus by Gas-Liquid Chromatography," *Journal of Chromatography*, Vol. 47, No. 3, pp. 421–426, 1970

[22] Recommended methods for the analysis of silver in industrial wastewaters at concentrations of 1 mg/L and above are inadequate where silver exists as an inorganic halide. Silver halides such as the bromide and chloride are relatively insoluble in reagents such as nitric acid but are readily soluble in an aqueous buffer of sodium thiosulfate and sodium hydroxide to a pH of 12. Therefore, for levels of silver above 1 mg/L, 20 mL of sample should be diluted to 100 mL by adding 40 mL each of *2 M* $Na_2S_2O_3$ *and 2M NaOH. Standards should be prepared in the* same manner. For levels of silver below 1 mg/L the recommended method is satisfactory

[23] Stevens, H.H., Ficke, J.F., and Smoot, G.F., "Water Temperature-Influential Factors, Field Measurement and Data Presentation," U.S. Geological Survey, Techniques of Water Resources Investigations, Book 1, Chapter D1, 1975

[24] Zinc, Zincon Method, Method 8009, Hach Handbook of Water Analysis, 1979, pages 2-231 and 2-333, Hach Chemical Company, Loveland, Colorado 80537

[25] "Selected Analytical Methods Approved and Cited by the United States Environmental Protection Agency," Supplement to the Fifteenth Edition of *Standard Methods for the Examination of Water and Wastewater (1981)*.

[26] The approved method is that cited in *Standard Methods for the Examination of Water and Wastewater*, 14th Edition. The colorimetric reaction is conducted at a pH of 10.0 ± 0.2. The approved methods are given on pp. 576–81 of the 14th Edition. Method 510A for distillation, Method 510B for the manual colorimetric procedure, or Method 510C for the manual spectrophotometric procedure

[27] ORION Research Instruction Manual, Residual Chlorine Electrode Model 97-70, 1977, Orion Research Incorporated, 840 Memorial Drive, Cambridge, Massachusetts 02138

Table B3. List of Approved Test Procedures for Non-Pesticide Organic Compounds

Parameter [1]	EPA Method Number [2, 7]			Other
	GC	GC/MS	HPLC	
1. Acenaphthene	610	625, 1625	610	
2. Acenaphthylene	610	625, 1625	610	
3. Acrolein	603	[4]624, 1624		
4. Acrylonitrile	603	[4]624, 1624		
5. Anthracene	610	625, 1625	610	
6. Benzene	602	624, 1624		
7. Benzidine		[5]625, 1625	605	Note 3, p. 1;
8. Benzo(a)anthracene	610	625, 1625	610	
9. Benzo(a)pyrene	610	625, 1625	610	
10 Benzo(b)fluroanthene	610	625, 1625	610	
11. Benzo(ghi)perylene	610	625, 1625	610	
12. Benzo(k)fluoranthene	610	625, 1625	610	
13. Benzyl Chloride				Note 3, p. 130, Note 6, p. S102.
14 Benzyl Butyl Phthalate	606	625, 1625		
15. Bis(2-chloroethoxy) methane	611	625, 1625		
16. Bis(2-chloroethyl) ether	611	625, 1625		
17. Bis(2-ethylhexyl) phthalate	606	625, 1625		
18 Bromodichloromethane	601	624, 1624		
19 Bromoform	601	624, 1624		
20 Bromomethane	601	624, 1624		
21. 4-Bromophenylphenyl ether	611	625, 1625		
22 Carbon tetrachloride	601	624, 1624		Note 3, p. 130;
23 4-Chloro-3-methylphenol	604	625, 1625		
24 Chlorobenzene	601, 602	624, 1624		Note 3, p. 130;
25 Chloroethane	601	624, 1624		
26 2-Chloroethylvinyl ether	601	624, 1624		
27 Chloroform	601	624, 1624		Note 3, p 130;
28 Chloromethane	601	624, 1624		
29 2-Chloronaphthalene	612	625, 1625		
30 2-Chlorophenol	604	625, 1625		
31 4-Chlorophenylphenyl ether	611	625, 1625		
32 Chrysene	610	625, 1625	610	
33 Dibenzo(a,h)anthracene	610	625, 1625	610	
34 Dibromochloromethane	601	624, 1624		
35 1,2 Dichlorobenzene	601, 602, 612	624, 625, 1625		
36 1,3 Dichlorobenzene	601, 602, 612	624, 625, 1625		
37 1,4 Dichlorobenzene	601, 602, 612	625, 1624, 1625		
38 3,3-Dichlorobenzidine		625, 1625	605	
39 Dichlorodifluoromethane	601			
40 1,1-Dichloroethane	601	624, 1624		
41 1,2-Dichloroethane	601	624, 1624		
42 1,1-Dichloroethene	601	624, 1624		
43 trans-1,2 Dichloroethene	601	624, 1624		
44 2,4-Dichlorophenol	604	625, 1625		
45 1,2-Dichloropropane	601	624, 1624		
46 cis-1,3-Dichloropropene	601	624, 1624		
47 trans-1,3-Dichloropropene	601	624, 1624		
48 Diethyl phthalate	606	625, 1625		

Table B3. (Continued)

Parameter [1]	EPA Method Number [2, 7]			Other
	GC	GC/MS	HPLC	
49. 2,4-Dimethylphenol	604	625, 1625		
50. Dimethyl phthalate	606	625, 1625		
51. Di-n-butyl phthalate	606	625, 1625		
52. Di-n-octyl phthalate	606	625, 1625		
53. 2,4-Dinitrophenol	604	625, 1625		
54. 2,4-Dinitrotoluene	609	625, 1625		
55. 2,6-Dinitrotoluene	609	625, 1625		
56. Epichlorohydrin				Note 3, p. 130; Note 6, p. S102
57. Ethylbenzene	602	624, 1624		
58. Fluoranthene	610	625, 1625	610	
59. Fluorene	610	625, 1625	610	
60. Hexachlorobenzene	612	625, 1625		
61. Hexachlorobutadiene	612	625, 1625		
62. Hexachlorocyclopentadiene	612	[5]625, 1625		
63. Hexachloroethane	612	625, 1625		
64. Ideno(1,2,3-cd)pyrene	610	625, 1625	610	
65. Isophorone	609	625, 1625		
66. Methylene Chloride	601	624, 1624		Note 3, p. 130;
67. 2-Methyl-4,6-Dinitrophenol	604	625, 1625		
68. Naphthalene	610	625, 1625		
69. Nitrobenezene	609	625, 1625		
70. 2-Nitrophenol	604	625, 1625		
71. 4-Nitrophenol	604	625, 1625		
72. N-Nitrosodimethylamine	607	625, 1625		
73. N-Nitrosodi-n-propylamine	607	[5]625, 1625		
74. N-Nitrosodiphenylamine	607	[5]625, 1625		
75. 2,2-oxybis(1-chloropropane)	611	625, 1625		
76. PCB-1016	608	625		Note 3, p. 43,
77. PCB-1221	608	625		Note 3, p. 43,
78. PCB-1232	608	625		Note 3, p. 43,
79. PCB-1242	608	625		Note 3, p. 43,
80. PCB-1248	608	625		Note 3, p. 43;
81. PCB-1254	608	625		Note 3, p. 43,
82. PCB-1260	608	625		Note 3, p. 43,
83. Pentachlorophenol	604	625, 1625		Note 3, p. 140,
84. Phenanthrene	610	625, 1625	610	
85. Phenol	604	625, 1625		
86. Pyrene	610	625, 1625	610	
87. 2,3,7,8-Tetrachlorodibenzo-p-dioxin		[a]613		
88. *1,1,2,2-Tetrachloroethane*	601	624, 1624		Note 3, p. 130;
89. Tetrachloroethene	601	624, 1624		Note 3, p. 130;
90. Toluene	602	624, 1624		
91. 1,2,4-Trichlorobenzene	612	625, 1625		Note 3, p. 130;
92. 1,1,1-Trichloroethane	601	624, 1624		
93. 1,1,2-Trichloroethane	601	624, 1624		Note 3, p. 130;
94. Trichloroethene	601	624, 1624		
95. Trichlorofluoromethane	601	624		
96. 2,4,6-Trichlorophenol	604	625, 1625		
97. Vinyl Chloride	601	624, 1624		

Table IC Notes

[1] All parameters are expressed in micrograms per liter (µg/L).

[2] *The full text of Methods 601-613, 624, 625, 1624, and 1625, are given at Appendix A,* "Test Procedures for Analysis of Organic Pollutants," of this Part 136. The standardized test procedure to be used to determine the method detection limit (MDL) for these test procedures is given at Appendix B, "Definition and Procedure for the Determination of the Method Detection Limit," of this Part 136.

[3] "Methods for Benzidine; Chlorinated Organic Compounds, Pentachlorophenol and Pesticides in Water and Wastewater," U.S. Environmental Protection Agency, September, 1978.

[4] Method 624 may be extended to screen samples for Acrolein and Acrylonitrile. However, when they are known to be present, the preferred method for these two compounds is Method 603 or Method 1624.

[5] Method 625 may be extended to include benzidine, hexachlorocyclopentadiene, N-nitrosodimethyamine, and N-nitrosodiphenylamine. However, when they are known to be present, Methods 605, 607, and 612, or Method 1625, are preferred methods for these compounds.

[a] 625, Screening only.

[6] "Selected Analytical Methods Approved and Cited by the United States Environmental Protection Agency," Supplement to the Fifteenth Edition of *Standard Methods for the Examination of Water and Wastewater* (1981).

[7] Each analyst must make an initial, one-time, demonstration of their ability to generate acceptable precision and accuracy with Methods 601-613, 624, 625, 1624, and 1625 (See Appendix A of this Part 136) in accordance with procedures each in section 8.2 of each of these Methods. Additionally, each laboratory, on an on-going bases must spike and analyze 10% (5% for Methods 624 and 625 and 100% for methods 1624, and 1625) of all samples to monitor and evaluate laboratory data quality in accordance with sections 8.3 and 8.4 of these Methods. When the recovery of any parameter falls outside the warning limits, the analytical results for that parameter in the unspiked sample are suspect and cannot be reported to demonstrate regulatory compliance.

Note.—These warning limits are promulgated as an "interim final action with a request for comments."

Table B4. List of Approved Test Procedures For Pesticides[1]

Parameter µg/L)	Method	EPA[2,7]	Standard Methods 15th Ed	ASTM	Other
1. Aldrin	GC	608	509A	D3086	Note 3, p. 7, Note 4, p. 30.
	GC/MS	625			
2. Ametryn	GC				Note 3, p. 83; Note 6, p. S68.
3. Aminocarb	TLC				Note 3, p. 94; Note 6, p. S16.
4. Atraton	GC				Note 3, p. 83; Note 6, p. S68.
5. Atrazine	GC				Note 3, p. 83; Note 6, p. S68.
6. Azinphos methyl	GC				Note 3, p. 25, Note 6, p. S51.
7. Barban	TLC				Note 3, p. 104; Note 6, p. S64.
8. α-BHC	GC	608	509A	D3086	Note 3, p. 7.
	GC/MS	[8] 625			
9. β-BHC	GC	608		D3086	
	GC/MS	625			
10. δ-BHC	GC	608		D3086	

Table B4. (Continued)

Parameter µg/L)	Method	EPA [2,7]	Standard Methods 15th Ed	ASTM	Other
	GC/MS	[5] 625			
11. γ-BHC (Lindane)	GC	608	509A	D3086	Note 3, p. 7, Note 4, p. 30
	GC/MS	625			
12. Captan	GC		509A		Note 3, p. 7.
13. Carbaryl	TLC				*Note 3, p. 94, Note 6, p. S60.*
14. Carbophenothion	GC				Note 4, p. 30, Note 6, p. S73.
15. Chlordane	GC	608	509A	D3086	Note 3, p. 7.
	GC-MS	625			
16. Chloropropham	TLC				Note 3, p. 104, Note 6, p. S64.
17. 2,4–D	GC		509B		Note 3, p. 115, Note 4, p. 35.
18. 4,4'–DDD	GC	608	509A	D3086	Note 3, p. 7; Note 4, p. 30.
	GC-MS	625			
19. 4,4'–DDE	GC	608	509A	D3086	Note 3, p. 7, Note 4, p. 30.
	GC/MS	625			
20. 4,4'–DDT	GC	608	509A	D3086	Note 3, p. 7, Note 4, p. 30.
	GC/MS	625			
21. Demeton-O	GC				Note 3, p. 25; Note 6, p. S51.
22. Dementon-S	GC				Note 3, p. 25; Note 6, p. S51
23. Diazinon	GC				Note 3, p. 25, Note 4, p. 30; Note 6, p. S51.
24. Dicamba	GC				Note 3, p. 115.
25. Dichlofenthion	GC				Note 4, p. 30; Note 6, p. S73.
26. Dichloran	GC		509A		Note 3, p. 7.
27. Dicofol	GC			D3086	
28. Dieldrin	GC	608	509A		Note 3, p. 7; Note 4, p. 30.
	GC/MS	625			
29. Dioxathion	GC				Note 4, p. 30; Note 6, p. S73.
30. Disulfoton	GC				Note 3, p. ; Note 6, p. S51
31. Diuron	TLC				Note 3, *p. 104;* Note 6, *p. S64.*
32. Endosulfan I	GC	608	509A	D3086	Note 3, p. 7.
	GC/MS	[5] 625			
33. Endosulfan II	GC	608	509A	D3086	Note 3, p. 7.
	GC/MS	[5] 625			
34. Endosulfan sulfate	GC	608			
	GC/MS	625			
35. Endrin	GC	608	509A	D3086	Note 3, p. 7, Note 4, p. 30.
	GC/MS	[5] 625			
36. Endrin aldehyde	GC	608			
	GC/MS	625			
37. Ethion	GC				Note 4, p. 30, Note 6, p. S73.
38. Fenuron	TLC				*Note 3, p.* 104, Note 6, *p.* S54.
39. Fenuron-TCA	TLC				Note 3, p. 104, Note 6, p. S64
40. Heptachlor	GC	608	509A	D3086	Note 3, p. 7; Note 4, p. 30.
	GC/MS	625			
41. Heptachlor epoxide	GC	608	509A	D3086	Note 3, p. 7; Note 4, p. 30; Note 6, p. *S73.*
42. Isodrin	GC/MS	625			
	GC				Note 4, p. 30, Note 6, p. S73.
43. Linuron	TLC				Note 3, p. 104, Note 6, p. S64
44. Malathion	GC		509A		Note 3, p. 25, Note 4, p. 30, Note 6, p. S51.
45. Methiocarb	TLC				Note 3, p. 94, Note 6, p. S60
46. Methoxychlor	GC		509A	D3086	Note 3, p. 7, Note 4, p. 30.
47. Mexacarbate	TLC				Note 3, p. 94, Note 6, p. S60.
48. Mirex	GC		509A		Note 3, p. 7.
49. Monuron	TLC				Note 3, p. 104, Note 6, p. S64
50. Monuron-TCA	TLC				Note 3, p. 104, Note 6, p. S64
51. Neburon	TLC				Note 3, p. 104, Note 6, p. S64
52. Parathion methyl	GC		509A		Note 3, p. 25, Note 4, p. 30
53. Parathion ethyl	GC		509A		Note 3, p. 25
54. PCNB	GC		509A		Note 3, p. 7
55. Perthane	GC			D3086	
56. Prometon	GC				Note 3, p. 83, Note 6, p. S68
57. Prometryn	GC				Note 3, p. 83, Note 6, p. S68
58. Propazine	GC				Note 3, p. 83, Note 6, p. S68
59. Propham	TLC				Note 3, p. 104, Note 6, p. S64
60. Propoxur	TLC				Note 3, p. 94, Note 6, p. S60
61. Secbumeton	TLC				Note 3, p. 83, Note 6, p. S68
62. Siduron	TLC				Note 3, p. 104, Note 6, p. S64.
63. Simazine	GC				Note 3, p. 83, Note 6, p. S68
64. Strobane	GC		509A		Note 3, p. 7
65. Swep	TLC				Note 3, p. 104, Note 6, p. S64
66. 2,4,5–T	GC		509B		Note 3, p. 115, Note 4, p. 35.
67. 2,4,5–TP (Silvex)	GC		509B		Note 3, p. 115
68. Terbuthylazine	GC				Note 3, p. 83, Note 6, p. S68.
69. Toxaphene	GC	608	509A	D3086	Note 3, p. 7, Note 4, p. 30
	GC/MS	625			
70. Trifluralin	GC		*509A*		*Note 3, p. 7*

Table ID Notes

[1] Pesticides are listed in this table by common name for the convenience of the reader. Additional pesticides may be found under Table IC, where entries are listed by chemical name.

[2] The full text of methods 608 and 625 are given at Appendix A, "Test Procedures for Analysis of Organic Pollutants," of this Part 136. The standardized test procedure to be used to determine the method detection limit (MDL) for these test procedures is given at Appendix B, "*Definition and Procedure for the Determination of the Method Detection Limit*", *of this Part 136.*

[3] "Methods for Benzidine, Chlorinated Organic Compounds, Pentachlorophenol and Pesticides in Water and Wastewater," U.S. Environmental Protection Agency, September, 1978. This EPA publication includes thin-layer chromatography (TLC) methods.

[4] "Methods for Analysis of Organic Substances in Water," U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 5, Chapter *A3 (1972)*

[5] The method may be extended to include α-BHC, δ-BHC, endosulfan I, endosulfan II, and endrin. However, when they are known to exist, Method 608 is the preferred method.

[6] "Selected Analytical Methods Approved and Cited by the United States Environmental Protection Agency," Supplement to the Fifteenth Edition of *Standard Methods for the Examination of Water and Wastewater* (1981)

[7] Each analyst must make an initial, one-time, demonstration of their ability to generate acceptable precision and accuracy with Methods 608 and 625 (See Appendix A of this Part 136) in accordance with procedures given in Section 8.2 of each of these methods. Additionally, each laboratory, on an on-going basis, must spike and analyze 10% of all samples analyzed with

Table B5. List of Approved Radiological Test Procedures

Parameter and units	Methods	EPA [1]	Reference (method No. or page)		
			Standard Methods 15th Ed.	ASTM	USGS [2]
1. Alpha-Total, p^{Ci} per liter	Proportional or scintillation counter	900 0	703	D1943-66	pp. 75 and 78.[3]
2. Alpha-Counting error, p^{Ci} per liter	Proportional or scintillation counter	Appendix B	703	D1943-66	p. 79.
3. Alpha-Counting error, p^{Ci} per liter	Proportional counter	900 0	703	D1890-66	pp. 75 and 78.[3]
4. Beta-Counting error, p^{Ci} per liter	Proportional counter	Appendix B	703	D1890-66	p. 79.
5. (a) Radium-Total, p^{Ci} per liter	Proportional counter	903 0	705	D2460-70	
(b) ^{226}Ra, p^{Ci} per liter	Scintillation counter	903.1	706	D3454-79	p. 81.

Table IE Notes

[1] "Prescribed Procedures for Measurement of Radioactivity in Drinking Water," EPA-600/4-80-032 (1980 update), U S Environmental Protection Agency, August 1980

[2] Fishman, M J and Brown, Eugene, "Selected Methods of the U S Geological Survey of Analysis of Wastewaters," U S Geological Survey, Open-File Report 76-177 (1976)

[3] The method found on p 75 measures only the dissolved portion while the method on p 78 measures only the suspended portion Therefore the two results must be added to obtain the "total"

Table B6. Required Containers, Preservation Techniques, and Holding Times

Parameter No./name	Container [1]	Preservation [2, 3]	Maximum holding time [4]
Table IA—Bacterial Tests:			
1–4 Coliform, fecal and total	P, G	Cool, 4°C, 0.008% $Na_2S_2O_3$ [5]	6 hours
5 Fecal streptococci	P, G	do	Do
Table IB—Inorganic Tests:			
1 Acidity	P, G	Cool, 4°C	14 days
2. Alkalinity	P, G	do	Do
4. Ammonia	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days
9 Biochemical oxygen demand	P, G	Cool, 4°C	48 hours
11. Bromide	P, G	None required	28 days
14. Biochemical oxygen demand, carbonaceous	P, G	Cool, 4°C	48 hours.
15. Chemical oxygen demand	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days
16. Chloride	P, G	None required	Do
17 Chlorine, total residual	P, G	do	Analyze immediately
21. Color	P, G	Cool, 4°C	48 hours.
23–24. Cyanide, total and amenable to chlorination	P, G.	Cool, 4°C, NaOH to pH>12, 0.6g ascorbic acid [5]	14 days [6]
25. Fluoride	P	None required	28 days
27. Hardness	P, G	HNO_3 to pH<2, H_2SO_4 to pH<2	6 months
28. Hydrogen ion (pH)	P, G	None required	Analyze immediately.
31, 43 Kjeldahl and organic nitrogen	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days
Metals:[7]			
18. Chromium VI	P, G	Cool, 4°C	24 hours.
35. Mercury	P, G	HNO_3 to pH<2	28 days.
3, 5–8, 10, 12, 13, 19, 20, 22, 26, 29, 30, 32–34, 36, 37, 45, 47, 51, 52, 58–60, 62, 63, 70–72, 74, 75. *Metals, except chromium VI and mercury.*	P, G	do	6 months.
38. Nitrate	P, G	Cool, 4°C	48 hours.
39 Nitrate-nitrite	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days
40 Nitrite.	P, G	Cool, 4°C	48 hours.
41. Oil and grease	G.	Cool, 4°C, H_2SO_4 to pH<2	28 days.
42. Organic carbon	P, G	Cool, 4°C, HCl or H_2SO_4 to pH<2	Do
44. Orthophosphate	P, G	Filter immediately, Cool, 4°C	48 hours.
46. Oxygen, Dissolved Probe	G Bottle and top	None required	Analyze immediately.
47 Winkler	do	Fix on site and store in dark	8 hours.
48. Phenols	G only	Cool, 4°C, H_2SO_4 to pH<2	28 days
49. Phosphorus (elemental)	G.	Cool, 4°C	48 hours.
50. Phosphorus, total	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days.
53. Residue, total	P, G	Cool, 4°C	7 days
54. Residue, Filterable	P, G	do	48 hours.
55. Residue, Nonfilterable (TSS)	P, G	do	7 days.
56. Residue, Settleable	P, G	do	48 hours.
57. Residue, volatile	P, G.	do	7 days.
61. Silica	P	do	28 days.
64. Specific conductance	P, G	do	Do.
65. Sulfate	P, G	do	Do
66. Sulfide	F, G	Cool, 4°C add zinc acetate plus sodium hydroxide to pH>9.	7 days.
67 Sulfite	P, G	None required	Analyze immediately.
68. Surfactants	P ,G	Cool, 4°C	48 hours.
69. Temperature	P, G	None required	Analyze.
73. Turbidity	P, G	Cool, 4°C	48 hours.
Table IC—Organic Tests:[8]			
13, 18–20, 22, 24–28, 34–37, 39–43, 45–47, 56, 66, 88, 89, 92–95, 97. Purgeable Halocarbons.	G, Teflon-lined septum	Cool, 4°C, 0.008% $Na_2S_2O_3$ [5]	14 days.
6, 57, 90. Purgeable aromatic hydrocarbons	do	Cool, 4°C, 0.008% $Na_2S_2O_3$ [5], HC1 to pH2 [9]	Do
3, 4, Acrolein and acrylonitrile	do	Cool, 4°C, 0.008% $Na_2S_2O_3$ [5], Adjust pH to 4–5 [10]	Do
23, 30, 44, 49, 53, 67, 70, 71, 83, 85, 96. Phenols [11]	G, Teflon-lined cap	Cool, 4°C, 0.008% $Na_2S_2O_3$ [5]	7 days until extraction, 40 days after extraction
7, 38. Benzidines [11]	do	do	7 days until extraction [13]
14, 17, 48, 50–52. Phthalate esters [11]	do	Cool, 4°C	7 days until extraction; 40 days after extraction.
72–74. Nitrosamines [11, 14]	do	Cool, 4°C, store in dark, 0.008% $Na_2S_2O_3$ [5]	Do
76–82. PCBs [11] acrylonitrile	do	Cool, 4°C	Do
54, 55, 65, 69. Nitroaromatics and isophorone [11]	do	Cool, 4°C, 0.008% $Na_2S_2O_3$ [5] store in dark	Do
1, 2, 5, 8–12, 32, 33, 58, 59, 64, 68, 84, 86. *Polynuclear aromatic hydrocarbons.*[11].	do	do	Do
15, 16, 21, 31, 75. Haloethers [11]	do	Cool, 4°C, 0.008% $Na_2S_2O_3$ [5]	Do.
29, 35–37, 60–63, 91. Chlorinated hydrocarbons [11]	do	Cool, 4°C	Do
87. TCDD [11]	do	Cool, 4°C, 0.008% $Na_2S_2O_3$ [5]	Do.
Table ID—Pesticides Tests:			
1–70 Pesticides [11]	do	Cool, 4°C, pH 5–9 [15]	Do
Table IE—Radiological Tests:			
1–5. Alpha, beta and radium	P, G	HNO_3 to pH<2	6 months.

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APPENDIX C

USEPA AMBIENT STANDARDS AND CRITERIA

APPENDIX C: USEPA AMBIENT STANDARDS AND CRITERIA*

	Applicable or Relevant Requirements		Other Criteria, Advisories, and Guidance				
					Safe Drinking Water Act, Health Advisories (mg/L)		
Chemical	Safe Drinking Water Act, MCLs (mg/L unless otherwise noted)	Clean Air Act, NAAQS (ug/m^3)	Clean Water Act, Water Quality Criteria for Human Health--Fish and Drinking Water	Clean Water Act, Water Quality Criteria for Human Health--Adjusted for Drinking Water Only[a]	1-day	10-day	Chronic (longer term)
Acenaphthene			20 ug/L (organoleptic)[b]	20 ug/L (organoleptic)			
Acrolein			320 ug/L	540 ug/L			
Acrylonitrile			0 (58 ng/L)[c]	0 (63 ng/L)			
Aldrin			0 (0.074 ng/L)	0 (1.2 ng/L)			
Antimony			146 ug/L	146 ug/L			
Arsenic	0.05		0 (2.2 ng/L)	0 (2.5 ng/L)			
Asbestos			0 (30,000 fibers/L)	0 (30,000 fibers/L)			
Barium	1.0						
Benzene			0 (0.66 ug/L)	0 (0.67 ug/L)		0.23	0.07
Benzidine			0 (0.12 ng/L)	0 (0.15 ng/L)			
Beryllium			0 (3.7 ng/L)	0 (3.9 mg/L)			
Cadmium	0.01		10 ug/L	10 ug/L			
Carbon monoxide		40,000 (1-hour)[d] 10,000 (8-hour)[d]					
Carbon tetrachloride			0 (0.4 ug/L)	0 (0.42 ug/L)	0.2	0.02	
Chlordane			0 (0.46 ng/L)	0 (22 ng/L)	0.0625	0.0625	0.0075
Chlorinated benzenes							
Hexachlorobenzene			0 (0.72 ng/L)	0 (21 mg/L)			
1,2,4,5-Tetrachlorobenzene			38 ug/L	180 ug/L			
Pentachlorobenzene			74 ug/L	570 ug/L			
Trichlorobenzene			Insufficient data	Insufficient data			
Monochlorobenzene			488 ug/L	488 ug/L			
Chlorinated ethanes							
1,2-Dichloroethane			0 (0.94 ug/L)	0 (0.94 ug/L)		Insufficient data	
1,1,1-Trichloroethane			18.4 mg/L	19 mg/L			1.0
1,1,2-Trichloroethane			0 (0.6 ug/L)	0 (0.6 ug/L)			
1,1,2,2-Tetrachloroethane			0 (0.17 ug/L)	0 (0.17 ug/L)			
Hexachloroethane			0 (1.9 ug/L)	0 (2.4 ug/L)			
Monochloroethane			Insufficient data	Insufficient data			
1,1-Dichloroethane			Insufficient data	Insufficient data			
1,1,1,2-Tetrachloroethane			Insufficient data	Insufficient data			
Pentachloroethane			Insufficient data	Insufficient data			

(continued)

* SOURCE: USEPA (1985)

APPENDIX C. (Continued)

Chemical	Applicable or Relevant Requirements		Other Criteria, Advisories, and Guidance				
	Safe Drinking Water Act, MCLs (mg/L unless otherwise noted)	Clean Air Act, NAAQS (ug/m^3)	Clean Water Act, Water Quality Criteria for Human Health--Fish and Drinking Water	Clean Water Act, Water Quality Criteria for Human Health--Adjusted for Drinking Water Only^{a}	Safe Drinking Water Act, Health Advisories (mg/L) 1-day	10-day	Chronic (longer term)
Chlorinated naphthalenes			Insufficient data	Insufficient data			
Chlorinated phenols							
3-Monochlorophenol			0.1 ug/L (organoleptic)	0.1 ug/L (organoleptic)			
4-Monochlorophenol			0.1 ug/L (organoleptic)	0.1 ug/L (organoleptic)			
2,3-Dichlorophenol			0.04 ug/L (organoleptic)	0.04 ug/L (organoleptic)			
2,5-Dichlorophenol			0.5 ug/L (organoleptic)	0.5 ug/L (organoleptic)			
2,6-Dichlorophenol			0.2 ug/L (organoleptic)	0.2 ug/L (organoleptic)			
3,4-Dichlorophenol			0.3 ug/L (organoleptic)	0.3 ug/L (organoleptic)			
2,3,4,6-Tetrachlorophenol			1.0 ug/L (organoleptic)	1.0 ug/L (organoleptic)			
2,4,5-Trichlorophenol			2600 ug/L	2600 ug/L			
2,4,6-Trichlorophenol			0 (1.2 ug/L)	0 (1.8 ug/L)			
2-Methyl-4-chlorophenol			1800 ug/L (organoleptic)	1800 ug/L (organoleptic)			
3-Methyl-4-chlorophenol			3000 ug/L (organoleptic)	3000 ug/L (organoleptic)			
3-Methyl-6-chlorophenol			20 ug/L (organoleptic)	20 ug/L (organoleptic)			
Chlorophenoxys							
2,4-Dichlorophenoxyacetic acid (2,4-D)	0.1						
2,4,5-Trichlorophenoxy-propionic acid (2,4,5-TP)	0.01						
Chloroalkyl ethers							
bis-(Chloromethyl) ether			0 (0.0038 ng/L)	0 (0.0039 ng/L)			
bis-(2-Chloroethyl) ether			0 (30 ng/L)	0 (30 ng/L)			
bis-(2-Chloroisopropyl) ether			34.7 ug/L	34.7 ug/L			
Chloroform	0.1^{e}		0 (0.19 ug/L)	0 (0.19 ug/L)			
2-Chlorophenol			0.1 ug/L (organoleptic)	0.1 ug/L (organoleptic)			
Chromium Cr+6	0.05		50 ug/L	50 ug/L			
Cr+3			170 mg/L	179 mg/L			
Copper			1 mg/L (organoleptic)	1 mg/L (organoleptic)			
Cyanide			200 ug/L	200 ug/L			
DDT			0 (0.024 ng/L)	0 (>1.2 ng/L)			
Dichlorobenzenes (all isomers)			400 ug/L	470 ug/L			
Dichlorobenzidines			0 (10.3 ng/L)	0 (20.7 ng/L)			
Dichloroethylenes							
1,1-Dichloroethylene			0 (33 ng/L)	0 (33 ng/L)	1.0		0.07
1,2-Dichloroethylene			Insufficient data	Insufficient data	4.0	0.4	(cis isomer)
					2.7	0.27	(trans isomer)

(continued)

APPENDIX C. (Continued)

	Applicable or Relevant Requirements		Other Criteria, Advisories, and Guidance				
					Safe Drinking Water Act, Health Advisories (mg/L)		
Chemical	Safe Drinking Water Act, MCLs (mg/L unless otherwise noted)	Clean Air Act, NAAQS (ug/m^3)	Clean Water Act, Water Quality Criteria for Human Health--Fish and Drinking Water	Clean Water Act, Water Quality Criteria for Human Health--Adjusted for Drinking Water Only[a]	1-day	10-day	Chronic (longer term)
Dichloromethane			See Halomethanes	See Halomethanes	13	1.3	0.15
2,4-Dichlorophenol			3.09 mg/L	3.09 mg/L			
Dichloropropanes/ Dichloropropenes							
Dichloropropanes			Insufficient data	Insufficient data			
Dichloropropenes			87 ug/L	87 ug/L			
Dieldrin			0 (0.071 ng/L)	0 (1.1 ng/L)			
2,4-Dimethylphenol			400 ug/L (organoleptic)	400 ug/L (organoleptic)			
2-4-Dinitrotoluene			0 (0.11 ug/L)	0 (0.11 ug/L)			
p-Dioxane					5.68	0.568	
1,2-Diphenylhydrazine			0 (42 ng/L)	0 (46 ng/L)			
Endosulfan			74 ug/L	138 ug/L			
Endrin	0.0002		1 ug/L	1 ug/L			
Ethylbenzene			1.4 mg/L	2.4 mg/L			
Ethylene glycol					19.0		5.5
Formaldehyde						0.03	
Fluoranthene			42 ug/L	188 ug/L			
Fluoride	1.4-2.4						
Haloethers			Insufficient data	Insufficient data			
Halomethanes			0 (0.19 ug/L)	0 (0.19 ug/L)			
Heptachlor			0 (0.28 ng/L)	0 (11 ng/L)			
Hexachlorobutadiene			0 (0.45 ug/L)	0 (0.45 ug/L)			
Hexachlorocyclohexanes							
Lindane (99% gamma-HCH)	0.004						
alpha-HCH			0 (9.2 ng/L)	0 (13 ng/L)			
beta-HCH			0 (16.3 ng/L)	0 (23.2 ng/L)			
gamma-HCH			0 (18.6 ng/L)	0 (26.4 ng/L)			
delta-HCH			Insufficient data	Insufficient data			
epsilon-HCH			Insufficient data	Insufficient data			
Technical-HCH			0 (12.3 ng/L)	0 (17.4 ng/L)			
Hexachlorocyclopentadiene			206 ug/L	206 ug/L			
n-Hexane					13	4.0	
Hydrocarbons (non-methane)		160 (3-hour)[d/f]					
Isophorone			5.2 mg/L	5.2 mg/L			
Kerosene/fuel oil no. 2						0.35[g] 0.23	

(continued)

APPENDIX C. (Continued)

	Applicable or Relevent Requirements		Other Criteria, Advisories, and Guidance				
Chemical	Safe Drinking Water Act, MCLs (mg/L unless otherwise noted)	Clean Air Act, NAAQS (ug/m^3)	Clean Water Act, Water Quality Criteria for Human Health-- Fish and Drinking Water	Clean Water Act, Water Quality Criteria for Human Health-- Adjusted for Drinking Water Only[a]	Safe Drinking Water Act, Health Advisories (mg/L)		
					1-day	10-day	Chronic (longer term)
Lead	0.05	1.5 (90-day)	50 ug/L	50 ug/L			
Mercury	0.002		144 ng/L	10 ug/L			
Methoxychlor	0.1						
Methyl Ethyl Ketone						7.5	0.750
Naphthalene			Insufficient data	Insufficient data			
Nickel			13.4 ug/L	15.4 ug/L			
Nitrate (as N)	10.0						
Nitrobenzene			19.8 mg/L	19.8 mg/L			
Nitrogen dioxide		100 (1-year)[h]					
Nitrophenols							
2,4-Dinitro-o-cresol			13.4 ug/L	13.6 ug/L			
Dinitrophenol			70 ug/L	70 ug/L			
Mononitrophenol			Insufficient data	Insufficient data			
Trinitrophenol			Insufficient data	Insufficient data			
Nitrosamines							
n-Nitrosodimethylamine			0 (1.4 ng/L)	0 (1.4 ng/L)			
n-Nitrosodiethylamine			0 (0.8 ng/L)	0 (0.8 ng/L)			
n-Nitrosodi-n-butylamine			0 (6.4 ng/L)	0 (6.4 ng/L)			
n-Nitrosodiphenylamine			0 (4.9 ug/L)	0 (7.0 ug/L)			
n-Nitrosopyrrolidine			0 (16 ng/L)	0 (16 ng/L)			
Ozone		235 (1-hour)					
Particulate Matter		260 (24-hour)[d] 75 (24-hour)[i]					
Pentachlorophenol			1.01 mg/L	1.01 mg/L			
Phenol			3.5 mg/L	3.5 mg/L			
Phthalate esters							
Dimethylphthalate			313 mg/L	350 mg/L			
Diethylphthalate			350 mg/L	434 mg/L			
Dibutylphthalate			34 mg/L	44 mg/L			
Di-2-ethylhexyl-phthalate			15 mg/L	21 mg/L			
Polychlorinated biphenyls (PCBs)			0 (0.079 ng/L)	0 (>12.6 ng/L)	0.125	0.0125	
Polynuclear aromatic hydrocarbons (PAHs)			0 (2.8 ng/L)	0 (3.1 ng/L)			

(continued)

APPENDIX C. (Continued)

	Applicable or Relevant Requirements		Other Criteria, Advisories, and Guidance				
					Safe Drinking Water Act, Health Advisories (mg/L)		
Chemical	Safe Drinking Water Act, MCLs (mg/L unless otherwise noted)	Clean Air Act, NAAQS (ug/m^3)	Clean Water Act, Water Quality Criteria for Human Health--Fish and Drinking Water	Clean Water Act, Water Quality Criteria for Human Health--Adjusted for Drinking Water Only[a]	1-day	10-day	Chronic (longer term)
Radionuclides							
Radium-226 and 228	5 pCi/L						
Gross alpha activity	15 pCi/L						
Tritium	20,000 pCi/L						
Strontium-90	8 pCi/L						
Other man-made	j						
Selenium	0.01		10 ug/L	10 ug/L			
Silver	0.05		50 ug/L	50 ug/L			
Sulfur dioxide		365 (24-hour)[d] 80 (1-year)[k]					
2,3,7,8-TCDD			0 (0.000013 ng/L)	0 (0.00018 ng/L)			
Tetrachloroethylene			0 (0.8 ug/L)	0 (0.88 ug/L)	2.3	0.175	0.02
Thallium			13 ug/L	17.8 ug/L			
Toluene			14.3 mg/L	15 mg/L	21.5	2.2	0.34
Toxaphene	0.005		0 (0.71 mg/L)	0 (25.8 mg/L)			
Trichloroethylene			0 (2.7 ug/L)	(2.8 ug/L)	2.0	0.2	0.075
Trihalomethanes (total)[k]	0.1						
Vinyl chloride			0 (2.0 ug/L)	(2.0 ug/L)			
Xylenes					12	1.2	0.62
Zinc			5 mg/L (organoleptic)	5 mg/L (organoleptic)			

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[a] These adjusted criteria, for drinking water ingestion only, were derived from published EPA Water Quality Criteria (45 FR 79318-79379, November 28, 1980) for combined fish and drinking water ingestion and for fish ingestion alone. These adjusted values are not official EPA Water Quality Criteria, but may be appropriate for Superfund sites with contaminated ground water. In the derivation of these values, intake was assumed to be 2 liters/day for drinking water and 6.5 grams/day for fish; human body weight was assumed to be 70 kilograms.

[b] Criteria designated as organoleptic are based on taste and odor effects, not human health effects. Health-based Water Quality Criteria are not available for these chemicals.

[c] The criterion for all carcinogens is zero; the concentration given in parentheses corresponds to a carcinogenic risk of 10^{-6}. Water Quality Criteria documents present concentrations resulting in risks from 10^{-5} to 10^{-7}. To obtain concentrations corresponding to risks of 10^{-4} and 10^{-5}, the 10^{-6} concentrations should be multiplied by 100 and 10, respectively. To obtain concentrations corresponding to risk of 10^{-7}, 10^{-6} concentrations should be divided by 10.

(continued)

APPENDIX C. (Concluded)

[d] Annual maximum concentration not to be exceeded more than once per year.

[e] Chloroform is one of four trihalomethanes whose sum concentration must be less than 0.1 mg/L.

[f] As a guide in devising implementation plans for achieving oxidant standards.

[g] Seven-day health advisory for benzene and benzo(a)pyrene in kerosene, respectively.

[h] Annual arithmetic mean concentration.

[i] Annual geometric mean concentration.

[j] Activity corresponding to total body or any internal organ dose of 4 mrem/year.

[k] Total trihalomethanes refers to the sum concentration of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

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APPENDIX D

TYPICAL CONFINED DISPOSAL FACILITY

APPENDIX D: DESIGN AND CONSTRUCTION OF A TYPICAL CONFINED DISPOSAL FACILITY

This appendix presents guidelines for designing an upland confined disposal facility for suspended solids retention. The focus in this section is on fine-grained dredged material. Guidelines presented here will provide the necessary guidance for designing a containment area for adequate area and volume for (a) retaining the solids within the containment area through settling and (b) providing storage capacity of dredged solids for a particular continuous dredged material disposal activity. The major objective is to provide solids removal by the process of gravity settling to a level that permits discharge of the transporting water from the area. Although ponding is not feasible over the entire surface area of many sites, an adequate ponding depth must be maintained over the design surface area as determined by these design procedures to ensure adequate retention of solids. Guidance is also presented in this appendix for design of weirs for release of ponded water. The laboratory tests referred to in this appendix were presented in Appendix A.

The generalized flowchart shown in Fig. D.1 illustrates the design procedures presented in the following paragraphs. The design procedures were adapted from procedures used in water and wastewater treatment and are based on field and laboratory investigations on sediments and dredged material at several active dredged material containment areas.

The design procedures presented here are for gravity settling of dredged solids. However, the process of gravity sedimentation will not completely remove the suspended solids from the containment area effluent since wind and other factors can resuspend solids and increase effluent solids concentration. The settling process, with proper design and operation, will normally provide removal of fine-grained freshwater dredged material down to a level of 1 to 2 g/ℓ or lower in the effluent. The settling process will usually provide removal of fine-grained saltwater dredged material down to a level of several hundred mg/ℓ or lower. If the required effluent standard is not met by gravity settling, the designer must provide for additional treatment of the effluent, e.g., flocculation or filtration.

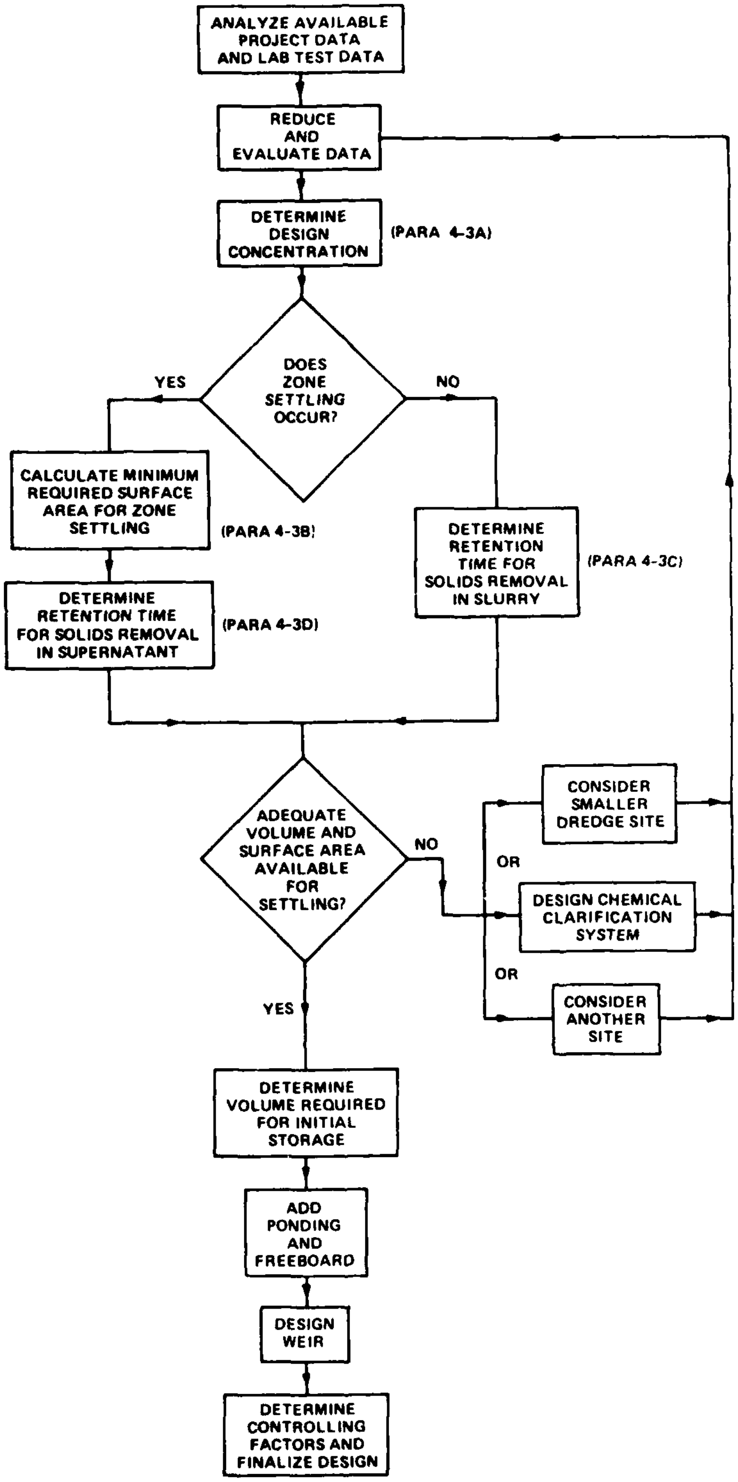


Figure D.1. Flowchart of design procedure for settling and initial storage

Disposal Facility Design for Suspended Solids Retention

Data Requirements

The data required to use the design guidelines are obtained from field investigations, laboratory testing, project-specific operational constraints, and past experience in dredging and disposal activities. The types of data required are described in the following paragraphs.

In situ sediment volume

The initial step in any dredging activity is to estimate the in situ volume of sediment to be dredged. Sediment quantities are usually determined from channel surveys on a routine basis by Corps district personnel.

Physical characteristics of sediment

Field sampling and sediment characterization should be accomplished according to the laboratory tests. Adequate sample coverage is required to provide representative samples of the sediment. Also required is the in situ water content of the fine-grained maintenance dredged sediment. Care must be taken in sampling to ensure that the water contents are representative of the in situ conditions. Water contents of representative samples, w, are used to determine the in situ void ratios e_i as follows:

$$e_i = \frac{wG_s}{S_D} \tag{D-1}$$

where

e_i = in situ void ratio of sediment
w = water content of the sample, percent
G_s = specific gravity of sediment solids
S_D = degree of saturation, percent (equal to 100 percent for sediment)

A representative value from in situ void ratios is used later to estimate volume for the containment area. Grain-size analyses are used to estimate the quantities of coarse- and fine-grained material in the sediment to be dredged.

Proposed dredging and disposal data

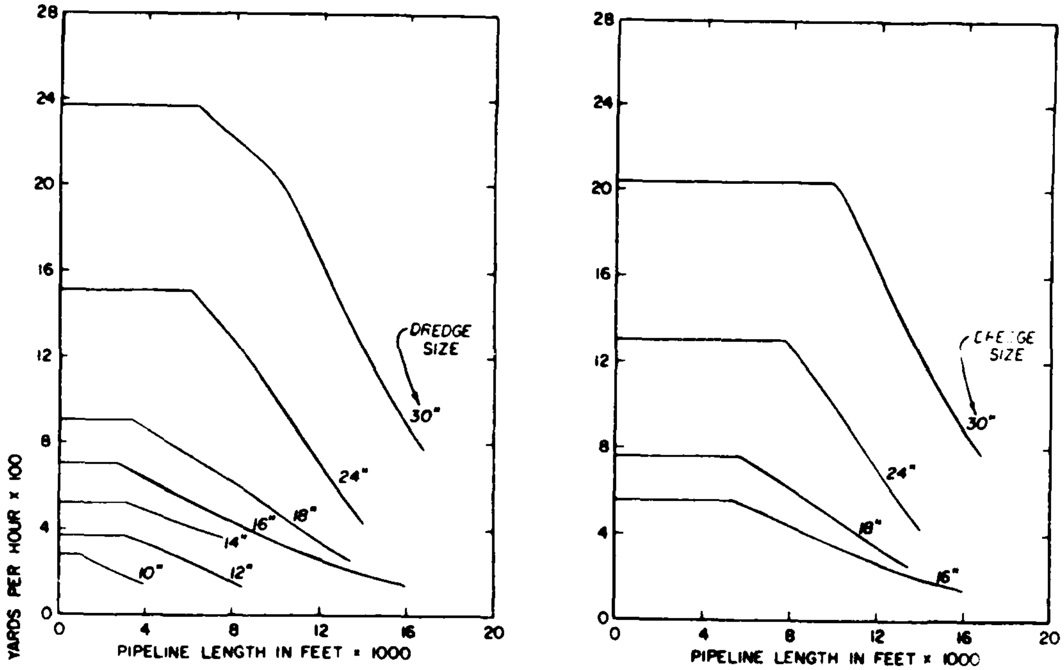
The designer must obtain and analyze data concerning the dredged material disposal rate. For hydraulic pipeline dredges, the type and size of dredge(s) to be used, average distance to containment area from dredging activity, depth of dredging, and average solids concentration of dredged material when discharged into the containment area must be considered. If the size of the dredge to be used is not known, the largest dredge size that might be expected to perform the dredging should be assumed. The time required for the dredging can be estimated based on past experience. If no data on past experience are available, Fig. D.2, which shows the relationship among solids output, dredge size, and pipeline length for various dredging depths, should be used. It was developed from data provided for Ellicott dredges (Turner 1977). For hopper dredges, an equivalent disposal rate must be estimated based on hopper or barge pump-out rate and travel time involved. Based on these data, the designer must estimate or determine containment area influent rate, influent suspended solids concentration, effluent rate (for weir sizing), effluent concentration allowed, and time required to complete the disposal activity. For hydraulic pipeline dredges, if no other data are available, an influent suspended solids concentration of 150 g/ℓ (14 percent by weight) should be used for design purposes. This value is based on a number of field investigations performed during the DMRP (Montgomery 1978).

Laboratory settling test data

Depending on the results of the sedimentation tests, the dredged material will either settle by zone processes (common for saltwater sediment) or flocculent processes (common for freshwater sediment). Regardless of the salinity, flocculent processes govern the concentration of solids in the effluent.

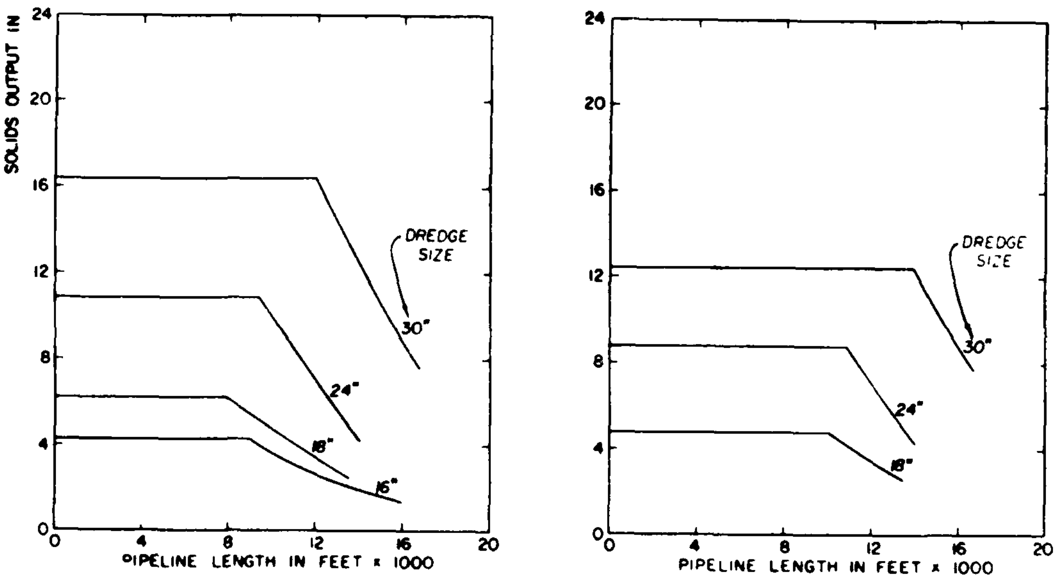
Selection of Ponding Depth

Before a disposal site can be designed for effective settling or before the required disposal area geometry can be finalized, a ponding depth H_{pd} during disposal must be assumed. The design procedures in the following paragraphs call for a ponding depth in estimating detention time, necessary for effective settling. A minimum ponding depth of 2 ft should be used in the



a. DREDGING DEPTH OF 20 FT

b. DREDGING DEPTH OF 30 FT



c. DREDGING DEPTH OF 40 FT

d. DREDGING DEPTH OF 50 FT

Figure D.2. Relationships among solids output, dredge size, and pipeline length for various dredging depths (developed from data provided by Turner, 1977).

estimates. If conditions will allow for greater ponding depths throughout the operation, the greater value can be used. For most cases, the ponding depth can be maintained at a constant depth by raising the pond as settled material accumulates in the site. In some cases it may be desirable to begin operations with the maximum ponding possible. The disposal site should be designed in this case such that the ponding depth in the last stages of the disposal operation (as the site is filled) is adequate to maintain effective settling.

Calculation of Volume for Initial Storage

Containment areas must be designed to meet volume requirements for a particular disposal activity. The total volume required of a containment area includes volume for storage of dredged material, volume for sedimentation (ponding depths), and freeboard volume (volume above water surface). Volume required for storage of the coarse-grained (>No. 40 sieve) material must be determined separately as this material behaves independently of the fine-grained (<No. 40 sieve) material.

Calculation of design concentration

The design concentration C_d is defined as the average concentration of the dredged material in the containment area at the end of the disposal activity and is estimated from the compression (15-day) settling tests. This design parameter is required both for estimating initial storage requirements and in determining minimum required surface areas for effective zone settling. The following steps can be used to estimate average containment area concentrations from the compression settling test.

(a) Compute concentration versus time for the compression settling test. Assume zero solids in the water above the solids interface to simplify calculations. The following equation can be used to calculate concentrations for various interface heights:

$$C = \frac{C_i H_i}{H} \tag{D-1}$$

where

C = slurry concentration at time t, g/ℓ

C_i = initial slurry concentration, g/ℓ

H_i = initial slurry height, ft

H = height of interface at time t.

(b) Plot concentration versus time on log-log paper as shown in Fig. D.3.

(c) Draw a straight line through the data points. This line should be drawn through the points representing the compression settling or consolidation zone.

(d) Estimate the time of dredging by dividing the dredge production rate into the volume of sediment to be dredged. Use Fig. D.2 for estimating the dredge production rate if no specific data are available from past dredging activities. (Note that curves in Fig. D.2 were developed for sand.) Total time required for dredging should consider anticipated down time.

(e) Enter the concentration versus time plot as shown in Fig. D.3 and determine the concentration at a time t equal to one half the time required for the disposal activity determined in step (d).

(f) The value computed in step (e) is the design solids concentration C_d.

Volume Estimation

The volume computed in the following steps is the volume occupied by dredged material in the containment area after the completion of a particular disposal activity. The volume is not an estimate of the long-term needs for multiple-disposal activities. The procedures given below can be used to design for the initial volume required for one disposal activity. The design for initial storage may be a controlling factor regardless of the settling behavior exhibited by the material. If the material initially exhibits compression settling at the expected inflow concentration, the design for

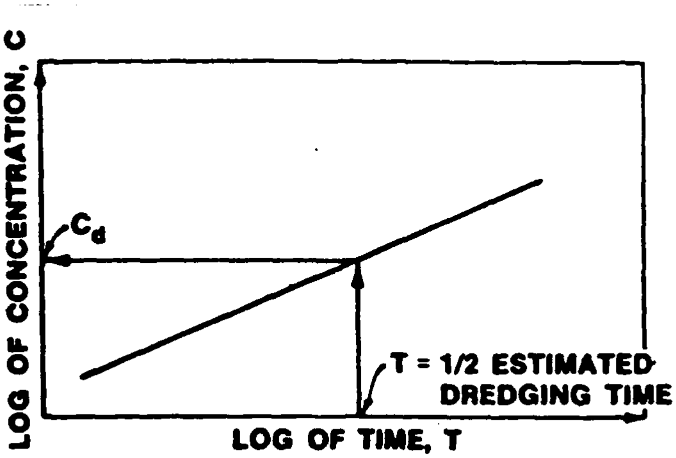


Figure D.3. Conceptual time versus concentration plot

initial storage is the only consideration (this is expected to be an exceptional case).

Compute the average void ratio of the fine-grained dredged material in the containment area at the completion of the dredging operation using the design concentration Cd determined earlier as the dry density of solids. Use the following equation to determine the void ratio:

$$e_o = \frac{G_s \gamma_w}{\gamma_d} - 1 \tag{D-2}$$

where

e_o = average void ratio of the dredged material in the containment area at the completion of the dredging operation

γ_w = density of water, g/ℓ (normally 1000 g/ℓ).

γ_d = dry density of solids, g/ℓ ($\gamma_d = C_d$ as determined)

Compute the volume of the fine-grained channel sediments after disposal in the containment area:

$$V_f = V_i \frac{e_o - e_i}{1 + e_i} + 1 \tag{D-3}$$

where

V_f = volume of the fine-grained channel sediment after disposal in the containment area, ft^3

e_i = average void ratio of the in situ channel sediment

V_i = volume of the fine-grained channel sediment, ft^3

Compute the volume required to store the dredged material in the containment area

$$V = V_f + V_{sd} \tag{D-4}$$

where

V = volume of the dredged material in the containment area at the end of the dredging operation, ft^3

V_{sd} = volume of sand (compute using 1:1 ratio), ft^3

If these limitations on the surface area available for disposal or an existing disposal site is being evaluated, check to determine if the site conditions will allow for initial storage of the volume to be dredged. First determine the maximum height at which the material can be placed using the following equation:

$$H_{dm(max)} = D - H_{pd} - H_{fb} \tag{D-4b}$$

where

D = maximum allowable dike height due to foundation conditions, ft

H_{pd} = ponding depth, ft

H_{fb} = freeboard (minimum of 2 ft can be assumed)

Compute the minimum surface area that could be used to store the material:

$$Ad_{(min)} = \frac{V}{Hd_{m\ (max)}} \tag{D-4c}$$

If $Ad_{(min)}$ is less than the available surface area, then adequate volumetric storage is available at the site.

Calculation of Minimum Surface Area for Effective Zone Settling

If the sediment slurry exhibited zone settling behavior at the expected inflow concentration, the zone settling test results are used to calculate a minimum required ponded surface area in the containment for effective zone settling to occur. The method is generally applicable to dredged material from a saltwater environment, but the method can also be used for freshwater dredged material if the laboratory settling tests indicate that zone settling properties govern in the initial settling process. Additional calculations using flocculent settling data for the solids remaining in the ponded supernatant water are required for designing the containment area to meet a specific effluent quality standard for suspended solids.

Analyze laboratory data

A series of zone settling tests must be conducted. The results of the settling tests are correlated to determine zone settling velocities at the various suspended solids concentrations. The procedure is as follows:

(a) Develop a settling curve for each test.

(b) Calculate the zone settling velocity v_s as the slope of the constant settling zone (straight-line portion of curve). The velocity should be expressed in feet per hour.

(c) Plot the v_s versus suspended solids concentration on a semilog plot. These points should form a straight line. Outliers of higher concentrations are indications of compression settling behavior and should not be included in developing the plot.

(d) Use the plot developed in (c) to develop a solids loading versus solids concentration curve as shown in Fig. D.4. The solids loading curve should be constructed to a concentration value along the abcissa equal to C_d.

Compute area required for zone settling

The minimum surface area determined according to the following steps should provide removal of fine-grained sediment such that suspended solids levels in the effluent do not exceed several hundred milligrams per liter. The area is required for the zone settling process to concentrate the dredged material to the design concentration. The area is computed as follows:

(a) Compute $S_{d(max)} = C_i V_s$ where V_s is taken as the zone settling velocity at C_i from the settling velocity versus concentration curve.

(b) Use the design concentration and construct an operating line from the design solids concentration tangent to the loading curve as shown in

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FOR CONTAMINATED DREDGED MATERIAL(U) ARMY ENGINEER
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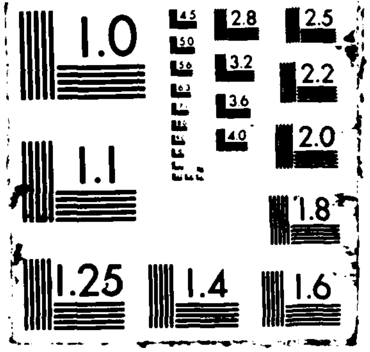
1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

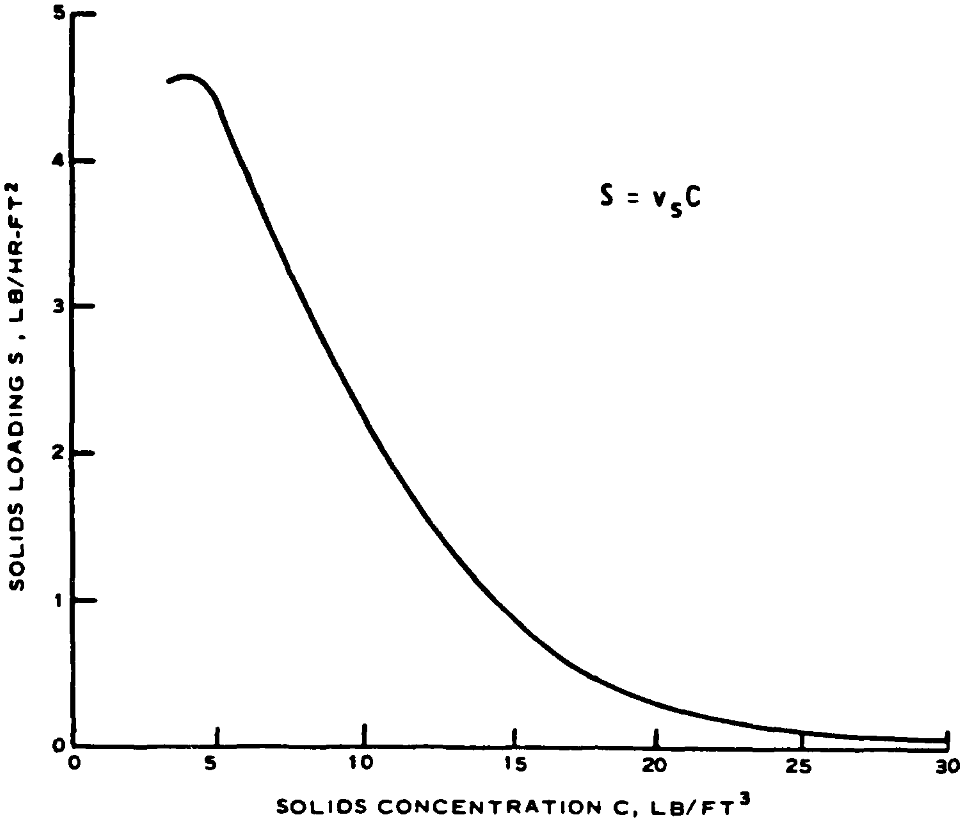

Figure D.4. Conceptual solids loading curve for dredged material

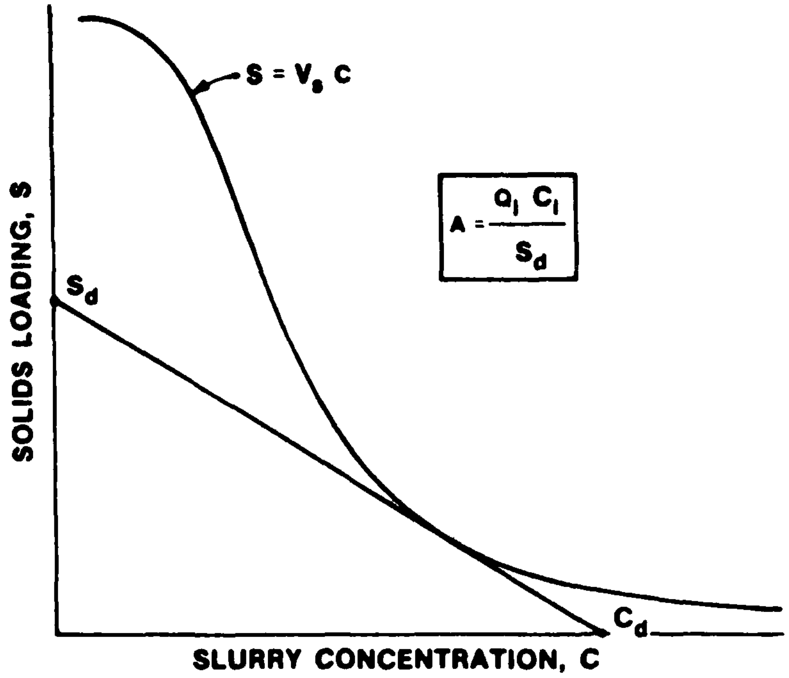

Figure D.5. Solids loading curve showing design line

Fig. D.5. The design loading is obtained on the y-axis as S_d. If no tangent can be graphically constructed due to the value of C_d and the shape of the solids loading curve, zone settling will not be a controlling factor and S_d = $S_{d(max)}$.

(c) Compute area requirements as

$$A = \frac{Q_i C_i}{S_d} \tag{D-5}$$

where

A = containment surface area requirement, ft^2

Q_i = influent rate, ft^3/hr ($Q_i = A_p V_d$; assume V_d = 15 fps in absence of data and convert Q_i calculated in cfs to ft^3/hr)

A_p = cross-sectional area of dredge pipeline, ft^2

V_d = velocity of discharge from dredge pipe, ft/sec

C_i = influent solids concentration, lb/ft^3 (assume 150 g/ℓ or 94 lb/ft^3 if no data are available)

S_d = design solids loading, lb/hr-ft^2

(d) Multiply the area by a hydraulic efficiency factor HEF to compensate for containment area inefficiencies

$$A_d = (HEF)\ A \tag{D-6}$$

where

A_d = design basin surface area, ft^2

A = area determined from Equation D-5, ft^2

HEF = hydraulic efficiency factor (determined as described later in this appendix)

Calculation of Required Retention for Flocculent Settling

Sediments dredged from a freshwater environment normally exhibit flocculent settling properties. However, in some cases, the concentration of dredged material slurry is sufficiently high that zone settling will occur. The method of settling can be determined from the laboratory tests.

Sediments in a dredged material containment area are comprised of a broad range of particle floc sizes and surface characteristics. In the containment area, larger particle flocs settle at faster rates, thus overtaking finer flocs in their descent. This contact increases the floc sizes and enhances settling rates. The greater the ponding depth in the containment area, the greater is the opportunity for contact among sediment and flocs. Therefore, sedimentation of freshwater dredged sediment is dependent on the ponding depth as well as the properties of the particles.

The design steps to determine the required retention time for a desired effluent quality are as follows:

(a) Calculate the removal percentage at various depths for various times using the concentration profile plot. As an example, the removal percentage for depth d_2 and time t_2 is computed as follows:

$$R = \frac{\text{Area right of profile}}{\text{Area total}} (100) = \frac{\text{Area 0, 1, 2, 3, 0*}}{\text{Area 0, 1, 2, 4, 0}} (100) \qquad \text{(D-7)}$$

where R is the removal percentage. Determine these areas by either planimetering the plot or by direct graphical measurements and calculations. This approach is used to calculate removal percentages for each depth as a function of time. The depths used should cover the range of ponding depths expected in the containment area. This report recommends a minimum of 2 ft of ponding depth.

(b) Plot the solids removal percentages versus time for various ponding depths (withdrawal depths) as shown in Fig. D.6.

(c) Mean detention times can be selected from Fig. D.6 for various solids removal percentages. Select the detention time T_d that gives the desired removal percentage for the design ponding depth.

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* These numbers indicate the area boundaries for the total area down to depth d_z and the area to the right of the line for t_2.

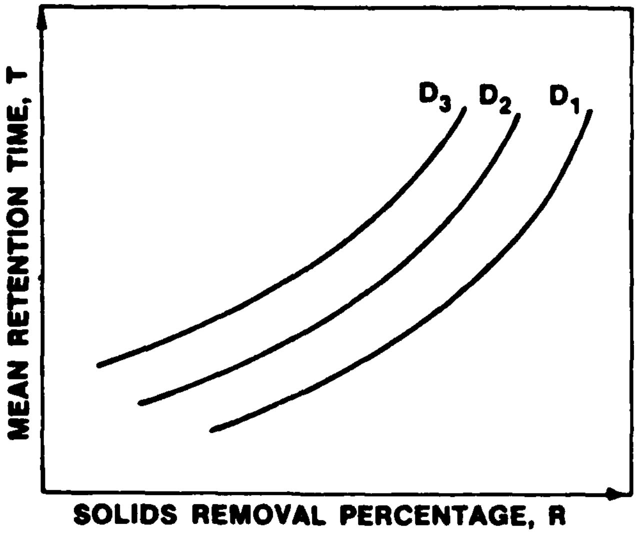

Figure D.6. Conceptual plot of solids removal versus time for slurries exhibiting flocculent settling

(d) The mean detention time T_d should be increased by an appropriate hydraulic efficiency factor HEF to compensate for the fact that containment areas, because of inefficiencies, have field mean detention times less than theoretical (volumetric) detention times. The volumetric or theoretical detention time is estimated as follows:

$$T = \text{HEF}\ T_d \qquad \text{(D-8)}$$

where T is the volumetric or theoretical detention time.

(e) Note that for the case of flocculent settling of the entire slurry mass, the solids will be removed by gravity sedimentation to a level of 1 to 2 g/ℓ. For this case, the selection of a required retention time for a percentage removal is more convenient. For the case of flocculent settling in the supernatant water where the slurry mass is undergoing zone settling, selection of a required retention time for an effluent suspended solids standard is more appropriate.

Calculation of Required Retention Time for Flocculent Settling in Supernatant Water.

For slurries exhibiting zone settling, flocculent settling behavior governs in the supernatant water above the interface. Therefore, a flocculent data analyses procedure as outlined in the following paragraphs is required. The steps in the data analyses are as follows:

(a) Use the concentration profile diagram to graphically determine percentages removed R for the various time intervals for various ponding depths. This is done by graphically determining the areas to the right of each concentration profile and its ratio to the total area above the depth as described for the case of flocculent settling above.

$$R = \frac{\text{Area right of profile}}{\text{Area total}} (100) \qquad \text{(D-9)}$$

(b) Compute the percentage remaining P as follows:

$$P = 100 - R \qquad \text{(D-10)}$$

(c) Compute values for the average suspended solids concentration in the supernatant at each time of extraction SS_t as follows:

$$SS_t = P_t \, SS_o \qquad \text{(D-11)}$$

where SS_o is the initial suspended solids concentration.

(d) Tabulate the data and plot a relationship for suspended solids concentration versus time using the value for each time of extraction as shown in Fig. D.7. An exponential curve fitted through the data points is recommended.

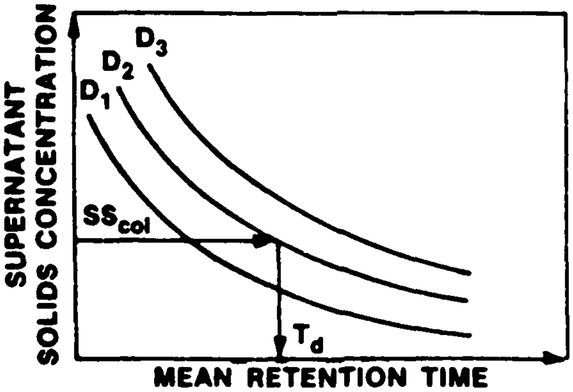

Figure D.7. Conceptual plot of supernatant suspended solids concentration versus time from column settling test

(e) By repeating steps (3) through (5), a family of curves showing suspended solids versus retention time for each of several ponding depths may be developed. These curves may be used to determine the required detention time to meet a standard for effluent suspended solids concentrations under good set conditions for a given estimated ponding depth. Simply use the curve the estimated field mean retention time T_d and select the value of suspended solids as predicted by the column test SS_{col} for the desired ponding depth. Guidance for adjusting the value derived from the column test for anticipated resuspension and for estimated field mean retention time is given in the following paragraphs.

Determination of Retention Time to Meet an Effluent Suspended Solids Concentration

The relationship of supernatant suspended solids versus time developed from the column settling test is based on quiescent settling conditions found in the laboratory. The anticipated retention time in an existing disposal area under consideration can be used to determine a predicted suspended solids concentration from the relationship. This predicted value can be considered a minimum value that could be achieved in the field assuming little or no resuspension of settled material. The relationship in Fig. D.6 can also be used to determine the required retention time to meet a standard for effluent suspended solids. However, an adjustment for anticipated resuspension is appropriate for dredged material exhibiting zone settling. The minimum expected value and the value adjusted for resuspension would provide a range of anticipated suspended solids concentrations in the effluent. The following procedure should be used:

(a) The standard for effluent suspended solids SS_{eff} considers anticipated resuspension under field conditions. A corresponding concentration under quiescent laboratory conditions is calculated as:

$$SS_{col} = \frac{SS_{eff}}{RF} \qquad \text{(D-12)}$$

where SS_{eff} = suspended solids concentration of effluent considering anticipated resuspension, mg suspended solids/ℓ of water

SS_{col} = suspended solids concentration of effluent as estimated from column settling tests, mg suspended solids/ℓ of water

RF = resuspension factor selected from Table D.1

Table D.1

Recommended Resuspension Factors for the Zone Settling Case for Various Ponded Areas and Depths (After Palermo 1985)

Anticipated Ponded Area	Anticipated Average Ponded Depth less than 2 feet	 2 feet or greater
less than 100 acres	2.0	1.5
greater than 100 acres	2.5	2.0

For dredged material slurries exhibiting flocculent settling behavior, the concentration of particles in the ponded water is 1 g/ℓ or higher. The resuspension resulting from normal wind conditions will not significantly increase this concentration, therefore an adjustment for resuspension is not required for the flocculent settling case.

(b) Using Fig. D.7 and the anticipated ponding depth, determine the required mean detention time corresponding to SS_{col}.

(c) As in the case for flocculent settling of the entire slurry mass, the mean detention time should be increased by an appropriate hydraulic efficiency factor HEF, using Equation D-8. The resulting volumetric or theoretical detention time T can be used to determine the required disposal area geometry.

Estimation of Field Mean and Volumetric or Theoretical Retention Times

Estimates of the field mean retention time for expected operational conditions are required for prediction of suspended solids concentrations in the effluent. Estimates of the retention time must consider the hydraulic efficiency of the disposal area, defined as the ratio of mean retention time to theoretical retention time. Field mean retention time T_d can be estimated for given flow rate and ponding conditions by applying a hydraulic efficiency factor to the theoretical detention time T as follows:

$$T_d = \frac{T}{(HEF)} \qquad \text{(D-13)}$$

where T_d = mean detention time, hr

HEF = hydraulic efficiency factor (HEF >1.0) defined as the inverse of the hydraulic efficiency

and T = theoretical detention time, hr

The theoretical detention time is calculated as follows:

$$T = \frac{V_P}{Q_i}(12.1) = \frac{A_P D_P}{Q_i}(12.1) \qquad \text{(D-14)}$$

where T = theoretical detention time, hr
V_P = volume ponded, acre-ft
A_P = area ponded, acres
D_P = average depth of ponding, ft
Q_i = average inflow rate, cfs
12.1 = conversion factor acre-ft/cfs to hr

Estimation of Hydraulic Efficiency Factor

The hydraulic efficiency factor, HEF, can be estimated by several methods. The most accurate estimate is made possible from dye-tracer data previously obtained at the site under operational conditions similar to those for the operation under consideration. In absence of dye-tracer data or values obtained from other theoretical approaches, the HEF can be assumed based on values obtained by dye-tracer studies at similar sites and under similar conditions. Montgomery (1978) recommended a value for HEF of 2.25 based on field studies conducted at several sites. This value should be used for the HEF in absence of additional data.

Determination of Controlling Factors for Disposal Area Geometry

Previous calculations have provided a design surface area A_d and/or a volumetric detention time T required for fine-grained dredged material sedimentation and the initial volume required for initial storage V. A ponding depth H_{pd} was also assumed. These values are then used, as described in the following paragraphs, to determine the required disposal area geometry. Throughout the design process, the existing topography of the containment area site must be considered since it can have a significant effect on the resulting geometry of the containment area. Any limitations on dike height should also be determined based on an appropriate geotechnical evaluation.

Surface area requirement for zone settling

The following procedure should be used:

(a) Estimate the thickness of the dredged material at the end of the disposal operation:

$$H_{dm_d} = \frac{V}{A_d} \qquad \text{(D-15)}$$

where

H_{dm_d} = thickness of the dredged material layer at the end of the dredging operation, ft

V = volume of dredged material in the basin, ft^3 (from Equation D-4)

A_d = design surface area, ft^2 (as determined from Equation D-6 or use the known surface area for existing sites)

(b) Determine the maximum height allowed for confining dikes. This height should be based on appropriate geotechnical design of the dikes.

(c) Add the ponding depth and freeboard depth to H_{dm} to determine the required containment area depth (dike height):

$$D = H_{dm} + H_{pd} + H_{fb} \qquad \text{(D-16)}$$

where

D = dike height, ft

H_{pd} = average ponding depth, ft (a minimum of 2 ft is recommended)

H_{fb} = freeboard above the basin water surface to prevent wave overtopping and subsequent damage to confining earth dikes, ft (a minimum of 2 ft is recommended)

(d) Compare this value with the allowable dike height

Containment area ponded volume requirement for flocculent settling

The following procedure should be used:

(a) Compute the volume required for sedimentation:

$$V_B = Q_i T_d \tag{D-17}$$

where V_B is the containment area ponded water volume in cubic feet required for meeting suspended solids effluent requirements.

(b) Determine the maximum height D allowed for confining dikes. (See previous paragraphs.) In some cases, it might be desirable to use less than the maximum allowed dike height.

(c) Compute a minimum for the design area required for storage:

$$A_d = \frac{V}{H_{dm(max)}} \tag{D-18}$$

where

$$H_{dm(max)} = D - H_{pd} - H_{fb} \tag{D-19}$$

or set the design area A_d equal to the known surface area for existing sites.

(d) Evaluate the volume available for sedimentation near the end of the disposal operation:

$$V^* = H_{pd} A_d \tag{D-20}$$

where V^* is the volume in cubic feet available for sedimentation near the end of the disposal operation.

(e) Compare V* and V_B. If the volume required for sedimentation is larger than V*, the containment area will not meet the suspended solids effluent requirements for the entire disposal operation. The following three measures can be considered to ensure that effluent requirements are met: (1) increase the design area A_d; (2) operate the dredge on an intermittent basis when V* becomes less than V_B or use a smaller size dredge; and (3) provide for posttreatment of the effluent to remove solids.

(f) Estimate the thickness of dredged material at the end of the disposal operation using Equation D-15 with A_d as determined using step c.

(g) Determine the required containment area depth using Equation D-16 and the results from step f.

(h) Compare this depth with the maximum allowable dike height.

(i) If the maximum dike height allowed by foundation conditions is less than the containment area depth requirement determined from Equation D-16, the design area A_d must be increased until the depth requirement can be accommodated by the allowable dike height; the thickness of the dredged material layer must also be decreased.

Weir Design and Operation

Weir Designs

Guidelines for weir design. The purpose of the weir structure is to regulate release of ponded water from the containment area. Proper weir design and operation can control resuspension and withdrawal of settled solids.

Weir design and containment sizing. Weir design is based on providing the capability for selective withdrawal of the clarified upper layer of ponded water. The weir design guidelines as developed in the following paragraphs are based on the assumption that the design of the containment area has provided sufficient area and volume for sedimentation and that short-circuiting is not excessive.

Effective weir length and ponding depth.

(a) Ponding depth and effective weir length are the two most important parameters in weir design. The weir design guidelines presented in this section allow evaluation of the trade-off involved between these parameters.

(b) In order to maintain acceptable effluent quality, the upper layers containing low levels of suspended solids should be ponded at depths greater than or equal to the depth of the withdrawal zone, the area through which fluid is removed for discharge over the weir as shown in Fig. D.8. The size of the withdrawal zone affects the approach velocity of flow toward the weir.

(c) The weir shape or configuration affects the dimensions of the withdrawal zone and consequently the approach velocity. Since weirs do not extend across an entire side of a containment area, flow concentrations of various degrees occur near the weir, resulting in possible resuspension of solids. Longer effective weir lengths result in less concentration of flow. The minimum width through which the flow must pass may be termed the effective weir length L_e.

(d) The relationship between effective weir length and ponding depth for various conditions of inflow and effluent suspended solids is illustrated by the nomographs for materials exhibiting flocculent and zone settling in Fig. D.9 and D.10, respectively. The nomographs were developed based on

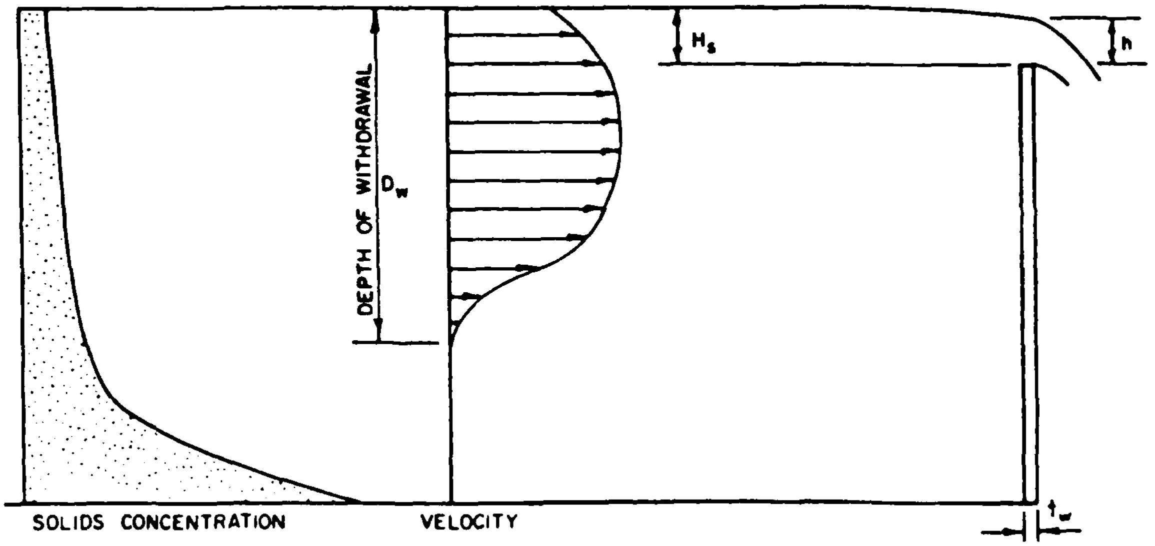

Figure D.8. Conceptual illustration of withdrawal depth and velocity profile where H_s is static head, h is flow depth over the weir, and t_w is weir thickness.

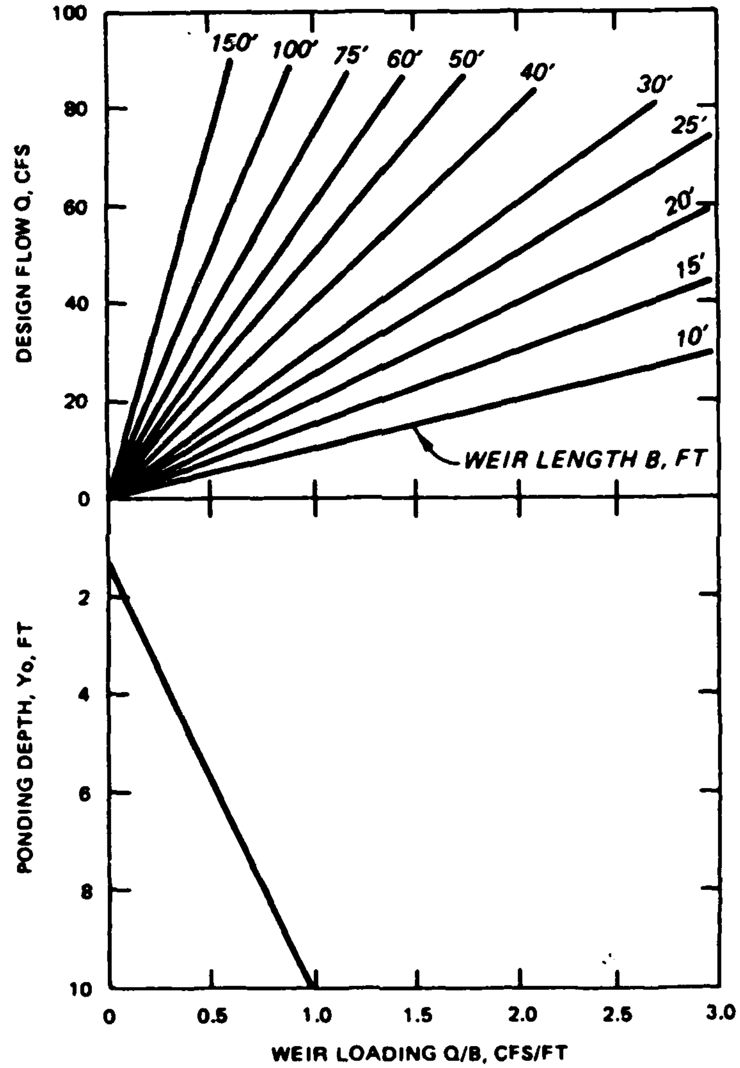

Figure D.9. Weir design nomograph for materials exhibiting flocculent settling (modified from Walski and Schroeder 1978)

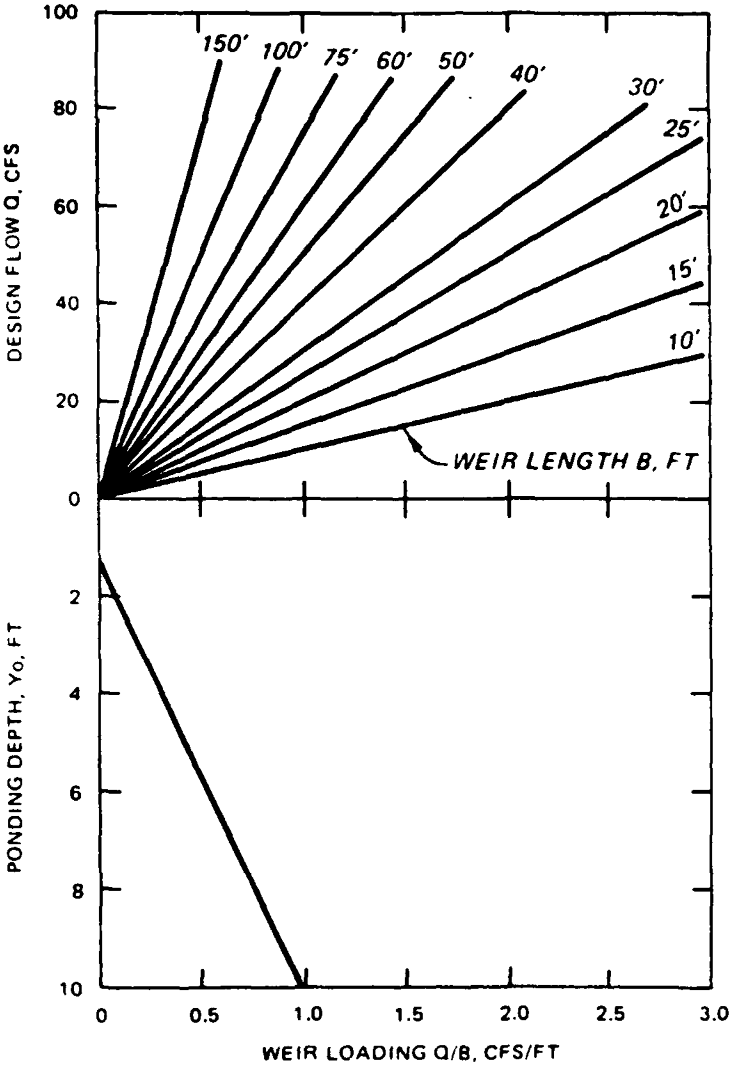

Figure D.10. Weir design nomograph for materials exhibiting zone or compression settling (from Walski and Schroeder, 1978) the principles of selective withdrawal assuming near-zero suspended solids at the surface and have been verified by limited field data.

Design procedure. To design a new weir to meet a given effluent suspended solids level, the following procedure should be used:

(a) Select the appropriate nomograph based on the governing settling behavior of the material (see Figs. D.9 or D.10) and the USCS classification of the fine-grained portion of the sediment.

(b) Determine the largest of the equivalent hydraulic pipeline dredge(s) expected to discharge into the area and then select the design inflow rate Q_i from the following tabulation or from other available data.

Discharge Pipeline Diameter, in.	Discharge Rate (for Flow Velocity of 15 ft/sec)* cfs	Discharge Rate (for Flow Velocity of 15 ft/sec)* gal/min
8	5.3	2,350
10	8.1	3,640
12	11.8	5,260
14	16.0	7,160
16	20.6	9,230
18	26.5	11,860
20	32.7	14,660
24	47.1	21,090
27	59.5	26,630
28	64.1	28,700
30	73.6	32,950
36	106.0	47,500

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* To obtain discharge rates for other velocities, multiply the discharge rate shown in this tabulation by the desired velocity and divided by 15.

(c) Using the selected nomograph, construct horizontal lines at the design inflow rate Q_i and the desired level of effluent suspended solids.

(d) Use vertical lines connecting the constructed horizontal lines to indicate various combinations of ponding depth and effective weir length required.

(e) Determine the number of weir structures, physical dimensions of each, and locations based on the weir type to be used and the configuration of the containment area.

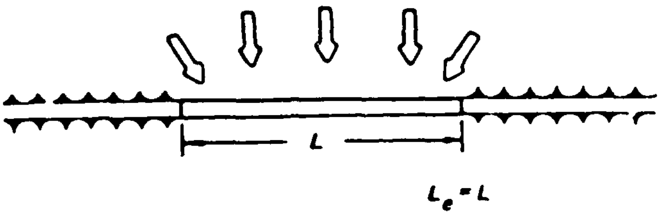
If a satisfactory balance between effective weir length and ponding depth cannot be achieved, intermittent operation or use of a smaller dredge will be required to meet the desired level of effluent suspended solids as the containment area is filled.

Effect of weir type

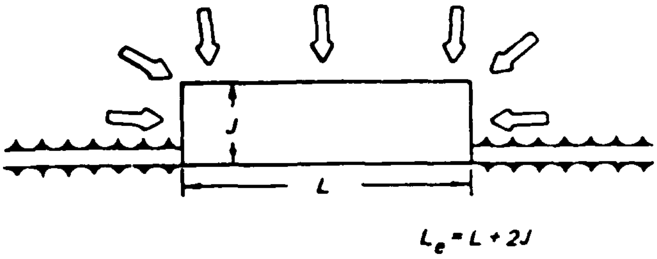
Rectangular weirs. Rectangular weirs are the commonly used weir type and may consist of a rectangular wood- or metal-framed inlet or half-cylindrical corrugated metal pipe riser(s). The effective weir length is equal to the actual weir crest length for rectangular weirs as illustrated in Fig. D.11a.

Jutting weirs. A modified form of the rectangular weir is the jutting weir (see Fig. D.11b). It is possible to achieve a greater effective weir length using a jutting weir since the effective length L_e equals L + 2J, as shown in Fig. D.11b.

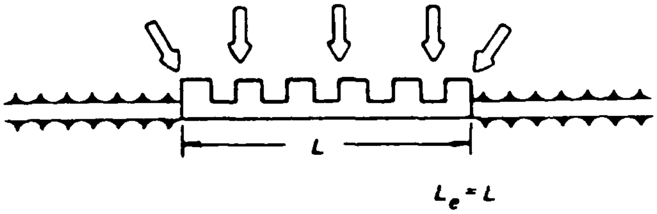
Polygonal (labyrinth) weirs. Polygonal (labyrinth) weirs have been used to reduce the depth of flow over the weir. However, use of such weirs has little impact on effluent suspended solids concentrations since the controlling factor for the depth of withdrawal is usually not the flow over the weir but the approach velocity. Therefore, the approach velocity and the



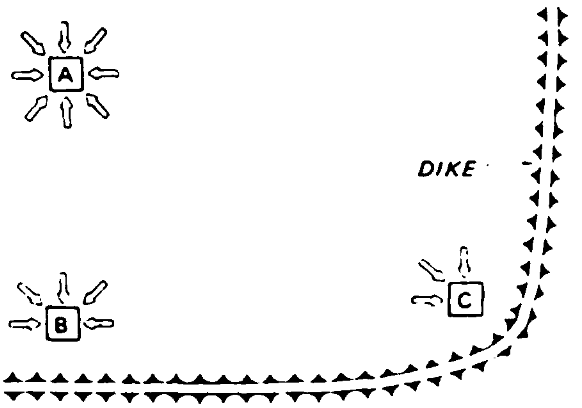
a. RECTANGULAR WEIR



b. JUTTING RECTANGULAR WEIR



c. POLYGONAL WEIR



d. SHAFT WEIRS

Figure D.11. Effective lengths of various weir types (from Walski and Schroeder 1978) withdrawal depth for the rectangular weir in Fig. D.11a would be the same as that for the polygonal weir in Fig. D.11c since both weirs have the same effective length L_e even though the total weir crest length for the polygonal weir is considerably greater. Use of polygonal weirs is not recommended because of the greater cost and the marginal improvement of effluent quality realized when using such a weir.

Shaft-type weirs. In some cases the outflow structure is a four-sided drop inlet or shaft located within the containment area as shown in Fig. D.11d. In evaluating the effective weir length for shaft-type weirs, the approach velocity is a key consideration. To minimize the approach velocity and hence the withdrawal depth, the shaft weir should not be placed too near the dike. In Fig. D.11, location A is the most desirable since flow can approach from all sides (four effective sides). Location B is less desirable since flow can approach from only three directions (three effective sides). Location C is the least desirable since it has only two effective sides. Since effluent pipes must run from the shaft weir under the dike to the receiving stream, a location such as A in Fig. D.11 may not be optimal since it is far from the dike and will require a longer pipe than Location B.

To convert the weir length determined from the design nomographs to length L_s of a side of the square shaft weir, use the following formula:

$$L_s = \frac{L_e}{n} \tag{D-21}$$

where n is the number of effective sides of a shaft type weir. A side is considered an effective side if it is at least $1.5L_s$ ft away from the nearest dike, mounded area, or other dead zone. This distance is generally accepted as being sufficient to prevent the flow restriction caused by the flow contraction and bending due to the walls.

Structural design. Weirs should be structurally designed to withstand anticipated loadings at maximum ponding elevations. Considerations should be given to uplift forces and potential piping beneath or around the weir.

Additional information regarding structural design of weirs is found in Hammer and Blackburn (1977). Outlet pipes for the weir structure must be designed to carry flows in excess of the flow rate for the largest dredge size expected. The larger flow capacity of the outlet pipes may be needed if emergency release of ponded water is required.

Weir operation

Weir boarding. Adequate ponding depth during the dredging operation is maintained by controlling the weir crest elevation. Weir crest elevations are usually controlled by placing boards within the weir structure. The boards should range in size from 2 by 4 in. to 2 by 10 in. (nominal dimensions).

Weir boarding should be determined based on the maximum ponding elevation expected during the dredging operation. Before dredging commences, the weir should be boarded to the highest possible elevation that dike stability and erosion considerations will allow. This practice will ensure maximum possible efficiency of the containment area. The maximum elevation must allow for adequate ponding depth above the highest expected level of accumulated settled solids and yet remain below the required freeboard. Small boards (e.g., 2 by 4 in.) should be placed at the top of the weir for a distance equal to the expected ponding depth at the end of the dredging operation in order to provide more flexibility in controlling ponding depth. Use of larger boards in this most critical area may result in increased effluent suspended solids concentrations as weir boards are manipulated during the operation. Figure D.12 shows the recommended weir boarding used for a minimum ponding depth of 2 ft.

Operational guidelines for weirs. Some basic guidelines for weir operation are given below:

(a) If the weir is properly designed, intermittent operation should not become necessary until the required ponding depth cannot be maintained.

(b) The weir crest should be maintained at the highest feasible elevation to ensure maximum effluent quality.

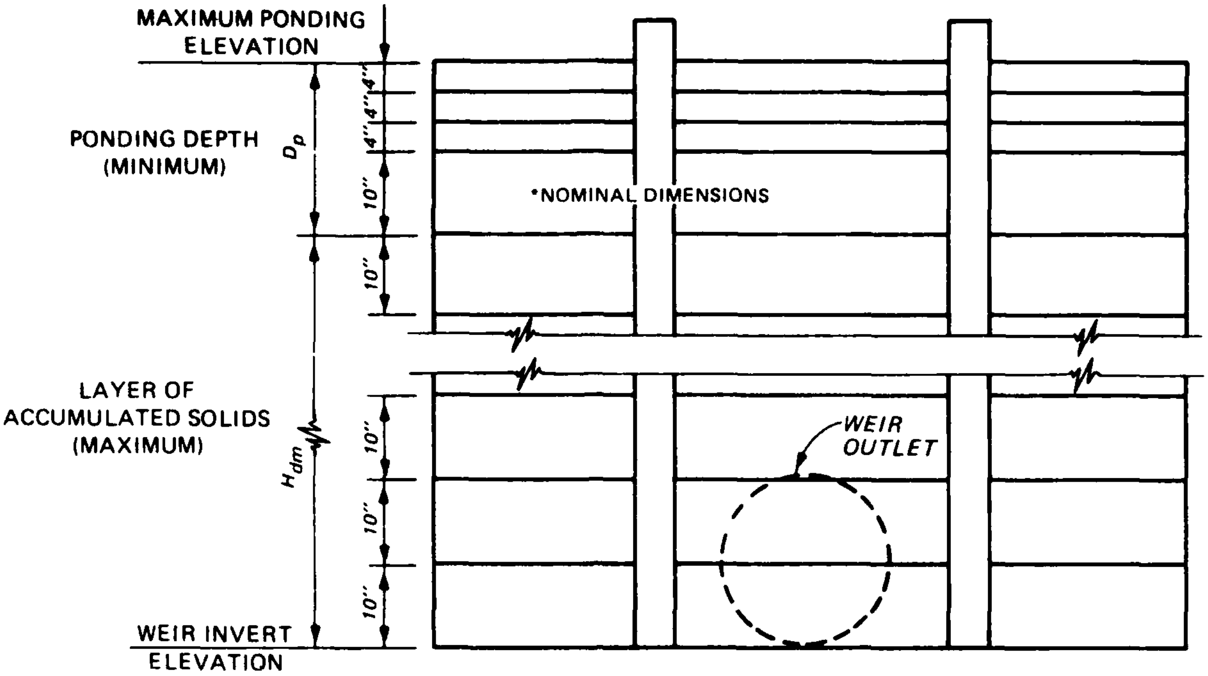


Figure D.12. Recommended boarding configuration (modified from Walski and Schroeder 1978)

(c) While operating the weir, floating debris should be periodically removed from the front of the weir to prevent larger withdrawal flows at greater depths.

(d) If multiple weirs or a weir with several sections are used in a basin, the crests of all weirs or weir sections should be maintained at the same elevation.

(e) If the effluent suspended solids concentration increases above acceptable limits, the ponding depth should be increased by raising the elevation of the weir crest.

However, if the weir crest is at the maximum ponding elevation and the effluent quality is still unacceptable, the flow into the basin should be decreased by operating intermittently.

(f) The weir may be controlled in the field by using the head over the weir as an operational parameter since the actual flow over the weir cannot easily be measured.

Operating head. The static head with the related depth of flow over the weir is the best criterion now available for controlling weir operation in the field. Weirs utilized in containment areas can usually be considered sharp crested where the weir thickness t_w is less than two-thirds the depth of flow over the weir h as seen in Fig. D.10. The ratio of depth of flow over the weir to the static head h/H_s equals 0.85 for rectangular sharp-crested weirs. The weir crest length L, static head H_s, and depth of flow over the weir h are related by the following equations for rectangular sharp-crested weirs:

$$H_s = 0.3 \frac{Q}{L}^{2/3} \qquad \text{(D-22)}$$

and

$$h = 0.85H_s \qquad \text{(D-23)}$$

where

Q = flow rate, ft³/sec ($Q = Q_i = Q_e$ for continuous operation)
Q_e = clarified effluent rate, ft³/sec
L = weir crest length, ft

These relationships are shown graphically in Fig. D.13.

For a desired flow rate and weir length, Fig. D.13 can be used to determine the maximum head allowable. If the head in the basin exceeds this value, dredging should be discontinued until sufficient water is discharged to lower the head to an acceptable level. Since the depth of flow over the weir is directly proportional to the static head, it may be used as an operating

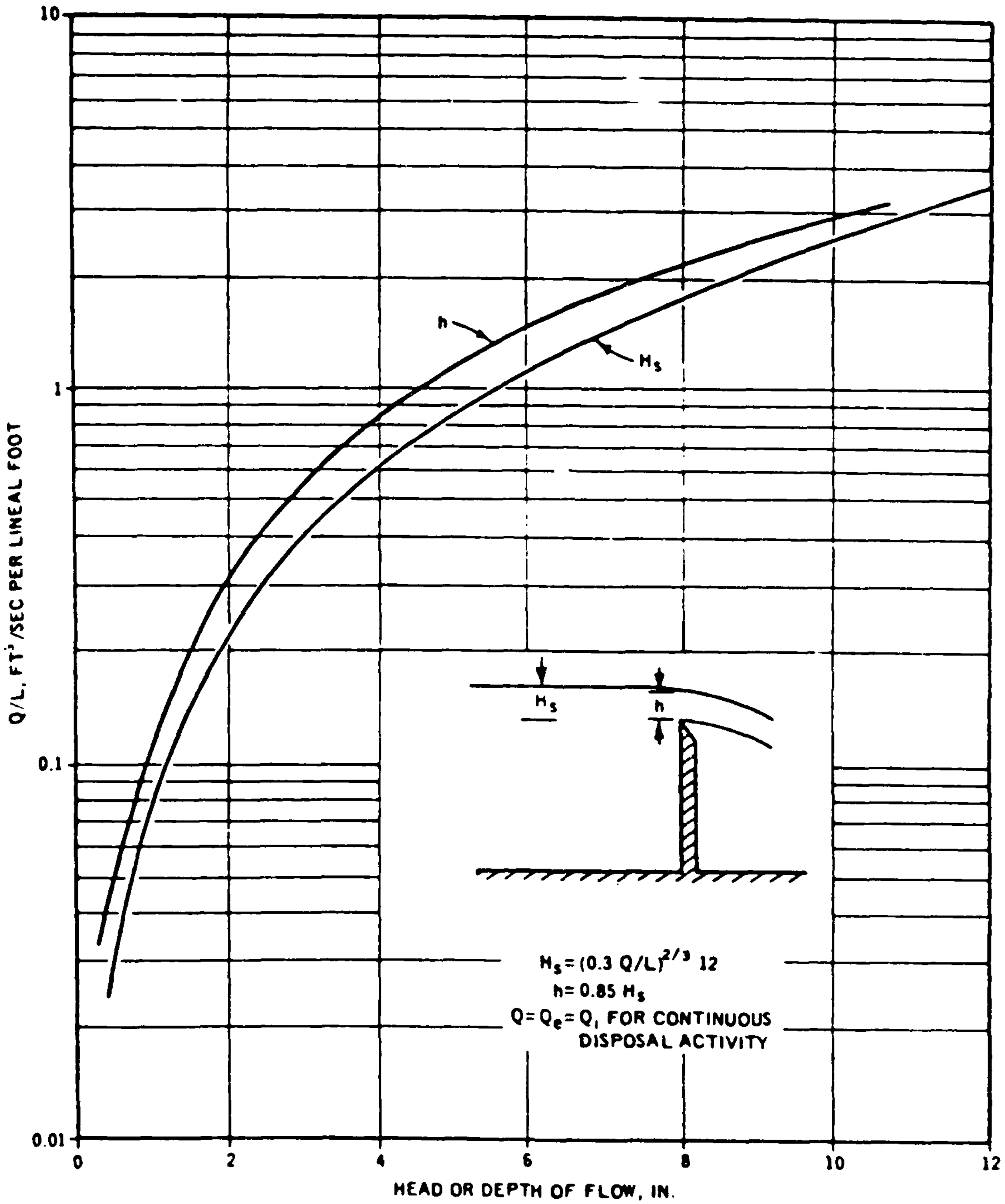


Figure D.13. Relationship between flow rate, weir length, and head (modified from B. J. Gallagher and Co. 1978) parameter. The dredging should then be performed intermittently to maintain the head within an acceptable range, not exceeding the maximum allowable head. The operator need not be concerned with head over the weir if effluent suspended solids concentrations are acceptable.

Weir operation for undersized basins. If the basin is undersized and/or inefficient settling is occurring in the basin, added detention time and reduced approach velocities are needed to achieve efficient settling and to avoid resuspension, respectively. Added detention time can be obtained by raising the weir crest to its highest elevation to maximize the ponding depth or by operating the dredge intermittently. The detention time with intermittent dredging can be controlled by maintaining a maximum allowable static head or depth of flow over the weir based on the effluent quality achieved at various weir crest elevations.

Weir operation for decanting. Once the dredging operation is completed, the ponded water must be removed to promote drying and consolidation of dredged material. Weir boards should be removed one row at a time to slowly decant the ponded water. Preferably, 2- by 4-in. boards should be located as described in previous paragraphs in order to minimize the withdrawal of settled solids. A row of boards should not be removed until the water level is drawn down to the weir crest and the outflow is low. This process should be continued until the decanting is completed. It is desirable to eventually remove the boards below the dredged material surface so that rainwater can drain from the area. These boards can be removed only after the material has consolidated sufficiently so that it will not flow from the basin. If it begins to do so, the boards should be replaced. In the final stages of decanting ponded water, notched boards may be placed in the weir to allow low flow for slow removal of surface water.

Dike Design and Equipment Requirement

Design Considerations and Requirements

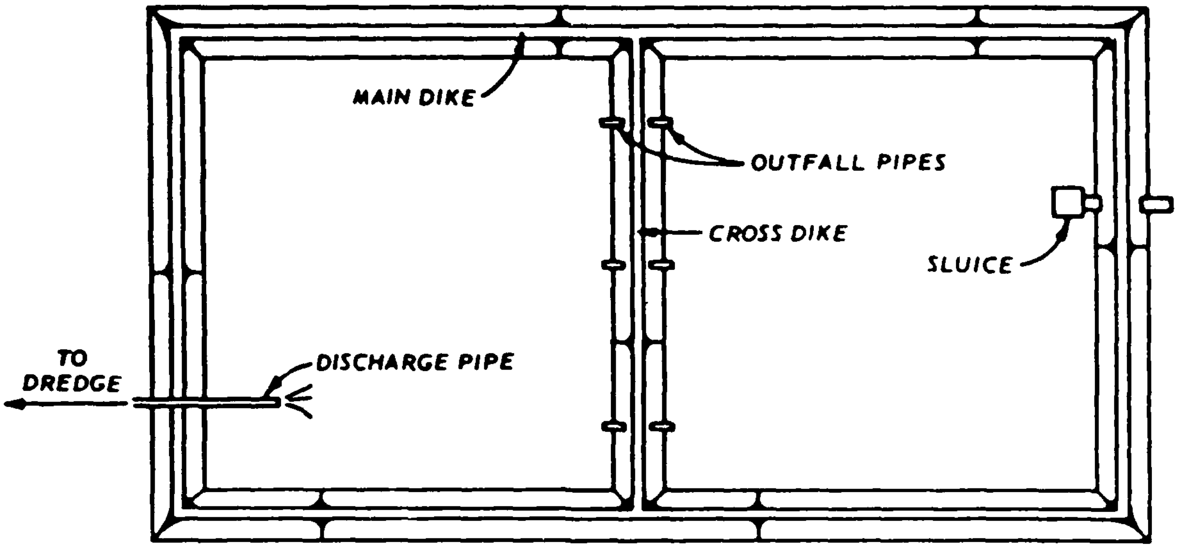
Retaining dikes used to form confined disposal facilities consist primarily of earth embankments and have the principal objective of retaining solid particles within the disposal area while at the same time allowing the release of clean effluent back to natural waters. Retaining dikes are similar to flood-protection levees in size and shape but differ in the following important respects: (a) a retaining dike will retain an essentially permanent pool, whereas most levees have water against them only for relatively short periods of time and (b) the location of a retaining dike will usually be established by factors other than foundation conditions and available borrow material (i.e., proximity to dredge, only land available, etc.) from which there will be little deviation. The heights and geometric configurations of retaining dikes are generally dictated by containment capacity requirements, availability of construction materials, and prevailing foundation conditions.

Types of Retaining Dikes

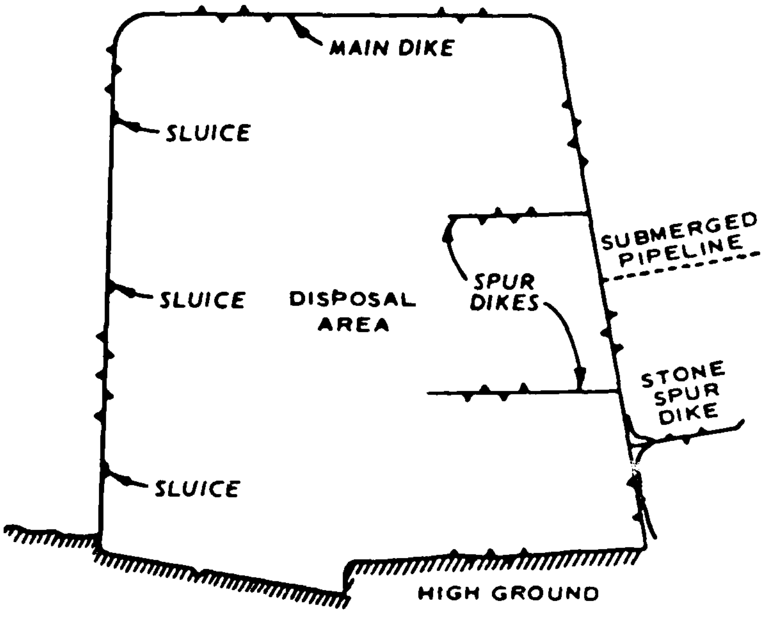
Main Dike. The most predominant retaining structure in a containment facility extends around the outer perimeter of the containment area and is referred to as the main dike. Except as otherwise noted, all discussion in this report applies to the main dike. The main dike and two other types of dikes that serve primarily as operational support structures for the main dike are shown in Fig. D.14.

Cross Dike. A cross or lateral dike (Fig. D.14) is a dike placed across the interior of the containment area connecting two sides of the main dike. The purpose of cross dikes is to separate the facility into two or more areas so that the slurry in one area is subjected to initial settling prior to passing over or through the cross dike to the other area. In order to accomplish this, the cross dike is placed between the dredged discharge point and the sluice discharge. Cross dikes can also be used with Y-discharge lines to divide an area into two or more areas, each receiving a portion of the incoming dredged material.

Spur Dike. Spur or finger dikes protrude into, but not completely across, the disposal area from the main dike (Fig. D.14). They are used mainly to prevent channelization by breaking up a preferred flow path and dispersing the slurry into the disposal area. Spur dikes are also used to allow simultaneous discharge from two or more dredges by preventing coalescing of the two dredged material inputs and thereby discouraging an otherwise large quantity of slurry from reaching flow velocities necessary for channelization.



a. DIKED DISPOSAL AREA WITH CROSS DIKE



b. DIKED DISPOSAL AREA WITH SPUR DIKES

Figure D.14. Examples of cross and spur dikes

Dike Failures

Retaining dike failures in the past have been largely the result of a combination of factors: foundation conditions, construction materials, and, in some cases, construction methods and disposal practices (Murphy and Zeigler 1974). Consequently, all of these factors must be taken into account during dike design. In addition to property damage, there is usually the expense of redredging the material and repairing the dike.

Foundation Conditions and Construction Materials. Available material at a site to serve as a foundation and/or of which the embankment will be composed is probably the single most important factor that affects dike design and construction. This is because dike design must generally be adapted to the most economically available materials compatible with prevailing foundation conditions. Available disposal sites are normally lands not economically suited for private development, often being composed of soft clay and silt of various organic contents. Since dike construction requiring the use of material from inside the disposal area and/or immediately adjacent borrow areas is often an economic necessity, initial dike heights may be limited or the use of rather large embankment sections may result, expensive foundation treatment may be required, or expensive construction methods may be dictated.

Construction Methods. The method used to construct the dike must also be given thorough consideration because each type of construction has characteristics that can strongly affect the desired dike section. The selection of a construction method, even though based largely on economics, must also be compatible with available materials and the geometry of the final dike section, as well as environmental considerations. The different types of construction, advantages and disadvantages of each, and their effects on the dike section are all discussed in detail in the section on dike construction.

Factors of Field Investigation and Design. The extent to which field investigations and design are carried out is dependent on the desired degree of safety against failure. This decision will usually be made by the local design agency and, of course, involves many site-specific factors. However, Table D.2 lists some general factors based on past practice that can be used as general guidelines in the planning stages of a project.

Table D.2

Factors Affecting the Extent of Field Investigations and Design Studies

Factor	Field Investigations and Design Studies Should be More Extensive Where
Construction experience	There is little or no construction experience in the area, particularly with respect to dikes
Consequence of failure	Consequences of failure involving life, property, or damage to the environment are great
Dike height	Dike heights are substantial
Foundation conditions	Foundation deposits are weak and compressible Foundation deposits are highly variable along the alignment Underseepage and/or settlement problems are severe
Borrow materials	Available borrow is of poor quality, water contents are high, or borrow materials are variable along the alignment
Structures in dikes	Sluices or other structures are incorporated into the dike embankment and/or foundation
Utility crossings	Diked area is traversed by utility lines

Field and Laboratory Tests

Table D.3 summarizes the general features of geologic and subsurface field investigations. Ideally, an exploration program should be carried out in the sequence given, with one stage immediately following the other. This will often reduce mobilization costs for exploration equipment, but requires that an engineer be on the job full time to digest all data as they are obtained.

Field Tests. It is often desirable to estimate foundation strengths during the preliminary stage of the exploration program. Table D.4 lists available methods for estimating foundation strength.

Laboratory Investigations. This part describes laboratory tests considered appropriate in establishing the engineering properties of foundation soils and embankment materials for use in the design of retaining dikes. The number and types of laboratory tests to be performed should be determined only

Table D.3

Stages of Field Investigation

Stage	Features
Preliminary geological investigation	a. Office study. Collection and study of: Topographic, soil, and geological maps Aerial photographs Boring logs and well data Information on existing engineering projects
	b. Field survey. Observations and geology of area, documented by written notes and photographs, including such features as: Riverbank and coastal slopes, rock outcrops, earth and rock cuts or fills Surface materials Poorly drained areas Evidences of instability of foundations and slopes Emerging seepage and/or soft spots Natural and man-made physiographic features
Subsurface exploration and field testing and more detailed geologic study*	a. Preliminary phase. Widely but not uniformly spaced disturbed sample borings (may include split spoon penetration tests) Tests pits excavated by backhoes, farm tractors, or dozers Geophysical surveys to interpolate between widely spaced borings Borehole geophysical tests
	b. Final phase. Additional disturbed sample borings including split spoon penetration tests Undisturbed sample borings Field vane shear tests for soft materials Water table observations

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* See WES TR D-77-9 for more detailed discussion.

Table D.4

Preliminary Appraisal of Foundation Strengths

Method*	Remarks
Penetration resistance from standard penetration test	In clay, provides data helpful in a relative sense; i.e., in comparing different deposits. Generally not helpful where number of blows per foot N* is low In sand, N-values less than about 15 indicate low relative densities
Natural water content of disturbed or general type samples	Useful when considered with soil classification and previous experience is available
Hand examination of disturbed samples	Useful where experienced personnel are available who are skilled in estimating soil shear strengths
Position of natural water contents relative to liquid limit (LL) and plastic limits (PL)	Useful where previous experience is available If natural water content is close to PL, foundation shear strength should be high
Field pumping tests used to determine field permeability	Natural water contents near LL indicate sensitive soils with low shear strengths
Torvane or pocket penetrometer tests on intact portions of general samples	Easily performed and inexpensive, but results may be excessively low; useful for preliminary strength estimates
Vane shear tests	Used to estimate shear strengths

* EM 1110-2-1907 contains details of these procedures.

after a careful study of the boring profiles in order to determine the parameters likely to control the design. Current laboratory soil testing procedures are fully described in EM 1110-2-1906, "Laboratory Soils Testing" (OCE Nov 1970). EM 110-2-1902, "Stability of Earth and Rock-Fill Dams," (OCE Apr 1970) outlines the applicability of the various laboratory strength tests to appropriate field loading conditions.

Lab Testing Programs. A laboratory testing program can generally be divided into two parts. The first part consists essentially of index tests, the purpose of which is to classify the soils and thereby develop the boring log with the end result of establishing soil profiles, i.e., determining what type of soils exist where. Index tests include visual classification, water content, Atterberg Limits, and mechanical analysis (gradation) tests. The second part consists of tests intended to determine the engineering properties of soils with respect to shear strength, consolidation, and sometimes permeability. It is these values that provide the input parameters for design analyses. Tables D.5 and D.6 contain the various tests that may be included in a laboratory testing program for fine-grained and coarse-grained soils, respectively. Also included in Table D.5 and D.6 are pertinent remarks concerning the purposes and scope of testing. Additional guidance is available in EM 1110-2-1906, WES TR D-77-9, Mil Std 619B, and WES Tech Memo 3-357.

Construction Materials

Acceptable Materials. Almost any type of material can be classified as acceptable (even though not the most desirable) for construction of retaining dikes, with the exception of very wet fine-grained soils and those containing a high percentage of organic matter. Highly plastic clays may present a problem because of their detrimental shrink-swell properties when subjected to alternate cycles of drying and wetting.

Compacted, Semicompacted, and Uncompacted (Cast) Fill. The natural water content of materials used in conjunction with these methods of construction is very important. When compacted dikes are planned, it is necessary to ensure that available borrow material has a low enough water content to allow placement and compaction. Semicompacted fill can tolerate material with higher water contents, while uncompacted cast fill can be placed at very high

Table D.5

Laboratory Testing of Fine-Grained Cohesive Soils

Type Test	Purpose	Scope of Testing
Visual classification	To visually classify the soil in accordance with the Unified Soil Classification System	All samples
Water content	To determine the water content of the soil in order to better define soil profiles, variation with depth, and behavioral characteristics	All samples
Atterberg limits	Foundation soils: for classification, comparison with natural water contents, or correlation with shear or consolidation parameters Borrow soils: for classification, comparison with natural water contents, or correlations with optimum water content and maximum dry densities	Representative samples of foundation and borrow soils. Sufficient samples should be tested to develop a good profile with depth
Compaction	To establish maximum dry density and optimum water content	Representative samples of all borrow soils for compacted or semicompacted dikes: Compacted - perform standard 25-blow test Semicompacted - perform 15-blow test
Consolidation	To determine parameters necessary to estimate settlement of dike and/or foundation and time-rate of settlement. Also, to determine whether soils are normally consolidated or over-consolidated and to aid in estimating strength gain with time	Representative samples of compacted borrow where consolidation of dike embankment itself is expected to be significant. Representative samples of foundation soils where such soils are anticipated to be compressible On samples of fine-grained adjacent and/or underlying materials at structure locations
Permeability	To estimate the perviousness of borrow and/or foundation soils in order to calculate seepage losses and time-rate of settlement	Generally not required for fine-grained cohesive soils as such soils can be assumed to be essentially impervious in seepage analyses. Can be computed from consolidation tests
Shear strength	To provide parameters necessary for input into stability analysis Pocket penetrometer, miniature vane, unconfined compression, and Q-tests to determine unconsolidated-undrained strengths R-tests to determine consolidated-undrained strengths S-tests to determine consolidated-drained strengths	Pocket penetrometer and miniature vane (Torvane) for rough estimates Unconfined compression tests on saturated foundation clays without joints, fissures, or slickensides Appropriate Q- and R-triaxial and S-direct shear tests on representative samples of both foundation and compacted borrow soils

Table D.6

Laboratory Testing of Coarse-Grained Noncohesive Soils

Test	Purpose	Scope of Testing
Visual classification	To visually classify the soil in accordance with the Unified Soil Classification System	All samples
Gradation	Determine grain-size distribution for classification and correlation with permeability and/or shear strength parameters	Representative samples of foundation and borrow materials
Relative density or compaction	Determine minimum-maximum density values or maximum density and optimum water content values; should use the test which gives greatest values of maximum density	Representative samples of all borrow materials
Consolidation	To provide parameters necessary for settlement analysis	Not generally required as pervious soils consolidate rapidly under load and post-construction magnitude is usually such as to be insignificant
Permeability	To provide parameters necessary for seepage analysis	Not usually performed as correlations with grain size are normally of sufficient accuracy. Where underseepage problems are very serious, best to use results from field pumping test
Shear strength	To provide parameters necessary for stability analysis	Representative samples of compacted borrow and foundation soils. Consolidated-drained strengths from S-direct shear or triaxial tests are appropriate for free-draining pervious soils Conservative values of ϕ can usually be assumed based on S-test results from similar soils

water contents. Since dike construction is normally in low wet areas, problems with materials being too dry are rarely encountered.

Materials of high water content must either be dried to a water content suitable for the desired type of construction, or the design must take into account the fact that the material has a high water content. Because the cost of drying material is very expensive, time consuming, and highly dependent on weather conditions, the design should incorporate the properties of the material at its natural water content or involve a minimum of drying.

Material Sources. Consideration of above factors and the necessary engineering and economic criteria for a given containment area construction project requires careful analysis of all available material sources. Possible sources are listed in the following paragraphs.

a. Required excavation. Material from required excavations should be given first consideration since it is usually the most economically desirable because it must be excavated and disposed of in any event. Included in this category is material from adjacent ditches, canals, appurtenant structures, and material from inside the containment area. The use of material from required excavation also eliminates the problem of dealing with borrow areas left permanently exposed after project completion.

b. Material Adjacent to Dike Toe. This is the most common source of dike material because it involves a short or no haul distance and is conducive to dragline operation. One important factor not to be overlooked when utilizing any source of borrow near a dike is effects of excavation on dike stability. As shown in Figure D.15, a berm should be left in place between the toe of the dike and the excavation to ensure stability of the dike and facilitate construction. The length of this berm should be based on stability analyses of the dike and the excavation.

c. Central Borrow Area. A central borrow is normally utilized when suitable material cannot be economically obtained from sources previously mentioned. Central borrow areas can be utilized for both hauled and hydraulic fill dikes. Dredging from a water-based central pit is usually an economical source of borrow where hydraulic fill dikes are to be constructed. Usually a deeper pit with a smaller surface area is the most economical since the less movement required by the dredge, the cheaper the operation. The chief disadvantage of hauling material from land-based central pits is the longer haul distance required.

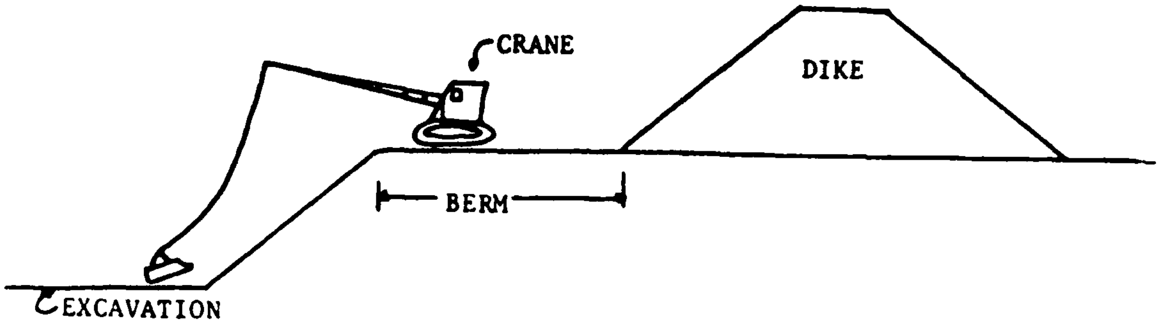


Figure D.15. Excavation adjacent dike toe

d. Maintenance Dredging. Maintenance dredging is a very economical source of material. However, fine-grained material from maintenance dredging is not suitable for dike construction without considerable drying as it has extremely poor engineering qualities in the "dredged" state. Sands and predominately coarser grained materials from maintenance dredging are desirable for dike construction. Zones around the dredge discharge usually will provide the highest quality material. Use of previously placed dredged material from maintenance operations has been common for the raising of existing dikes since it is so readily available and its use increases the capacity of the retention area.

Borrow Area Operations. Efficient borrow area operations will result in greater cost savings and reduce the impact to surrounding environments. The following paragraphs outline important factors to consider when conducting borrow area operations.

a. Clearing, grubbing, and stripping. Clearing, grubbing, and stripping of borrow areas should be carried out to obtain fill material free from objectional matter such as trees, brush, vegetation, stumps, roots, and organic soil. In marshy areas, a considerable depth of stripping may be required due to the frequent existence of 3- to 4-ft root mats, peat, and underlying highly organic soil. However, such operations may be restricted in soft marshy areas because of lack of support for equipment. All stripped organic material should be wasted in low areas or, where useable as topsoil, stockpiled for later placement on outer dike slopes, berms, exposed borrow slopes, or other areas where vegetative growth is desired.

b. Excavation. Excavation operations in borrow areas should be carefully planned with consideration given to proximity of areas to the dike, topography, location of groundwater table, possible excavation methods and equipment, and surface drainage. The operation should be conducted so that no useable areas will become inaccessible, thereby causing a reduction in obtainable quantities.

c. Drainage. Proper drainage of borrow areas (entailing control of surface and ground water) is necessary to achieve a satisfactory degree of utilization. Proper drainage of borrow areas can often be achieved by working the area in accordance with natural topography and drainage patterns. Many times, however, natural drainage is poor and the only choice is to begin at the lowest point and work toward the higher areas, thus creating a sump to aid in draining the work area. In some cases pumping of sumps or low areas may be necessary. Maximum utilization of ditches, especially in shallow borrow areas, should be made, as ditches provide a cheap method of controlling water and drying material. It is desirable that the ditching be done well ahead of the excavation, especially in fine-grained soil. This allows maximum drying of the material prior to excavation.

d. Environmental considerations. The treatment of permanently exposed borrow areas to satisfy aesthetic and environmental considerations has, in the past few years, become standard operating practice. Generally, projects near heavily populated or industrial areas will require more elaborate treatment than those in sparsely populated areas. Minimum treatment should include proper drainage, topographic smoothing and blending, and promotion of conditions conducive to vegetative growth. Insofar as possible, borrow areas should be planted to conform to the surrounding landscape. Restoration of vegetative growth is important because it is not only aesthetically pleasing but serves as protection against erosion and promotes wildlife habitation. Mann et al. (1975) should be consulted for more detailed information concerning landscaping techniques.

Design and Construction Considerations

General. Factors that should be considered in the design and construction of retaining dikes are foundation conditions; dike materials; dike stability with respect to shear strength, seepage, settlement, and erosion; and construction methods. Foundation conditions and dike materials have previously been discussed. The purpose of this section is to present some of the remaining items to be considered in the design and construction of retaining dikes.

Dike Geometry. Dike geometry refers to crown width, height, and side slopes. Because these variables are primarily dependent on foundation conditions, embankment materials, construction methods, and project objectives, it is not possible to arrive at many specific recommendations relative to the geometry of dike cross sections that can be generally applied to all dikes regardless of site conditions and project requirements. A summary of some dike cross sections constructed in various CE districts is given in Table D.7.

Dike Materials and Foundation. The types of materials available for building a retention dike are the most important of all variables in the selection of a dike section. Available materials not only affect the design of a dike from the stability standpoint but usually also dictate the method of construction. Where materials with suitable engineering properties for dike construction are either unavailable in the immediate vicinity of the disposal area or are not accessible to conventional types of hauling or casting equipment, hydraulic dredging of material may be the only practical means of construction available. In such cases, the dike may have a high factor of safety with respect to stability because of the very flat side slopes, but still be more economical than a smaller section constructed by other methods. Where adequate borrow material is available, construction of a dike system utilizing draglines or hauling equipment may be the most economical. Where a competent dike foundation exists, considerable flexibility is available for selection of the dike section. As the adequacy of the foundation decreases, the flexibility in selection of the section and method of construction also decreases.

Method of Construction. Dike embankments, classified according to general construction methods, are listed in Table D.8. The choice of construction will be governed by available materials, foundation conditions, and economics. As can be seen in Table D.8, there are basically three types of embankments with respect to material placement and compaction: compacted, semicompacted, and uncompacted. Classification by these means does not necessarily refer to the end quality of the embankment, rather it specifically refers to how much compaction effort and water content control was applied in construction of the embankment.

Table D.7

Summary of Corps of Engineers Dikes Sections

District	Foundation Material	Dike Material	Height, ft Initial	Height, ft Increment	Height, ft Maximum	Crown Width, ft	Side Slopes	Remarks
Galveston	Soft marsh clay and dredged sandy silt	Dredged clay and silty sand from disposal area	4 to 5	2 to 4	10	4 to 8	1V on 2H to 1V on 4H	Dike placed by dragline with some compaction by dozers
	Soft to stiff clay with some silt and sand	Dredged sandy clay from disposal area	(Interior height of 6 to 10 ft)		15 to 25	8	1V on 3H	Semicompacted fill raising existing dikes
	Dredged silt, sand, and clay	Dredged clay and clayey sand from disposal area	(Interior height of 10 ft)		17	8	1V on 3H	Semicompacted fill raising existing dikes
Charleston	Dredged silty sand and clay overlying soft marsh deposits	Dredged sandy silt from disposal area	(Interior height of 3 to 5 ft)		10 to 15	8	1V on 1.5H	Dike placed by dragline with no compaction. Failures occurred in two reaches
	Soft organic silt and clay	Fine silty sand with high organic clay and shell content	--	--	--	10	1V on 1.5H	Dike placed by dragline with no compaction. Raised existing dikes
	Dredged silty sand and clay overlying soft marsh deposits	Dredged sandy silt from disposal area	7	--	7	10	Broken 1V on 8H then 1V on 25H	Hydraulic fill shaped with dozers
Philadelphia	Dredged silt and clay underlain by marsh	Dredged silt and clay from disposal area	10 to 12	--	10 to 12	8	1V on 1.5H	Dike compacted by hauling equipment
	Dredged silty sand underlain by marsh	Dredged silty sand from disposal area	10	--	10	10	1V on 1.5H	Dike compacted by hauling equipment
Wilmington	Dredged clay, silt, and sand	Sand and clayey sand	20 to 25	--	20 to 25	15	1V on 2H	Dike compacted by hauling equipment
Norfolk	Dredged silt and sand with variable organic content	Dredged silt and sand from disposal area	6 to 8	--	6 to 8	3	1V on 1H	Dike placed by dragline with no compaction
Detroit	Dredged organic silt and clay and sandy silt	Clay with some sand and gravel	--	--	15 to 18	25	1V on 2H	Dike compacted by routing construction equipment
Sacramento	Sand	Silt, clay, and sand	10 to 15	--	10 to 15	12	1V on 2H	Semicompacted fill

Table D.8

Dike Classification According to Method of Construction

Type Compaction	Method of Construction	Requirements, Use, and Remarks
Compacted	Hauled, spread, and compacted with compaction equipment Requires specification of: Water content with respect to optimum Loose-lift thickness Type compaction equipment and number of passes	Requirements: a. Strong foundation of low compressibility b. Fill materials with natural water content reasonably close to specified ranges Provides: a. Steep-sloped embankment, occupying minimum space b. Strong embankment of low compressibility
Semicompacted	Hauled or cast with draglines Compacted with fewer passes of light roller or controlled traffic of hauling, spreading, or shaping equipment Fill material placed at natural water content (i.e., no water content control) Usually placed in thicker lifts than compacted method	Used where: a. Steep-sloped compacted embankments are not required b. Relatively weak foundations exist that cannot support steep-sloped compacted embankments c. Underseepage requirements are such as to require a wider emb[illegible]ment base than is necessary f[illegible] compacted embankments d. Water content of fill material or amount of rainfall during construction season is such as to not justify compacted embankments, but low enough to support equipment
Uncompacted	Hauled (dumped in place), cast, or pumped hydraulically Little or no spreading or compaction Usually shaped to final lines and grade No lift thickness control Fill material placed at natural water content (i.e., no water content control)	Used where: a. Nearby materials are inadequate for compacted or semicompacted construction b. It is the most economical method of placement c. Dike heights are low for cast or dumped-in-place methods d. Relatively weak foundations exist e. Embankments with wide bases are required for stability (for pumped methods)

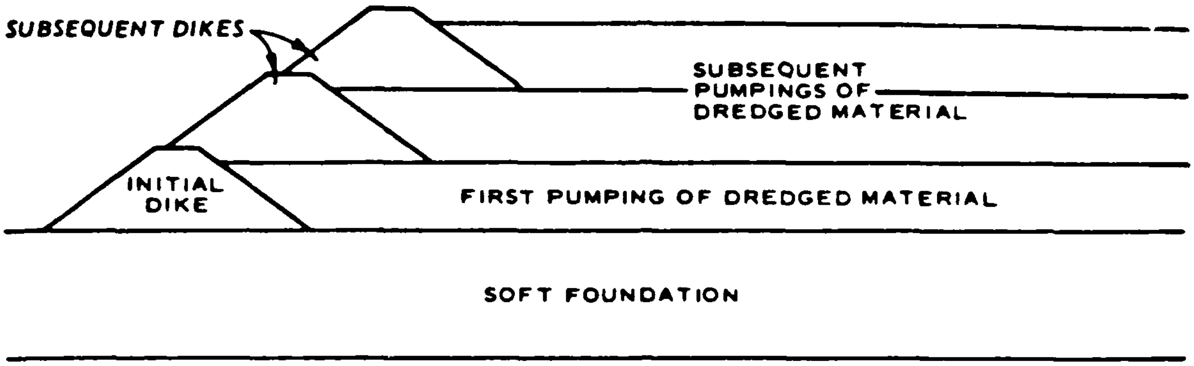
Raising of Existing Dikes. Due to the weakness of many dike foundations, the height to which a dike can be built in one stage is often limited. This limits the capacity of the containment area. Raising existing dikes to higher elevations than were possible initially is made possible by consolidation (and consequent strength gain) of foundation materials over a period of time due to the imposed load of the initial fill. Construction of dikes in increments is usually accomplished by incorporating the initial dike into the subsequent dike as shown in Figure D.16a, although in some cases interior dikes are constructed at some distance from the inside toe of the existing dike as shown in Figure D.16b.

Dike Stability

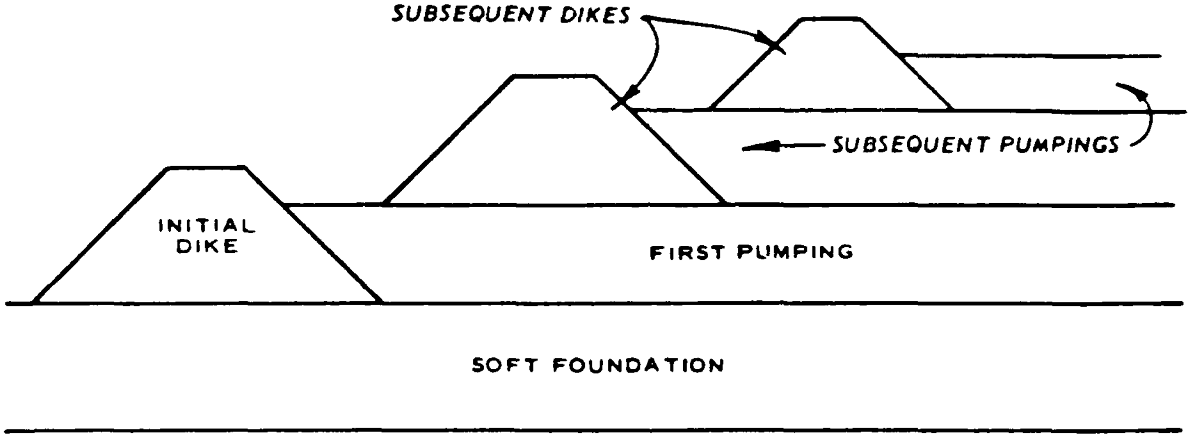
This part describes common causes of instability in dikes and presents recommended methods and procedures for analyzing dike stability with respect to inadequate foundation and/or embankment shear strength, seepage, settlement, and external erosion. The analyses described and referenced herein contain procedures that have proven satisfactory from past use, and most are currently employed by the CE. WES Technical Report D-77-9 contains specific details concerning dike stability.

Causes of Dike Instability.

a. Inadequate shear strength. Shear failures in retaining dikes are the result of overstressing the embankment and/or foundation materials. Low shear strengths in the dike and/or foundation (often coupled with seepage effects) are the cause of most dike failures. Failures of this type are usually the most catastrophic and damaging of all since they usually occur quickly and can result in the loss of an entire section of dike along with the contained dredged material. These failures may involve the dike alone or both the dike and the foundation. Failures within a dike alone result when the dike material possesses insufficient shear strength. Failures of this type generally take the form of a rotational slide involving the dike slope as shown in Fig. D.17. However, if a weak plane or layer should exist at the contact between the dike fill and the foundation, the failure could take the form of a wedge-type configuration characterized by horizontal sliding or translation near the base of the fill (see Fig. D.18). Rotational type slides as shown in Fig. D.19 also occur that involve the foundation as well as the embankment. This type of failure generally develops where the foundation is relatively homogeneous with insufficient foundation shear strength being the usual cause



a. INCORPORATION OF INCREMENTAL DIKES



b. SEPARATE INCREMENTAL DIKES

Figure D.16. Incremental or stage construction of dike

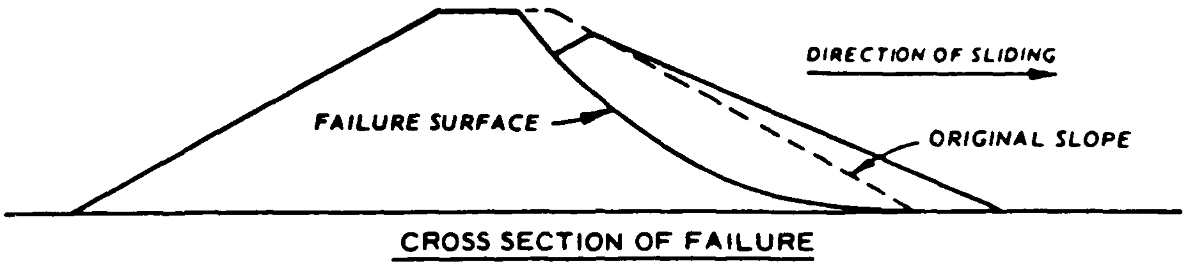


Figure D.17. Rotational failure in dike

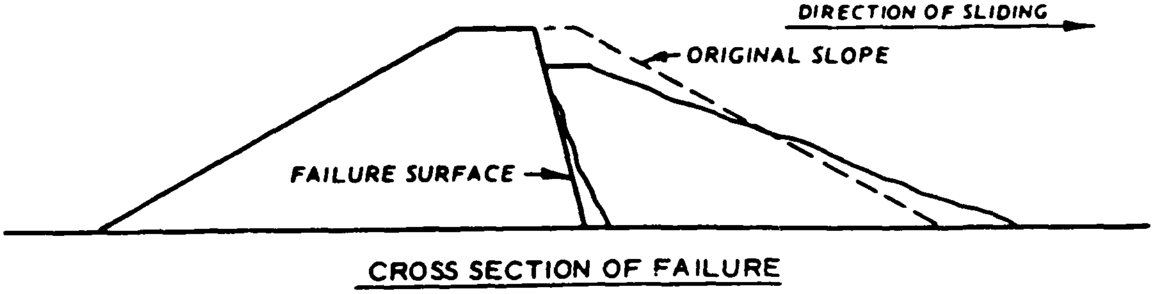


Figure D.18. Translatory failure in dike

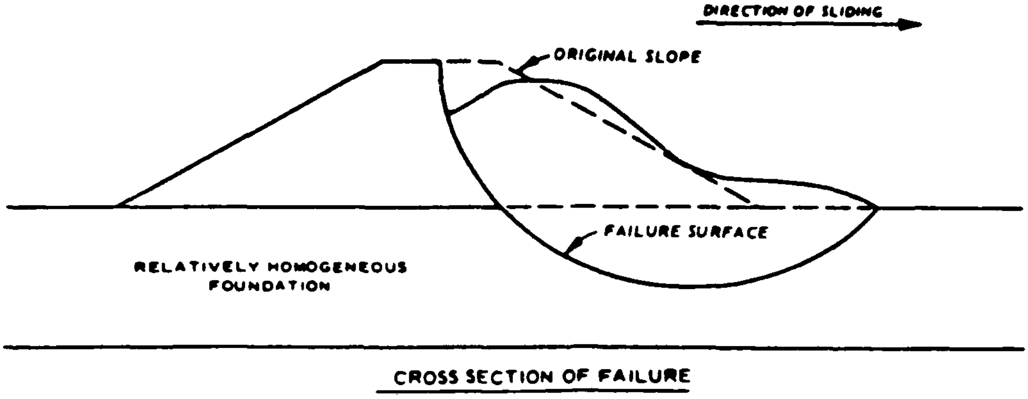


Figure D.19. Rotational failure involving both dike and foundation

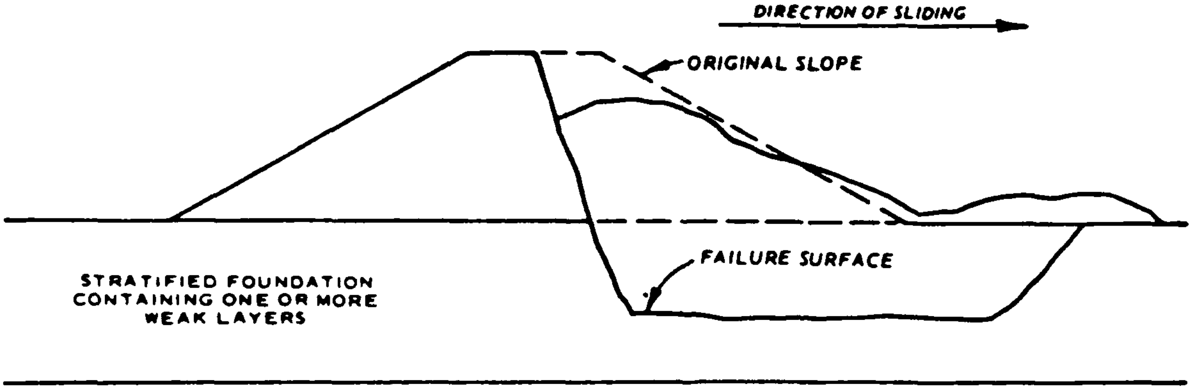


Figure D.20. Translatory failure in dike and foundation of failure. A translatory or wedge-type failure can also occur in the foundation where the foundation consists of stratified layers of various soil types (see Fig. D.20). Horizontal sliding generally occurs in one of the weaker strata in the foundation.

b. Seepage. Uncontrolled seepage will occur through earth dikes and foundations consisting of pervious or semipervious material unless prevented by positive means such as impervious linings, blankets, or cutoffs. Seepage effects can create instability through internal erosion (piping) of dike or foundation materials or may lead to a shear failure by causing a reduction in the available shear strength of the dike and/or foundation through increased pore pressure or by the introduction of seepage forces. The following conditions may create or contribute to seepage problems in retention dikes:

(a) Dikes with steep slopes composed of coarse-grained pervious material or fine-grained silt. In this case the seepage line through the embankment may exit on the outer slope above the dike toe resulting in raveling of the slope. If the dike contains alternating layers of pervious and impervious materials, the seepage surface may even approach a horizontal line at the ponding surface elevation, thus creating an even more severe stability problem (Fig. D.21).

(b) Dikes built on pervious foundation materials or where pervious materials are near the surface or exposed as a result of nearby excavation (Fig. D.22). This is a common condition where dikes are constructed by dragline using an adjacent borrow ditch. In this case surface or near-surface peat and other fibrous materials are included as pervious foundation materials. This condition may lead to the development of large uplift pressures beneath and at the outer toe of the dike causing overall instability from inadequate shear strength or may result in piping near the embankment base.

(c) Dikes constructed by casting methods with little or no compaction. This method of construction may leave voids within the dike through which water can freely flow, resulting in piping of dike material.

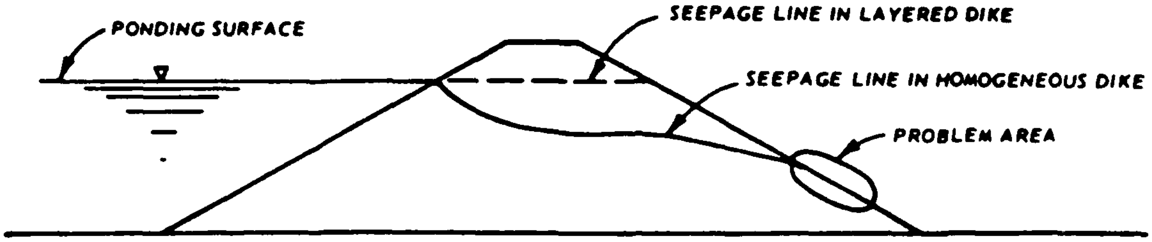


Figure D.21. Seepage lines through dike

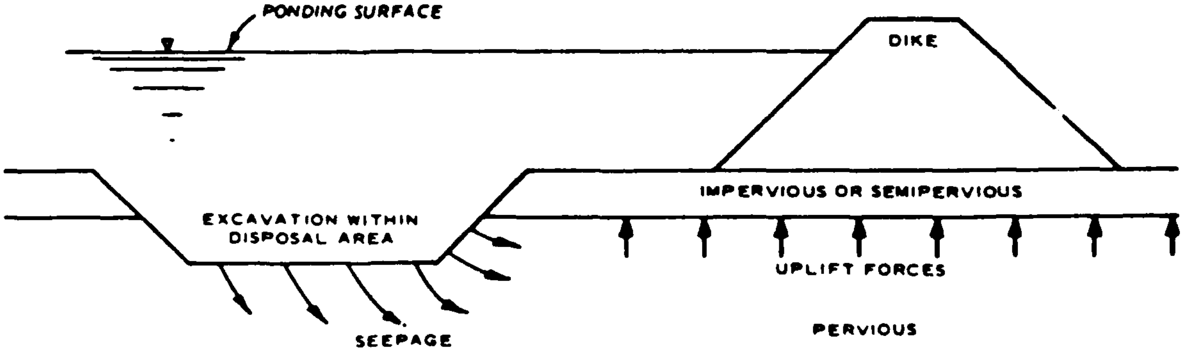


Figure D.22. Seepage entrance through area excavated within disposal area

(d) The existence of seepage paths along the plane between the foundation and the dike. Reasons for the occurrence of this condition have been described previously. Seepage occurring at this point can result in piping of the embankment material along the base of the dike or the development of high uplift pressures, either of which can eventually cause failure of the embankment.

(e) The existence of seepage paths along the contact between structures within the dike and the dike. This condition can be caused by inadequate compaction of dike materials against structures, shrinkage of material adjacent to structures, or differential settlement. As in previous cases, piping of the dike material usually results and normally leads to breaching of the dike.

c. Dike settlement. Settlement of dikes can result from consolidation of embankment and/or foundation materials, shrinkage of embankment materials, or lateral deformation of foundation materials. Like uncontrolled seepage, settlement of dikes can result in failure of the dike, but more likely will serve to precipitate failure by another mode such as seepage or shear failure. Distress from settlement usually takes some time to develop as consolidation, shrinkage, and lateral deformation are time dependent and are directly related to the soil permeability and loading. Some lateral deformation can occur quickly, however, such as during construction (particularly in relation to the displacement method of construction). Settlement problems in dikes are almost always related to fine-grained soil because settlement of coarse-grained permeable soil is generally much less, occurs relatively quickly, and is compensated for during construction.

Specific forms of settlement that commonly cause problems with dikes include: excessive uniform settlement; differential settlement; shrinkage of uncompacted embankment materials; and settlement resulting from lateral deformation (sometimes referred to as creep) of soft foundation soil. Excessive uniform settlement can cause a loss in containment area capacity due to loss of dike height (Fig. D.23). Differential settlement can result in cracking of the dike, which can lead to a shear or piping failure. This is an especially acute problem at junctions between dikes and structures in dikes. Examples of differential settlement resulting various causes are shown in

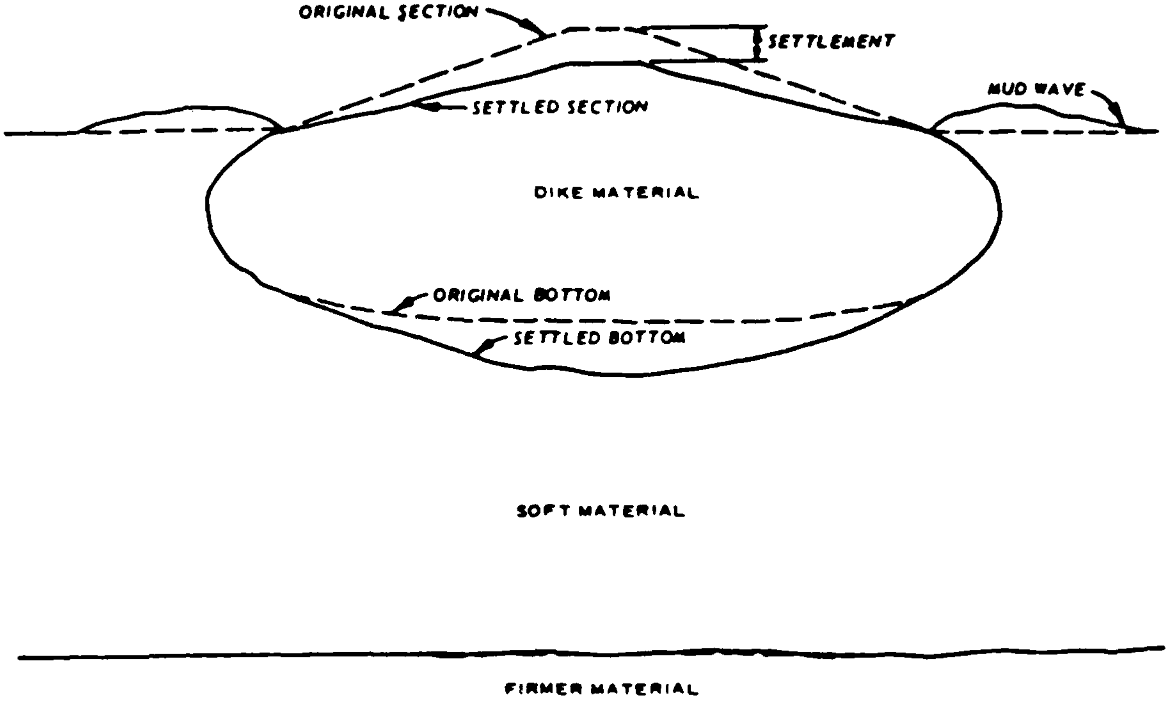


Figure D.23. Example of excessive uniform settlement

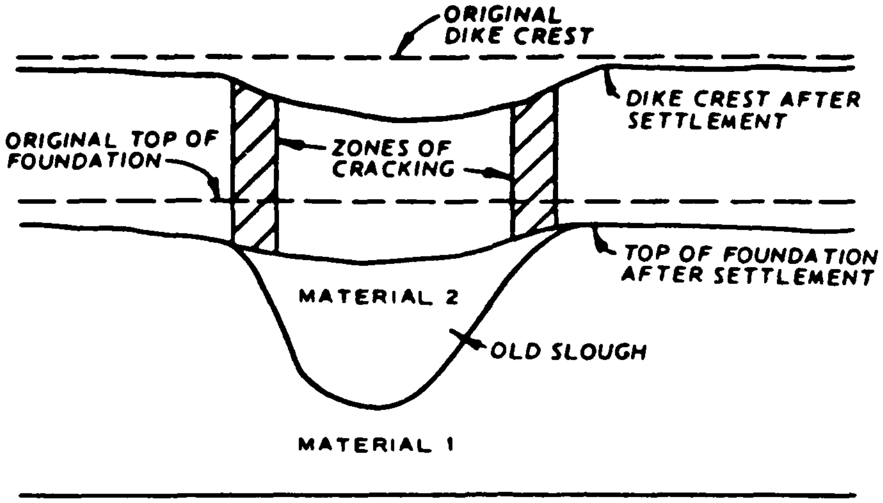
Figs. D.24 and D.25. Both excessive uniform and differential settlement can cause distortion and/or rupture of weir discharge pipes located under or through dikes and can cause distortion of the weir box itself. Embankment shrinkage in dikes built with fine-grained cohesive material by hydraulic or cast methods can result in volume reductions as high as 35 percent. Shrinkage of loosely placed cohesive materials is differentiated from consolidation in that it occurs from evaporation of water in the soil rather than a squeezing out of water, as occurs with consolidation, although both result in a loss of volume.

d. Erosion. Retaining dike failures can be initiated by the effects of wind, rain, waves, and currents that can cause deterioration of interior and exterior dike slopes. The exterior slopes of dikes subject to constant or intermittent wave and/or current action of tidal or flood waters are generally exposed to the most severe erosion. However, interior dike slopes may also be subjected to this type of erosion, particularly in large containment areas. Dikes adjacent to navigable rivers and harbors are also subject to erosion from wake waves of passing vessels.

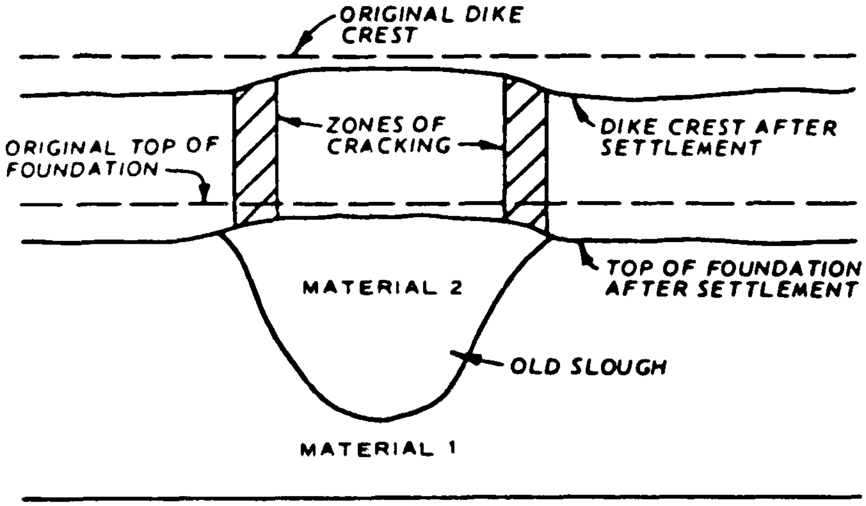
e. Weathering. Erosion of dike slopes due to the effects of wind, rain, and ice is a continuing process. While these forces are not as immediately damaging as wave and current action, they can gradually cause extensive damage to the dike section, particularly dikes composed of coarse-grained cohesionless materials.

f. Disposal operations. Normal disposal operations can cause erosion of interior dike slopes near the pipeline discharge and exterior slopes at outlet structures. Improper and/or poorly supervised operations of this type can cause dike failure. The pipeline discharge of dredged material is a powerful eroding agent, particularly if the flow is not dispersed.

Slope Stability. The stability of dike slopes is dependent on forces acting on the dike and on shear strengths of embankment and foundation materials. Forces that the slope must resist include those from embankment weight, unbalanced water pressure, seeping water, and external loads such as equipment, water, etc. As previously discussed, many factors can affect dike stability. WES TR-77-9 presents methods of slope stability analyses along with discussions of various possible loading conditions, determination of design shear strengths, and recommended minimum factors of safety. Also discussed are methods of improving dike stability against shear failure. The



a. COMPRESSIBILITY OF MATERIAL 2 >> MATERIAL 1



b. COMPRESSIBILITY OF MATERIAL 2 << MATERIAL 1

Figure D.24. Differential settlement from foundation containing materials of different compressibility

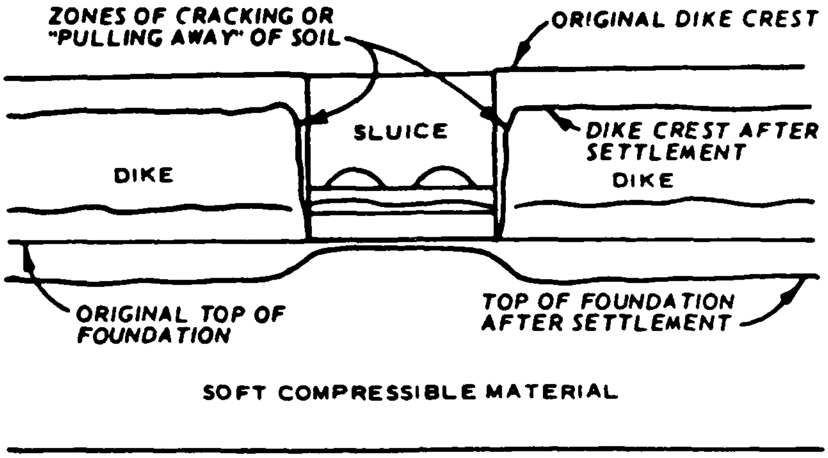


Figure D.25. Cracking at dike-structure junction caused by differential settlement due to dike load on foundation being much greater than sluice load methods and procedures described are applicable to all types of dikes such as main, cross, spur, and toe dikes, as well as dikes built by various construction methods.

Dike Construction

General. As previously discussed, the method of dike construction is of primary importance and can have a profound effect on the final dike cross section. Generally speaking, there are three basic categories of dike construction: hauled, cast, and pumped (hydraulic fill). Of course, there are many variations and combinations of these methods that can and have been used. The purpose of this part of the report is to discuss some of the salient features of each type of construction, including advantages and disadvantages, applicability, inherent effects on the dike cross section, effect of material types, etc.

Equipment. Types of equipment commonly used in dike construction are listed in Table D.9 according to the operation they perform. Most of the equipment listed is commonly used in construction. However, because many dikes are founded on soft to very soft ground, low-ground-pressure equipment must often be used.

a. Bulldozers. Bulldozers are often used for spreading, compacting, and shaping fill material for dike construction. They are used in construction of nearly all types of dikes including hauled, cast, and pumped. They are also extensively utilized in foundation preparation. Conventional crawler tractors that exert ground pressures of about 8 psi and higher are often unable to operate on soft ground. Several equipment manufacturers now offer modified tractors with lower ground pressures made especially for soft-ground construction. These machines utilize wider tracks and exert ground pressures of 4 psi and lower.

b. Draglines. Draglines are used to construct cast dikes. Through the use of wide-track machinery and/or proper matting techniques, draglines can operate in areas so soft that they are almost inaccessible to a person on foot. This often requires use of a timber matting under the dragline that can be single, double, or triple layers of timber.

While small draglines may exert less ground pressure and may be more maneuverable than larger machines, they are often at a disadvantage due to their short boom and small-capacity bucket. Their short reach (about 40 ft) frequently necessitates rehandling material. Also, the small bucket tends to

Table D.9

Equipment Commonly Used in Dike Construction

Operation	Equipment
Excavation	Draglines Scrapers Dredges
Transportation	Scrapers (hauled) Truck (hauled) Draglines (cast) Dredges (pumped)
Spreading	Bulldozer
Scarification	Disk
Compaction	Sheepsfoot roller Pneumatic roller Vibratory roller Bulldozer Hauling equipment
Shaping	Bulldozer Dragline

greatly disturb the material being excavated, which is a distinct disadvantage when working sensitive materials.

When excavating soft weak material along the proposed dike alignment, a wide shallow cut is the most desirable and feasible geometric shape. To successfully handle this operation, draglines with 60- to 70-ft booms and 1-1/4- to 2-cu-yd buckets have been found adequate. Their use will allow utilization of a wide shallow borrow cut with a minimum of disturbance to the material. Also, these size machines have been found adequate for operation on soft ground.

Barge-mounted draglines are used extensively in areas where the groundwater table is at or very near the ground surface. These machines excavate their own waterway ahead and cast material to the side to form the dike. This technique allows the use of very large machines. These machines can excavate and place about 14,000 cu yd of material in a 24-hr period.

Pontoon-mounted draglines that can actually float are also useful on very soft ground or in shallow inundated areas. These machines have wide tracks mounted around pontoons. The disadvantage of these machines is their smaller size. Pontoon-mounted draglines are often used for the construction of toe dikes used in connection with the pumping of hydraulic fill.

c. Dredges. Hydraulic cutterhead dredges are most often used to construct hydraulic fill dikes as they are equipped to pump the dredged material to the disposal site through a pipeline simultaneously with the dredging operation. Other types such as hopper and bucket dredges have the disadvantage of either having to stop dredging and transport the material to the site or load in onto scows for transportation. There are many variations and sizes of hydraulic cutterhead dredges in use today, and the type and size dredge can affect the condition of the pumped material, especially clay. For detailed information on dredges, reference should be made to "Hydraulic Dredging" by Huston (1970).

d. Compaction Equipment. There are three principal types of rollers for earthwork compaction: sheepsfoot, pneumatic, and smooth-drum vibratory rollers. The sheepsfoot roller is for compaction of cohesive materials; the smooth-drum vibratory roller for cohesionless materials; and the pneumatic roller can be used on both types of materials, but is primarily for cohesive materials. EM 1110-2-1911 (OCE 1972) contain detailed descriptions of these rollers including uses, features, advantages, and disadvantages of each.

Construction Control. Thorough inspection of all operations involved in the dike construction is necessary. Exact items to be closely monitored during construction will vary with the design and method of construction. Some items pertinent to all projects are:

(a) Familiarization of field personnel with the plans and specifications for the disposal area.

(b) Interaction between the design engineer and field personnel.

(c) Preparation and distribution of a document entitled "Instructions to Field Personnel."

(d) Familiarization of field personnel with the borrow sources.

(e) Continuous inspection of dike construction by field personnel.

(f) Maintenance of good records.

Dike Construction

Hauled Dikes

Hauled dikes are defined as dikes built by fill hauled in from borrow areas, usually by trucks or scrapers. Hauled dikes can be compacted, semicompacted, or uncompacted, depending on treatment the material receives after deposition by the hauling equipment. However, when hauling procedures are used, most dikes will be compacted or semicompacted.

Compacted Dikes. The main advantage of a compacted dike is that it results in the highest quality embankment occupying the least amount of space. It is also a product in which the designer can have the best assurance of obtaining what has been designed. Disadvantages include a relatively high cost and the fact that it requires a reasonably competent foundation, one item that, due to most prevailing dike foundation conditions, somewhat limits its applicability to dike construction.

Semicompacted Dikes. Semicompacted dikes usually are built on weaker foundations than compacted dikes and can provide a stable dike at a lower unit price than compacted dikes. Normally, semicompacted dikes are built of materials placed at their natural water content. Semicompacted dikes are often specified because of oft-required large sections with flat slopes, which would result in an uneconomical and impracticable design if a fully compacted dike were specified. Disadvantages of semicompacted dikes include the larger section usually required and the uncertainty as to the end product with respect to uniformity of compaction.

Uncompacted Dikes. About the only advantage of an uncompacted hauled dike is the fact that, due to foundation conditions, it may be the only type of dike that can be built. It is also a low-cost construction method. However, with uncompacted dikes, there is considerable uncertainty as to the end product, and estimating required quantities of material with any degree of accuracy is often a hopeless task. Also, there is little or no guarantee that the design elevation will be attained due to uncertainty as to the amount of settlement of the embankment. Uncompacted hauled dikes should only be considered if construction of other types of dikes appears impossible.

Hauling, Spreading, and Blending. Where borrow conditions permit and where space on the fill is sufficient for turning, scrapers are the most economical means of moving fill. Where borrow areas are too wet to allow direct excavation and trafficking, transportation can be by trucks loaded by clamshell, dragline, or other excavating equipment. After dumping, the material is spread to the proper loose lift thickness by a dozer. For compacted fills, the material should be thoroughly worked with a disk (capable of cutting through the entire loose lift) after spreading and prior to compaction. This will help eliminate lumps, aid in a more uniform distribution of moisture, and, in general, ensure a more homogeneous fill material. When moisture control is specified and where the water content of fill material is too high, disking should continue until the water content is reduced to an acceptable level; where the water content is too low, water should be added and the material disked until a uniform distribution of moisture is attained at an acceptable water content.

Compaction (Compacted Fill). Compaction for a fully compacted fill is usually carried out by one of the rollers listed in Table D.9. Sheepsfoot rollers are the most often utilized equipment for compacting impervious and semipervious fill, with rubber-tired rollers being used to a lesser extent. Loose-lift thicknesses for the sheepsfoot and rubber-tired rollers are normally on the order of 8 in. and 10 to 12 in., respectively. Scarification by disking of lift surfaces after compaction to ensure good bonding between lifts is always a good procedure no matter what type of compaction equipment is used, but is a necessity when a rubber-tired roller is used because of the smooth surface left by the roller. A vibratory roller is the best means of compacting pervious fill, although crawler tractors have often been successfully employed for this purpose. Saturation for the pervious fill during compaction will aid in the compaction process but is generally not a necessity unless very high densities are required. Merely sprinkling the material prior to compaction has little if any benefit due to bulking effects that result from the addition of only a minor amount of water.

Compaction (Semicompacted Fill). Compaction for semicompacted fill is usually accomplished through utilization of trafficking of hauling and spreading equipment on the fill, although in some instances a few passes of a light sheepsfoot roller or a dozer is specified as the compaction procedure. When utilizing traffic compaction, it is important that the equipment not be allowed to track (i.e., follow in the same set of tracks) but be made to operate in such a fashion that as much of the fill surface as possible is covered. Tracking not only results in an appreciable portion of the fill obtaining little compaction, but also often results in rutting and pumping of the material in the tracks.

Special Procedures for Soft Foundations. Due to the difficulty of operating equipment on very soft foundations, it may be necessary when building compacted or semicompacted fill to first construct a working platform over the dike base area upon which equipment can operate. This is basically an uncompacted layer 2 to 4 ft thick (only as thick as necessary to support the equipment) formed by dumping material and it shoving it ahead with dozers (Fig D.26) until the platform covers the entire dike alignment or necessary portion. Coarse-grained soils are the best materials of which to construct working platforms, but fine-grained materials dry enough to support equipment have also been successfully employed. If coarse-grained materials are used, some sort of seepage barrier may be required in order to prevent seepage through the platform. Material forming the platform should not be stockpiled on the platform or a shear failure may occur in the foundation. Only small dozers should be used to spread and shove ahead. When required, compaction of the platform should be accomplished by using more passes of lighter equipment (such as rubber-tired hauling or loading equipment) or tracked equipment (such as dozers, end-loaders, etc.). Where the foundation is extremely weak, it may be necessary to place the material by casting it over the area with a small dragline or clamshell. After this base has been established, controlled placement and compaction procedures may commence.

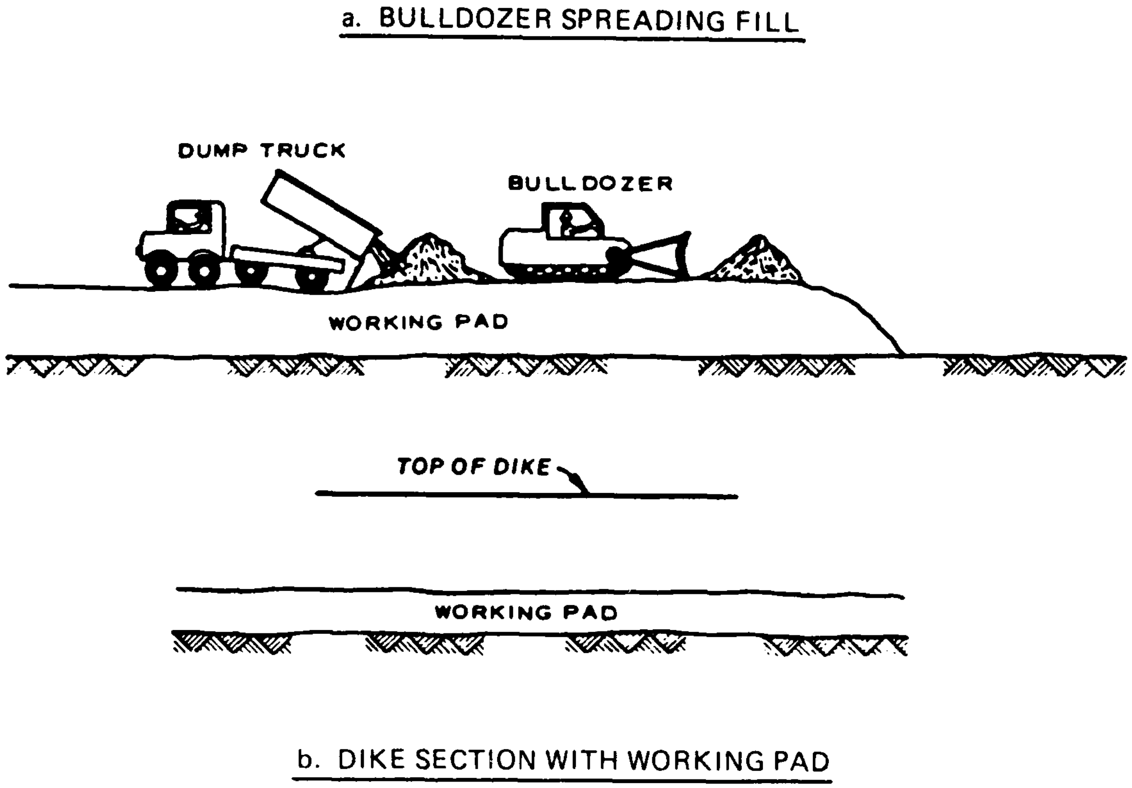


Figure D.26. Construction of working pad

Uncompacted Fill. Placement of uncompacted fill by hauling refers to fill placed by end-dumping and shoving ahead, resulting in a dike section formed by the displacement technique as previously discussed. The fill above original ground does get some compaction from hauling equipment and dozers, but such traffic is usually uncontrolled and results in essentially an uncompacted section. In using this method of construction, the item of greatest concern is ensuring that no soft material is trapped in the fill.

Construction Control. The control of construction operations is an extremely important facet of dike operations. Some of the more pertinent items to be checked during construction of hauled dikes are given in Table D.10. For specific instructions as to how earthwork operations should be controlled during construction, reference should be made to EM 1110-2-1911 (OCE 1972) and "Earth Manual" (BOR 1963).

Table D.10

Operations or Items to Be Checked During Construction of Hauled Dikes

Type Construction	Items or Operation to be Checked
Compacted	Proper fill material Loose lift thickness Disking Water content Type of compaction equipment and number of passes Density
Semicompacted	Proper fill material Loose lift thickness Water content (if required) Number of passes (if required) Routing of hauling and spreading equipment
Uncompacted (displacement technique)	Proper fill material Dumping and shoving techniques Ensuring fill is advanced in V-shape and with slopes as steep as possible Elevation of fill surface Prevention of rutting of fill surface by hauling equipment

Cast Dikes

Dikes built by casting material up with draglines are termed cast dikes. This procedure involves use of a borrow ditch parallel to the dike usually located inside the retention area. A berm is left between the dike and the borrow ditch, the purpose of which is not only for dike stability, but also to avoid future dike increments from being founded on soft dredged material that is deposited in the ditch. This berm also provides a convenient working platform for the dragline.

Cast Dike Construction with Dragline. Casting dikes with draglines has been a very common method of dike construction in the past due to its low cost, but unfortunately it often does not necessarily result in an adequate embankment. This is primarily due to the fact that it results in essentially an uncompacted dike and requires relatively steep slopes because of features inherent to draglines (i.e. limits on casting distances). Cast dikes can be semicompacted if placed in lifts and shaped and compacted by a bulldozer working simultaneously with the dragline. However, this is usually not the case as it is more expensive than casting a dike up to full height as the section advances with no compaction.

Foundation Impacts. Cast dikes on very soft foundations are often difficult to construct due to the relatively steep slopes required that can result in considerable displacement of the soft foundation as well as frequent shear failures. Consequently, dikes constructed by casting on soft foundations sometimes must be limited to a few feet in height and must be built in increments.

Construction Procedures. No special techniques are normally required when handling firm or pervious materials; however, soft silt and clay cannot be handled by normal methods because of the sensitivity and very low remolded strengths these materials exhibit. When these types of materials are handled, it is necessary to keep disturbance to a minimum. During excavation of soft materials, a special effort should be made to load and pick the bucket straight up rather than dragging the bucket through the material. Past practice has shown this procedure to create the least amount of disturbance. During unloading it is desirable to place the material in its desired location and dump it without dropping the material from any appreciable height (i.e., lay it in place). If soft material is dropped from a height greater than about 1 to 2 ft, the material will tend to liquefy and flow thus creating no buildup of fill. These procedures are slower than usual procedures but are often the only means of obtaining a satisfactory section. For purely cast dikes (i.e., no compaction specified) of firm or pervious materials, some compaction can be attained by dropping the bucket on the fill; however, this procedure should not be used on soft materials due to reasons previously discussed.

After the desired height of dike is attained, the dike should be shaped to final lines and grades with a bulldozer. On very soft materials subject to remolding, shaping may have to be done after the dike has cured for awhile and the surface material dried to some extent. As a final measure after shaping, the dike slopes should be trackwalked. This will greatly aid in erosion control until a vegetative cover is established.

Construction Control. Since there is no density or water content control for cast dikes, construction control (other than ensuring that the embankment is being constructed to the proper lines and grades) consists primarily of determining that construction procedures are in compliance with specification requirements and are proper with respect to providing the desired end product. For cast dikes placed in lifts and semicompacted, inspection should consist of ensuring placement of material in the proper lift thickness and proper coverage by the compaction equipment specified. For uncompacted cast dikes, inspection should be carried out to ensure that the dike material is being placed by procedures necessary to obtain the highest quality embankment obtainable. Several of these procedures (i.e. proper bucket control, placement procedures, etc.) have been previously discussed. For any type of construction involving side casting techniques, it is very important to ensure that the proper width of berm between the dike toe and excavation ditch is obtained. The importance of this berm has previously been stressed. It is also very important on jobs where construction procedures are very critical (such as cast dikes on soft foundations) that experienced personnel be assigned to construction control. In doing this, many problems can be avoided and those that do occur can be more easily solved by working closely with the contractors, who may or may not be experienced in the area.

Hydraulic Fill Dikes

The hydraulic fill method of dike construction consists of excavating material with a dredge and pumping the resulting mixture of soil and water through a pipeline to the desired area. The term hydraulic fill as used herein is defined as material obtained in this manner. When dike material is obtained from the area to be dredged, the hydraulic method is usually the most economical means of construction because it combines both excavation and transportation of excavated material in one operation.

Advantages. The hydraulic fill method is an economical means of excavating and transporting large volumes of material over long distances and, as such, offers a practical and economical means of establishing a wide large-volume dike section that is often required for dikes located on soft weak materials or for dikes requiring seepage control. The use of the hydraulic fill method in areas where near-surface materials consist of soft organic clay, peat, and wood can provide a practical and economical means of obtaining higher quality materials that may exist either below near-surface materials or in areas other than adjacent to the dike alignment. The higher quality material obtained in this manner may be either stronger clay occurring at depth that will discharge as clay balls or sandy materials from nearby lakes or waterways. A dike constructed of such hydraulic fill will, in most cases, be more desirable from the standpoint of stability and through seepage than will one built by casting methods using poor near-surface materials.

The use of suitable hydraulically dredged material for initial construction of or raising retaining dikes can result in a more efficient and effective use of a given disposal area, as the entire available disposal area is usable for placement of the dredged material. It may also eliminate the need for performing excavation adjacent to the dike as is normally required in order to construct the dike by casting methods. As previously discussed, such excavations can contribute to the instability of the dike by providing a more ready access for seepage beneath the dike through relatively pervious surface layers of highly organic peaty marsh deposits or through substratum sand layers that may be exposed in the excavation.

Disadvantages. Water is the transporting agent in hydraulic fill and is, therefore, introduced in great volume into the fill material. This, coupled with the fact that dredged material is often of poor engineering quality, can cause initial height of the dike to be limited to a relatively small value, possible long time lapses between the hydraulic filling for the dike and the use of the disposal area, the dike to be wider due to flatter slopes to achieve stability and thereby utilizing both more fill material and real estate, and the dike to be a poor foundation for a future dike enlargement.

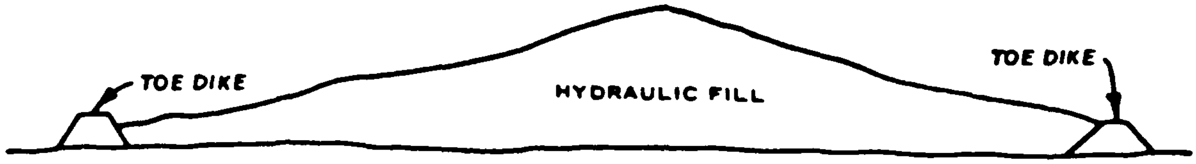
The water used to transport the fill must meet applicable water-quality standards when released to natural waters. In an attempt to satisfy this requirement, the effluent is normally held in the disposal area for some period of time to allow most of the suspended material to settle out before being discharged over weirs. Achieving an effluent suitable for release can be both time consuming and costly. Operational difficulties, such as channelization from the point of discharge to the sluice and insufficient ponding area, have resulted in excessive amounts of solids being discharged. This in turn has caused delays in pumping while the material is allowed to settle out. Also, the discharge sluices invite seepage problems that may lead to ultimate dike failure.

The construction of a retaining dike using directly placed hydraulic fill will often require the construction of small parallel cast retention dikes usually referred to as toe dikes. This procedure requires additional types of equipment and hence may be more expensive.

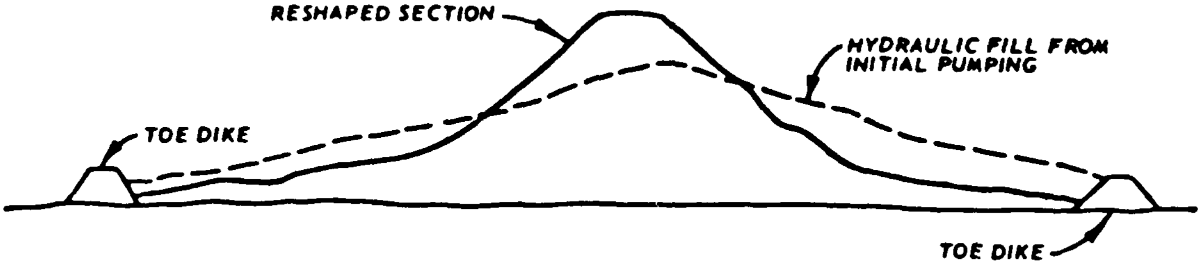
In instances where the in situ foundation material along a proposed dike alignment is of high quality from both a foundation and borrow standpoint, the appropriateness of using a hydraulic fill retaining dike is diminished, particularly if the material to be dredged is of poor quality. In such cases, engineering, economic, and environmental factors may favor cast or hauled fill construction.

Methods of Forming Dike Sections. Hydraulically placed material can be incorporated into retention dikes by several methods: (a) discharging material directly in the location of the desired dike with no shaping; (b) discharging material directly in the location of the desired dike and shaping the material to the desired section either immediately, if coarse-grained material, or at some later date after the material has undergone some drying and strengthening, if fine-grained material; (c) moving material previously deposited by hydraulic means by conventional means and building the dike as a cast or hauled fill; and (d) some combination of the above methods. Schematic diagrams of dikes constructed by these methods are shown in Fig. D.27. The method selected will depend on the long-range plan for the disposal area, the type and engineering properties of both the foundation and hydraulic fill, and economics.

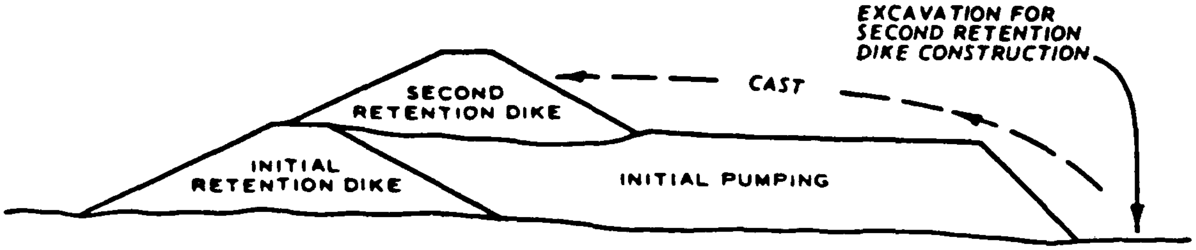
Use of Toe, Transverse, and End Dikes. The construction of retaining dikes with hydraulic fill often requires the construction of toe dikes (as



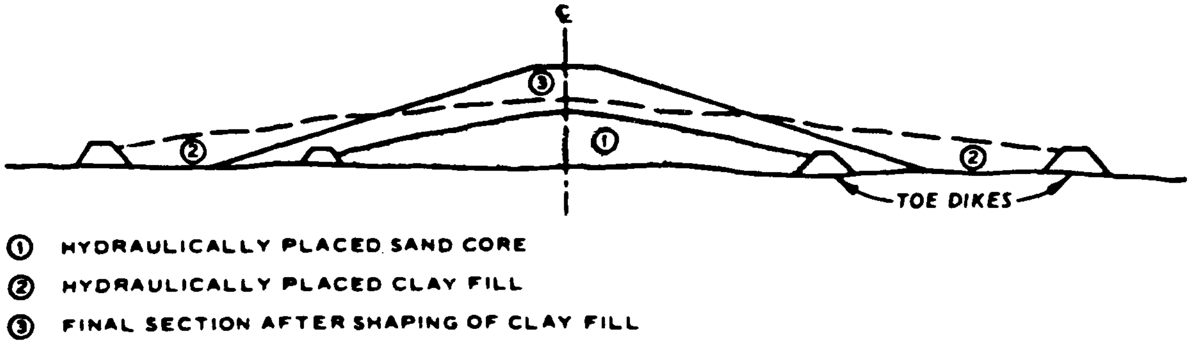
a. DIRECT DISCHARGE



b. DIRECT DISCHARGE AND SHAPING



c. CASTING PREVIOUSLY DEPOSITED HYDRAULIC FILL



d. COMBINATION OF METHODS

Figure D.27. Dikes formed by hydraulic fill methods shown in Fig. D.28) containing sluices parallel to and along the outer edges of the main dike to confine the fill within the desired area and retain the discharge water until it can be released to natural waters as a pollutant-free effluent. Transverse dikes, also shown in Fig. D.28, are usually provided across the main dike alignment to separate the long, relatively narrow fill area into smaller fill areas. This is done to provide sufficient ponding or retention time within each area for optimum soil retention, to control channelization, and to help confine the hydraulic fill to desired slopes and grades. End dikes, also shown in Fig. D.28, are temporary retaining dikes constructed at canals, streams, or other crossings and are sometimes required to retain the fill until closure of the crossing can be made. Such crossings often require changes in construction techniques and/or material.

In some instances it may be feasible to construct the main hydraulic fill dike section without the aid of toe dikes on one or both sides. The feasibility of doing this will depend on the type of material being pumped and

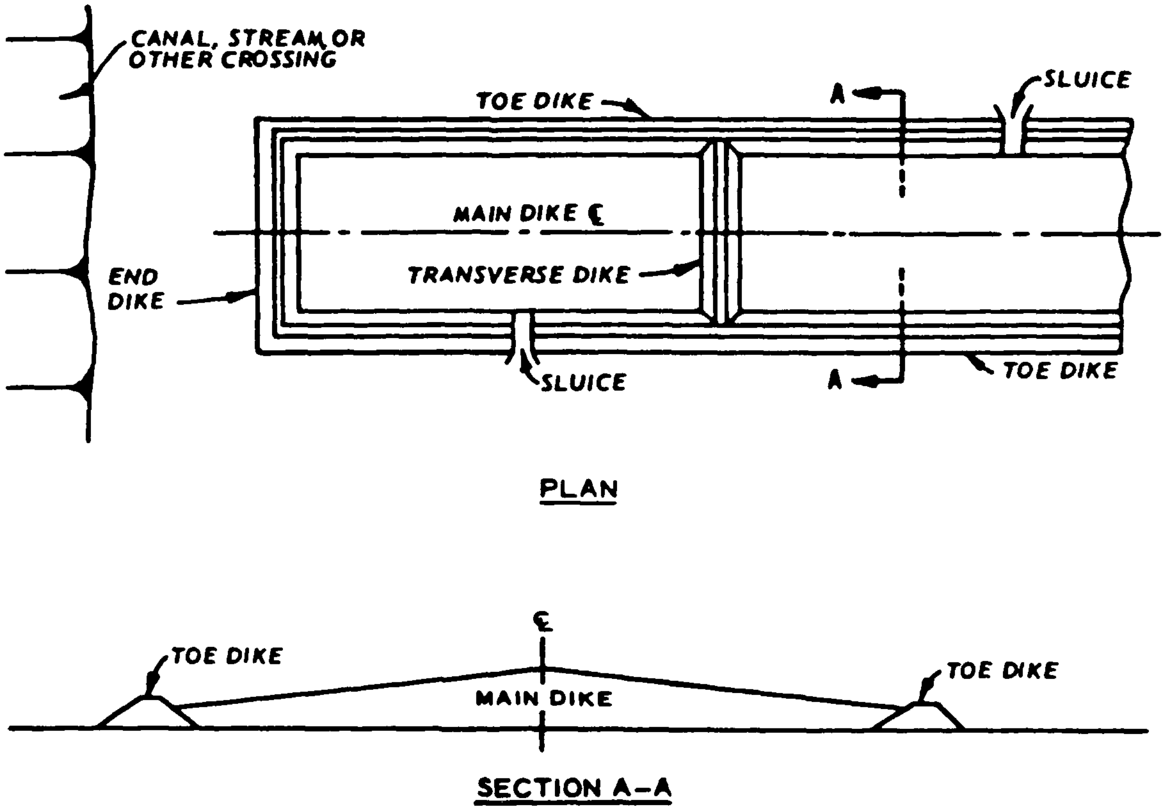


Figure D.28. Toe, transverse, and end dikes its angle of repose, adjacent land use and topography, and the possibility of adverse environmental effects of the unretained effluent on adjacent lands and water bodies.

Deposition of Hydraulic Fill. Hydraulic fill material is placed directly in a retaining dike by the direct discharge method and in some cases by the bleeder pipe method. These methods are discussed briefly in the following two paragraphs. A more detailed discussion can be found in Huston (1970).

Direct Discharge. The direct discharge method is the most commonly used procedure and involves release of the dredged material at the end of the discharge pipe. Frequent moving of the discharge pipe and/or adding lengths to the pipe are necessary when this method is utilized. By strategically locating the discharge pipe, the best materials can be located in the desired section of the dike. This is because the coarser or better materials settle out near the discharge while the finer particles remain in suspension longer and are carried further out.

Bleeder Pipes. A bleeder pipe is a discharge pipe with holes on the underside varying in size from 2 x 2 in. to 6 x 6 in. The discharge line is place along the center line of the proposed dike and is supported on cribbing or piling. During pumping the heavier materials drop out as they come to the holes, but the finer particles that are in solution flow on past and out the line to a ponding or disposal area. This method is used primarily in the placement of sand since clay in the form of clay balls will tend to plug the bleeder holes. This procedure is sometimes used around utility crossings on soft foundations where the fill height must be brought up uniformly on each side of the crossing to prevent shear failure and/or lateral displacement of the utility.

Construction Control. Before initiating dredging, field personnel should:

(a) Understand fully the method of operation to be used by the contractor.
(b) Understand fully the methods of communications to be used between the dredge and discharge area.
(c) Verify that the discharge facilities are constructed in accordance with the plans and specifications.
(d) Verify that foundation preparation is adequate.

(e) Verify that alignments and elevations are properly established.

(f) Verify that toe dikes are constructed as required by the plans and specifications.

After dredging is commenced, field personnel should continuously:

(a) Inspect toe dikes to ensure that they are being properly maintained.

(b) Check toe dikes to see that they are not being overtopped and that design freeboard is being maintained.

(c) Monitor the quality of the dredged material to see that it is as specified and that the dike section is being constructed as designed.

(d) Observe the overall operation to ensure that no potential hazard is being created.

(e) Monitor the quality of the effluent to see that it meets the specification requirements.

(f) Check the discharge facilities (spill boxes) as this is probably the weakest point in the toe dike system. Included also should be the control of effluent on the outside of the toe dikes.

Foundation Preparation

Included in foundation preparation are clearing, grubbing, stripping, and final foundation preparation. A particular dike project may include one or all of the above items, depending on site conditions and method of construction. In the past, many retaining dikes have received no foundation preparation at all. However some degree of foundation preparation is desirable and necessary to help ensure the integrity of the structure. Clearing and grubbing is considered minimum foundation preparation and should be accomplished, where necessary, for all dike projects. In marshy areas where a surface mat of marsh grass and roots exists over underlying soft clay, experience has shown it is often more beneficial from a stability standpoint to leave the surface mat in place than to remove it. However, it should be remembered that such a mat is essentially pervious and may not be beneficial from a seepage standpoint.

Clearing. Clearing consists of the complete removal of all objectional and obstructive matter above the natural ground surface. This includes trees, fallen timber, brush, vegetation, abandoned structures, and similar debris. The dike foundation area should be cleared well ahead of any subsequent construction operations. Clearing should be required for all dikes except as previously noted.

Grubbing. Grubbing consists of the removal of stumps, roots, buried logs, and other objectional matter. All holes and/or depressions caused by grubbing operations should have their sides flattened and should be backfilled in lifts up to the foundation grade with compacted fill. This will avoid soft spots under the dike and maintain continuity of the natural foundation blanket. Grubbing should be required for all compacted dikes and dikes on fairly firm foundations. It is often impractical to grub on very soft foundations.

Stripping. After clearing and grubbing operations have been completed, the dike area is stripped to remove low-growing vegetation and organic topsoil. The depth of stripping is determined by local conditions and usually ranges from 6 to 12 in. Stripping is normally limited to the dike foundation proper and is not necessary beneath stability berms. All stripped material suitable for use as topsoil should be stockpiled for later use on dike slopes. Stripping is not normally required for dikes on soft, wet foundations or for dikes built by methods other than compacted.

Disposal of Debris. Debris from clearing, grubbing, and stripping operations can be disposed of by burning in areas where permitted. Where burning is prohibited, disposal is usually accomplished by burial in suitable areas (such as old sloughs, ditches, and depressions) outside the embankment limits. Debris should never be placed in locations where it may be carried away by streamflow or where it may block drainage of an area. Material buried within the containment area must be such that no debris may escape and damage or block the outlet structure. All buried debris should be covered by a minimum of 3 ft of earth.

Final Foundation Preparation. Final foundation preparation consists of thoroughly breaking up the foundation surface in order to provide a good bond between the embankment and foundation. This treatment is only required for compacted dikes on firm foundations. Scarification of foundation surfaces that are adversely affected by remolding (soft or sensitive foundations for instance) should not be accomplished. Scarification should take place just prior to fill placement in order to avoid saturation by rainfall. No fill should be placed on frozen surfaces.

Construction Control. Since the particular foundation preparation techniques vary considerably with project site conditions, design, and construction method, it is not practical to include a detailed checklist. It should suffice to reiterate the importance of proper foundation preparation on the integrity of the structure. The base of a dike is often its weakest point from the standpoint of shear strength and seepage; therefore, it is imperative that procedures in the plans and specifications be followed as closely as possible. This can only be accomplished by close, continual inspection. If specified foundation preparation procedures seem to be inadequate or for some other reason do not appear to be in the best interests of the project, the designer should be immediately consulted. Changes in specified procedures and requirements should not be made without concurrence of the designer.

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APPENDIX E

SECURE FACILITY DESIGN

APPENDIX E: SECURE FACILITY DESIGN

The application of the Resource Conservation and Recovery Act (RCRA) facility design and siting requirements to the disposal of contaminated dredged material remains the subject of discussion between the CE and other regulatory and resource management facilities. A secure facility for disposal of contaminated dredged material is defined as a disposal facility that meets the technical design and siting requirement of RCRA. Based on information collected to date concerning the mobility of contaminants, the RCRA technical requirement would only be appropriate in cases of dredged material that was highly contaminated or was to be disposed in an area extremely sensitive to risks associated with contaminant mobility. In such cases, the development of alternate disposal sites would probably be much more cost effective than implementing a secure facility. However, since the technical requirements of RCRA are often discussed in conjunction with contaminated dredged material, this Appendix is designed to present a brief discussion of these technical requirements and their potential impact on the disposal of contaminated dredged material.

Site Requirements

The siting requirements for a secure confined disposal facility should be concerned with environmental, climatological, and hydrogeological aspects of a proposed site. These requirements should preclude a site in areas of seismic instability, in a 100-year floodplain, or where the integrity of the liner system would be adversely affected. The development of baseline environmental quality including air, surface water, ground water, and terrestrial ecology data would also be required. Climatological data including precipitation analysis, water budgets, and design storm analysis are important in determining runon and runoff control features. Hydrogeological data to determine the physical and chemical characterization of underlying materials, the condition of affected aquifers - quality, use, flow velocity and direction - are also required. These data would also determine the potential risks posed by the depth to ground water at the site and the degree of naturally available ground-water protection if the liner system should fail.

Design Considerations

Liner Requirements. This section describes the design of an upland confined disposal facility with a double liner system and two leachate detection, collection, and removal systems. Figure E.1 shows a diagram that illustrates the double liner design. Basically the system consists of a primary leachate collection and removal system; a primary synthetic liner; a secondary leachate detection, collection, and removal system; and a secondary liner.

Specific requirements pertaining to secure confined disposal facility liner systems include the following (Cope et al. 1984):

(a) Liner materials must be compatible with the dredged material being disposed and must be able to withstand any unforeseeable physical abuse such as hydrostatic pressure, hydrogeologic forces, adverse climatic changes, and other physical stresses.

(b) Liners must be placed on a stable foundation designed to prevent failure due to settlement, compression, uplifting, or warping likely to be caused by unexpected changes in pressure gradients above, below, or adjacent to the liner material.

(c) All liners must be installed to ensure that the dredged material leachate cannot come into contact with the surrounding soil.

(d) The liner system must be monitored and inspected during construction and installation, and inspected for uniformity, damage, and imperfections following installation.

Soil-based and admixed liners and covers must be inspected for imperfections including lenses, cracks, channels, root holes, or other structural nonuniformities that may cause an increase in the permeability of the liner or cover.

Evaluation of the site's geotechnical and hydrological conditions is critical to developing a well engineered liner system. Table E.1 summarizes the major adverse site conditions that can result in liner failure. Preventive measures must be taken to prevent liner failure under these conditions.

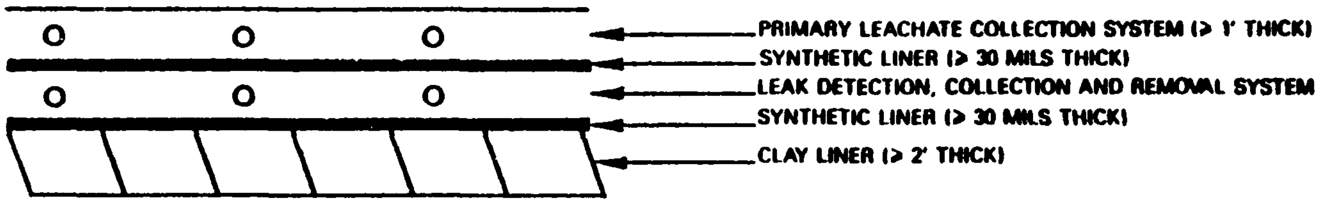

Figure E.1. Schematic diagram of double liner design for secure upland confined disposal facility

Table E.1

Summary of Adverse Site Conditions Affecting Liner Performance*

Unfavorable Condition	Potential Liner Problem
Geotechnical/Hydrogeologic	
Moderate to active seismic area	Dike instability; liner failure
Settlement or subsidence	Cracks in clay or tears in synthetic liners
High groundwater table	Lifting or rupturing of liner
Voids	Cracking of liner
Sinkholes	Liner failure
Subsurface gas	Lifting of liner prior to backfilling
High permeability soils	Piping of subgrade
Climatic	
Frozen ground/ice	Cracking, tearing
Wind	Lifting and tearing liner
Sunlight	Dehydration of clay liner (permitting cracks to develop) Destruction of some synthetic liners (caused by ultraviolet radiation)
High humidity	Poor seam adhesion caused by absorption of moisture by the solvents

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* Source: Cope et al. (1984).

A variety of synthetic and natural materials are available for use as liners. While soil liners are suitable for use as secondary liners, synthetic membranes are the primary mechanisms for long-term containment. Table E.2 summarizes the major characteristics, advantages, and disadvantages of various materials.

A critical first step in designing a liner system for a contaminated sediment containment area is an evaluation of the physical and chemical composition of the dredged material to be contained within the facility. Since the primary purpose of a liner is to prevent liquids from leaving a confined disposal facility, the physical integrity of the liner and its chemical compatibility with the constituents of the dredged material must be ensured. A test method accepted by the USEPA for evaluating waste synthetic liner compatibility is presented in Appendix B of RCRA guidance document Landfill Design-Liner Systems and Final Cover. The method basically involves exposing a liner sample to the dredged material or leachate encountered at the facility and, after exposure, testing the sample for strength and weight loss. Significant deterioration in these properties is considered evidence of incompatibility unless otherwise demonstrated (Cope et al. 1984).

Once a synthetic liner is selected (based on the criteria described earlier), the major focus of the design activities is on preparing a firm and smooth base for the membrane by compacting, scraping, and rolling the base. The major concerns during the installation of a synthetic membrane liner are providing protective soil layers above and below the liner and proper seaming of the liner. This requires that manufacturer's installation procedures and practices be followed for the specific type of membrane proposed. Each type of membrane liner also requires specific seaming provisions to ensure an effective bond, as summarized in Table E-2. Since adverse weather conditions (e.g., extreme heat or cold, precipitation, winds) can affect adequate bonding of the liner field seams, installation should be avoided during these periods, unless protective measures are used (Cope et al. 1984).

During placement of the liner and before dredged material is placed in the disposal area, tests of seam strength and bonding effectiveness should be conducted. In addition, random samples of seams should be cut from the liner

Table E.2

Characteristics, Advantages, and Disadvantages of Selected Synthetic Liners*

Liner Material	Characteristics	Range of Cost	Advantages	Disadvantages
Butyl rubber	Copolymer of isabutylene with small amounts of isoprene	M	Low gas and water vapor permeability; thermal stability only slightly affected by oxygenated solvents and other polar liquids	Highly swollen by carbon solvents and petroleum oils; difficult to seam and repair
Chlornated polyethylene	Produced by chemical reaction between chlorine and high density polyethylene	M	Good tensile strength and elongation strength; resistance to many inorganics	Will swell in presence of aromatic hydrocarbons and oils high elongation poor memory
Chorosulfonated polyethylene	Family of polymers prepared by reacting polyethylene with chlorine and sulfur dioxide	M	Good resistance to ozone, heat, acids, and alkalis; easy to seam	Tensile strength increases on aging; good tensile strength when supported; poor resistance to oil

(Continued)

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* Source: Cope et al. (1984).

NOTES:
1. Adapted from "Technologies and Management Strategies for Hazardous Waste Control," Office of Technology Assessment, Congress of the U.S., 1983. Modified in consultation with industry experts.
2. Cost ranges: L=\$1-4/yd^2. M=\$4-8/yd^2. H=\$8-12/yd/^{2} (installation costs).
3. All ratings are based on property compounded materials designed for that specific applications.

Table E.2 (Continued)

Liner Material	Characteristics	Range of Cost	Advantages	Disadvantages
Epichiarachynn rubbers	Saturated high molecular weight, auphatic polyethers with choromethyl side chains	H	Good tensile and tear strength; thermal stability; low rate of gas and vapor permeability; weathering; resistant to hydrocarbons, solvents, fuels, and oils	Difficult to field seam or repair
Neoprene	Synthetic rubber based on chloroprene	H	Resistant to oils, weathering, ozone and ultraviolet radiation; resistant to puncture, abrasion, and mechanical damage	Difficult to seam or repair
Polyvinyl chloride	Produced in roll form in various widths and thicknesses; polymeniation of vinyl chloride monomer	L	Good resistance to inorganics; good tensile, elongation, puncture and abrasion resistant properties; wide ranges of physical properties; easy to seam	Attacked by many organics, including hydrocarbons, solvents and oils; not recommended for exposure to weathering and ultraviolet light conditions

(Continued)

Table E.2 (Concluded)

Liner Material	Characteristics	Range of Cost	Advantages	Disadvantages
Thermoplastic elastomers	Relatively new class of polymeric materials ranging from highly polar to nonpolar	M	Excellent oil, fuel, and water resistance with high tensile strength and excellent resistance to weathering and ozone	None reported
High Density Polyethylene	Blow or sheet extended P.E.	M to H (based on thickness)	Good resistance to oils and chemicals; resistant to weathering; available in 20 to 150 mil thickness; resistance to high temperature	Thicker sheets require more field seams; subject to puncture at lower thicknesses. Poor tear propagation

and subjected to onsite and laboratory testing. Liner placement, seaming, and testing are covered in detail in the USEPA technical document Lining of Waste Impoundments and Disposal Facilities, SW-870 (Cope et al. 1984). Liner performance, compatibility, and operation and maintenance are discussed in more detail in Part 4 of this report.

Leachate Collection and Removal. The primary leachate collection and removal system is placed immediately above the primary liner. Such systems must be capable of maintaining a leachate depth of 1 ft or less above the liner and withstanding clogging, chemical attack, and forces exerted by clogging, chemical attack, and forces exerted by wastes, equipment, or soil cover.

EPA guidance documents recommend that the leachate collection system consist of a drainage layer at least 1 ft thick, with a hydraulic conductivity $\geq 1 \times 10^{-3}$ cm/sec, and a minimum slope of 2 percent. When installed over a second clay liner with hydraulic conductivity of 1×10^{-7} cm/sec, such a system provides the four-order-of-magnitude difference in permeability know to significantly increase drainage efficiency (Cope et al. 1984). The drainage layer should be covered by a filter (graded sand layer or geotextiles) to prevent infiltration of fines from the dredged material and subsequent clogging of the drainage layer.

Leachate collection pipe networks should consist of slotted or perforated drain pipe bedded and backfilled with a gravel envelop. Layouts should include base liner slopes ≥ 2 percent and pipe grades ≥ 0.005. All pipes should be joined and, where appropriate, bonded (Cope et al. 1984).

Sumps or basins should be installed at low points on the base of the fill to collect leachate discharging from the collection network. A riser pipe extending from the sump to the ground surface enables leachate removal. The lower segment of the riser pipe in the drain rock of the sump is slotted and can be connected to a slotted header pipe in the sump to allow a higher rate of flow to, and withdrawal from, the riser pipe (Cope et al. 1984).

The secondary leachate collection system is located between the two liners and is generally used to detect and remove any liquid that could migrate into the space separating the liners. It is designed similarly to the primary leachate collection and removal system in which liquid is collected in a porous medium and subsequently removed by gravity using a network of perforated pipes.

The operation and maintenance of the leachate collection and removal system can be minimized by avoiding unnecessary leachate generation. This can be accomplished by minimizing the operating life of the disposal facility, which will prevent leachate generation caused by rainfall into an open cell. It may be more efficient to construct several cells in sequence rather than to construct one large cell that would remain open for a long time period. This determination is made by calculating and comparing the marginal costs of extra leachate treatment with the marginal costs of extra liner materials.

Capping Requirements. Modern caps that would be applicable to covering an upland contaminated dredged material disposal site usually conform to the design standards in 40 CFR 264.310, which addresses RCRA landfill closure requirements. These design standards include minimum liquid migration through the dredged material, low cover-maintenance requirements, efficient site drainage, high resistance to damage by settling or subsidence, and a permeability lower than or equal to the underlying liner system or natural soil. The design standards may not always be appropriate particularly in instances where the cap is intended to be temporary, where there is very low precipitation, or when the capped dredged material is not leached by infiltrating rain water.

There are a variety of cap designs and capping materials available. Most cap designs are multilayered to conform with the above-mentioned design standards; however, single-layered designs are also used for special purposes. The selection of capping materials and a cap design is influenced by specific factors such as local availability and costs of cover materials, desired functions of cover materials, the nature of the dredged material being covered, local climate and hydrogeology, and projected future use of the site in question.

The design of multilayered caps generally conforms to EPA's guidance under RCRA, which recommends a three-layered system consisting of an upper vegetative layer, underlain by a drainage layer over a low-permeability layer (USEPA 1982). Figure E.2 illustrates a multilayered cap. The cap functions by diverting infiltrating liquids from the vegetative layer through the drainage layer and away from the underlying dredged material.

The low-permeability layer of the multilayered cap can be composed of natural soil, admixed soil, a synthetic liner, or any combination of these materials. However, a synthetic liner overlying at least 2 ft of low-permeability natural soil or soil admix is recommended because the synthetic liner allows virtually no liquid penetration for a minimum of 20 years, while the soil layer provides assurance of continued protection even if the synthetic liner fails.

Standard design practices specify permeabilities of less than or equal to 10^{-7} cm/sec for the soil liner (Cope et al. 1984). This specification would require a natural soil in the CL/CH range of the Unified Soil Classification System (USCS) (not less than 50 percent by weight passing a No. 200 sieve). However, blending of different onsite soil types can broaden the grain size distribution of a soil and minimizes its infiltration capacity. Well-graded soils are less permeable than those with a small range of grain sizes, and mixing of local coarse- and fine-grained soils is a cost-effective method of creating stronger and less porous cover soil (Lutton, Regan, and Jones, 1979). When sufficient fine-grained soils are not available to achieve the desired permeability, clay material can be brought in. Bentonite, a natural clay with high swelling properties, is often transported to a site and mixed with onsite soil and water to produce the low-permeability layer of the cap. Blending can often be accomplished in place using a blade or harrow to turn and mix the soil to suitable depths (Lutton, Regan, and Jones 1979).

Chemical stabilizers and cements can be added to relatively small amounts of onsite soil to create stronger and less permeable surface sealants. Portland cement or bitumen (emulsified asphalt or tar) is suitable for mixing with sandy soils to stabilize and waterproof them. Site-specific mixing, spreading, and compacting procedures are required. For a soil-cement,

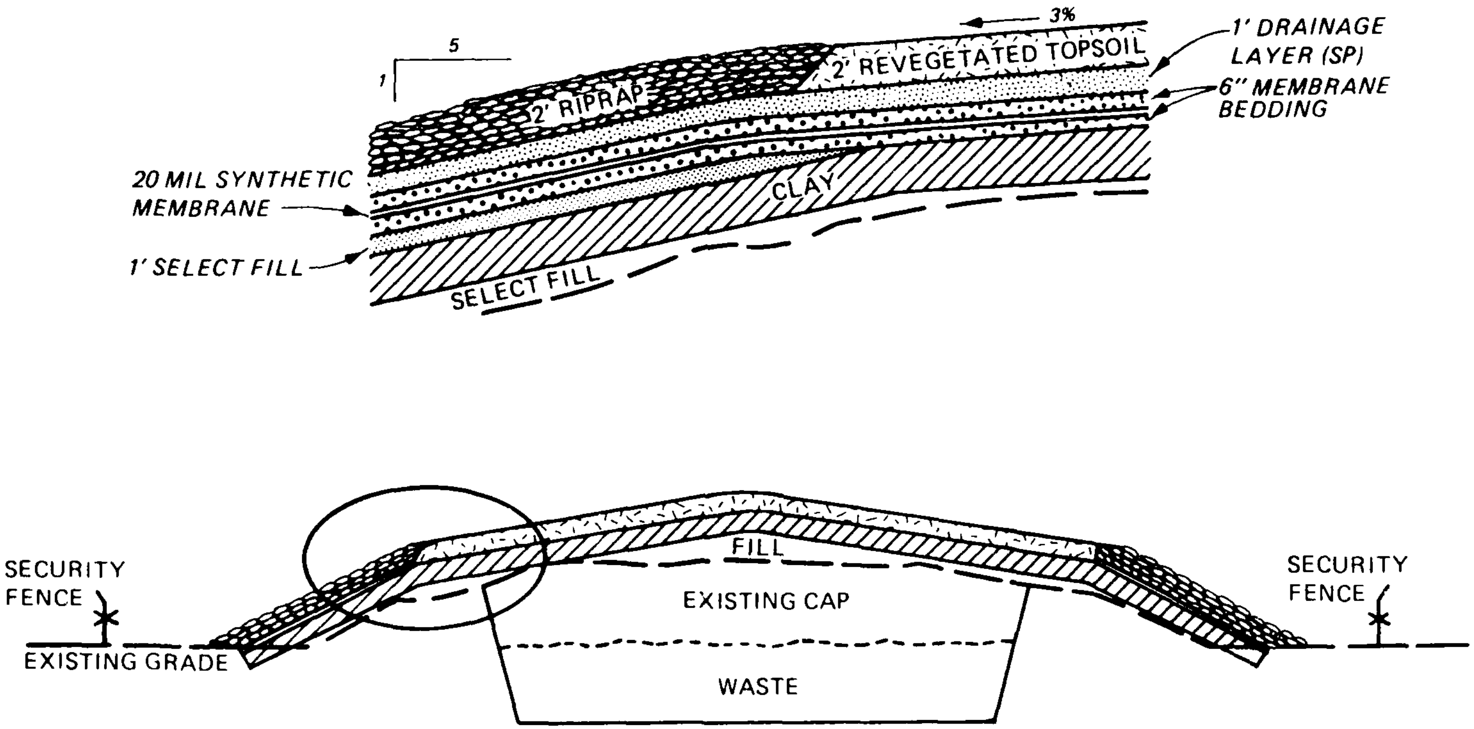

Figure E.2. Multilayered cap

approximately 8 percent (by weight) dry cement is blended into the soil with a rotary hoe or tiller as water is added. Intermittent sprinkling over several days may be required before compaction and solidification are achieved (Lutton, Regan, and Jones 1979).

Soils may also be treated with lime, fly ash, bottom ash, and furnace slag; however, these materials should be tested for hazardous metals and organics prior to use. These materials contribute pozzolanic (cementing) properties to the resulting mixture, optimize the grain-size distribution, and reduce shrink/swell behavior. Lime applied at 2 to 8 percent (by weight) calcium oxide or hydroxide is suitable for cementing clayey soil. Sand and gravel are more suitable for combined lime-fly ash treatment than are finer grained soils (Lutton, Regan, and Jones 1979). Rotary tiller mixing followed by water addition and compaction is the general application sequence for these mixtures. If a synthetic liner is present, liner life may be prolonged by lime addition to supporting soil (Fields and Lindsay 1975). Other soil additives include chemical dispersants and swell reducers. Soluble salts such as sodium chloride, tetrasodium pyrophosphate, and sodium polyphosphate are added primarily to fine-grained soil with clay minerals to deflocculate the soils, increase their density, reduce permeability, and facilitate compaction. Additives are more effective with montmorillonite clay than with kaolinite or illite.

Flexible synthetic membranes are made of polyvinyl chloride (PVC), chlorinated polyethylene (CPE), ethylene propylene rubber, butyl rubber, Hypalon and neoprene (synthetic rubbers), and elasticized polyolefin. Synthetic liners are generally more expensive and require labor-intensive sealing materials that require special field-installation methods. Thin sheets are available in sections of various widths, and the sheets are overlaid and spliced in the field (according to manufacturer's specifications). Special adhesives and sealants are used to ensure liner integrity. The chemical resistance of a cap synthetic liner is not usually critical. However, the potential for organic and/or corrosive vapors should be carefully evaluated before dismissing the resistance factor. The thickness and flexibility of a cap synthetic liner are crucial and should be carefully researched during the material selection process. Cope et al. (1984) and Matrecon, Inc. (1983)

describe several important considerations for selecting synthetic liners. The slope of the low-permeability layer should be between 3 and 5 percent to prevent erosion (if the upper synthetic layer fails) and pooling of rainwater. The underlying base of this layer should consist of fine- to medium-grade fill that will support the weight of the entire cap and not abrade the liner. If a clay or similarly fine-grained soil liner is to be used, the underlying base must be sufficiently fine to preclude piping of the liner. Piping occurs when sections of an overlying fine-grained soil layer erode and fall into an underlying coarse grained soil layer (Matrecon, Inc. 1983). Piping may be prevented by placement of a suitably fine-meshed filter fabric between the two layers.

The drainage layer of the multilayered cap is placed directly above the low-permeability layer. The permeability of the drainage layer should be sufficiently high that it minimizes contact of infiltrating rainwater with the low-permeability layer (Lutton 1982). Current designs generally specify a material with greater than or equal to 10^{-3} cm/sec permeability (Cope et al. 1984). This layer can be composed of a sand in the SW or SP range of USCS (less than 5 percent passing through a No. 100 sieve) or a coarser material. The thickness of the drainage layer depends on the amount of settling expected and the maximum volume of water that could enter it.

The vegetative layer of the multilayer cap is placed above the drainage layer, usually with a layer of filter fabric in between to prevent piping. The vegetative layer usually exceeds 2 ft in thickness, but may be greater depending on the frost depth, the maximum depth of root penetration, and the rate of anticipated soil loss. Frost must not be allowed to reach the low-permeability layer because freezing and thawing cycles could greatly increase its permeability. The selection of a vegetative cover should include consideration of root penetration, erosion potential, and competitive advantage over other plant species in the area. These factors can be determined by consulting with local botany professors. Erosion potential of the soil, however, can occur even when the vegetative cover has good soil-retaining capabilities. Therefore, it is recommended that the soil in the vegetative layer have an erosion rate of less than 2 tons per acre per year using the

U.S. Department of Agriculture Universal Soil Loss Equation (USLE). This equation is written:

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

where: A = average soil loss in tons/acre for time period used for R

quantitative:
R = rainfall and runoff erosivity index
K = soil erodibility factor
L = slope length factor
S = slope steepness factor

qualitative:
C = cover/management factor
P = supporting practices factor

Directions for determining variables are given in Lutton, Regan, and Jones (1979) pp. 127-133. For information regarding soil sampling and testing, for local data on soils and climate, or for any form of technical assistance regarding selection of cover materials, regional and county Soil Conservation Services (SCS) offices should be consulted.

Single-layered caps can be constructed of any of the low-permeability materials mentioned above. However, natural soil and admixes are not recommended because they are disrupted by freeze/thaw cycles and exposure to drying causes them to shrink and crack (Matrecon, Inc. 1983). The most effective single-layer caps are composed of concrete and/or bituminous asphalt. The thickness of these liners is dependent on the amount of anticipated settlement and the local weather conditions. Periodic application of special surface treatments for asphalt and concrete liners can greatly improve their life and effectiveness. It should be noted that single-layered caps will not usually be acceptable unless there are extreme circumstances. For example, an asphalt cap that can be inspected on a frequent basis may be acceptable. Similarly, a temporary cap constructed of clay or natural soil may be used depending on the length of time before a final cap is completed. Another potential opportunity to use a single-layered cap may arise in an area where evapotranspiration greatly exceeds precipitation and/or there is a great distance between the waste and the nearest source of usable groundwater. In these cases it may be acceptable to use an extremely low-permeability soil or admix buried by natural soil beneath the frost-penetration depth. The overlying soil would also protect the cap from drying and cracking.

Construction considerations for single-layered caps vary depending on the cap materials used (e.g., concrete, asphalt, clay); therefore, appropriate construction guidance should be acquired according to the cap material being considered. The EPA document entitled Lining of Waste Impoundment and Disposal Facilities (Matrecon, Inc. 1983) contains references for constructing caps out of several different materials.

The first layer of a multilayered cap is the foundation layer. It should be composed of soil that is structurally capable of supporting the weight of the cap. The tests to be used in evaluating this layer include unconfined compressive strength tests (ASTM D2166), triaxial compression tests (ASTM D2850), and direct shear tests (ASTM D3080) (USEPA 1983). The foundation material should be spread over the dredged material in 6-in. lifts and compacted to its maximum achievable density (ASTM D698 and D1557). The structural stability tests mentioned above should be run on each lift in sufficient number to ensure uniformity. The final shape of this layer should be the same as the final design shape. If the foundation layer is also intended to be the bedding layer for the overlying low-permeability layer, it should meet grain-size specifications contained in Evaluating Cover Systems for Solid and Hazardous Waste (Lutton 1982). Otherwise, an appropriately sized filter fabric should be used between the foundation and low-permeability layers.

The low-permeability layer should be placed in 6-in. lifts and compacted to over 90 percent of its dry density at its optimum water content (Ehrefelder and Bass 1983). Permeability should be measured at the completion of each lift at a rate of at least 2 tests per acre. Compaction can be accomplished with a bulldozer or a sheepsfoot roller. Permeability and density tests will determine the minimum weight of the compaction equipment and the number of passes needed. The selection of materials for the low-permeability layer should consider all of the structural stability tests mentioned above, the

Atterberg Limit tests (ASTM D423, D424, D427, and D2217) (USEPA 1983). These Atterberg Limits should be as wide as possible to prevent future increases in permeability due to drying or wetting of the cap. The thickness of the low permeability zone should be at least 2 ft, but should be increased if excessive settling is expected in the underlying wastes.

A synthetic liner should be placed and seamed according to manufacturers' specifications. This liner should be at least 20 mils thick, and the material and seams should be tested for peel adhesion (ASTM D413, Method 1 and D1876) and shear strength (ASTM D816, Method B, modified and D882, Method A modified) (Cope et al. 1984). Additional tests on the liner should be conducted as recommended by the liner installation company.

The drainage layer should have a permeability of 10^{-3} cm/sec or greater (USEPA 1982). This layer should be placed in 6-in. lifts and should be at least 1 ft thick. A thicker liner should be used if more than a few inches of settling or subsidence is expected in the underlying dredged material. If it is placed directly over the synthetic liner, the drainage layer material must be free of sharp objects that might puncture the liner. Sand classified as SP by the USCS would fulfill the liner bedding requirements.

Filter fabric should be placed above the drainage layer to prevent clogging by soil from the overlying vegetative layer. This material is generally rolled in overlapping strips over the drainage layer in accordance with manufacturers' specifications. The pore size of this layer should be large enough to allow proper drainage, but small enough to prevent soil migration into the drainage layer.

The vegetative layer should be at least 2 ft thick to accommodate expected root penetration, and it should be spread evenly and not overly compacted. The thickness of this layer should be greater than the deepest zone of frost penetration found in the area (USEPA 1982). The vegetation should be a nonwoody plant, preferably grass, with almost no maintenance required once it is established.

The operation and maintenance of a final cap includes inspection on a regular basis for signs of erosion, settlement, or subsidence. It is recommended that inspections be conducted frequently in the first 6 months because problems are most likely to appear during this period (Lutton 1982). Maintenance of the final cap should be limited to periodic mowing of the vegetation layer to prevent invasion by deep-rooted vegetation and burrowing animals. Any sign of unexpected settling or subsidence should be addressed immediately by removing the overburden to inspect and repair the affected areas.

Monitoring

Liners and Groundwater. The liner system must be monitored and inspected during construction and installation, and inspected for uniformity, damage, and imperfections following installation. Soil-based and admixed liners must be inspected for imperfections including lenses, cracks, channels, root holes, or other structural nonuniformities that may cause an increase in the permeability of the liner.

A ground-water monitoring program should also be established. The ground-water monitoring program must be capable of determining the disposal site's impact on the quality of ground water in the uppermost aquifer underlying the facility.

The minimum requirements for any ground-water monitoring system involve at least one upgradient well that is capable of yielding representative background samples and at least three downgradient wells whose location and depth ensure immediate detection of any statistically significant amounts of contaminants or constituents in the upper aquifer. An alternative to dedicating a particular well for background determination would be to monitor the wells before dredged material disposal in the facility. This may present a better indication of background conditions especially in areas where ground water may flow in all directions from a site and location of a background well unaffected by the site is difficult. When using such an approach, the background conditions should be determined over a period of time to determine the seasonal influences on ground-water conditions. Where these minimum requirements do not allow the owner or operator to meet the overall performance objectives, he must determine where and how many additional wells are needed. Once established, ground-water monitoring programs must continue for an average of 30 years depending on site-specific conditions. During this period, ground-water samples are generally taken semiannually and analyzed for indicator parameters, which are developed on a site-specific basis. Concentration of indicator parameters from samples collected at the downgradient wells are individually compared to average background concentrations established from the upgradient well(s) or from predisposal background conditions.

Caps. Any caps will need to be periodically inspected for settlement, ponding of liquids, erosion, and naturally occurring invasion by deep-rooted vegetation. The performance of a properly installed multilayered cap is generally excellent for the first 20 years of service. However, after this time period, the integrity of the synthetic liner becomes uncertain and should be regularly investigated. Unforeseen settling and invasions by burrowing animals and deep-rooted plants also contribute to the need for periodic monitoring and maintenance of the cap in perpetuity.

Costs

Liners. The costs for constructing a liner system including a leachate collection and removal system depends on the size of the facility, the design features of each layer of the liner system, and site-specific engineering factors. However, general material and installation unit costs for various components of a liner installation including liner material and installation, underdrains, excavation, and filters are presented in Tables E.3 and E.4.

Caps. The cost of installing a cap depends on the type and amount of materials selected, the thickness of each layer, and the area of the country. General material and installation costs for caps larger than 4000,000 ft^2 are presented in Table E.3.

Monitoring. The costs for monitoring well construction, sampling, and sample analyses can vary by orders of magnitude because of the number of factors involved. These factors include well depth, diameter, type of drill rig, type of substrate, types of dredged material in the disposal area, number of indicator parameters, level of indicator parameters, number of wells,

Table E.3

1985 Unit Costs Associated With Capping Disposal Sites*

Element	Cost
Cleaning and grubbing	$\$1,100/\text{acre}$
Excavation	$\$1.60/\text{yd}^3$
Earthfill	
berms and levees	$\$2.10/\text{yd}^3$
soil liners	$\$3.10/\text{yd}^3$
Backfill soil import	
drainage sand	$\$10.50/\text{yd}^3$
drainage rock (rounded)	$\$10.50/\text{yd}^3$
Soil placement	$\$1.00/\text{yd}^3$
Vegetation, mulch, and hydroseed	$\$1,100/\text{acre}$
Geotextile fabrics	$\$1.00 - \$3.10/\text{yd}^2$
Bentonite admix (2-9 lb/yd^3)**	$\$0.20 - \$1.10/\text{ft}^2$
Membrane liners	
Nonreinforced	
30 mil PVC	$\$0.25 - \$0.35/\text{ft}^2$
30 mil CPE	$\$0.35 - \$0.45/\text{ft}^2$
30 mil Butyl/EDPM	$\$0.45 - \$0.55/\text{ft}^2$
30 mil Neoprene	$\$0.70 - \$0.80/\text{ft}^2$
100 mil HDPE	$\$1.10 - \$1.60/\text{ft}^2$
Reinforced	
36 mil Hypalon (CSPER)	$\$0.50 - \$0.60/\text{ft}^2$
60 mil Hypalon (CSPER)	$\$0.80 - \$1.00/\text{ft}^2$
36 mil Hypalon	$\$0.50 - \$0.60/\text{ft}^2$
Installation, excluding earthwork	$\$0.60 - \$1.20/\text{ft}^2$

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* Based on costs for a 400,00-ft^2 area presented in Cope et al. (1984) as updated by construction, labor, and material cost indices in Engineering News-Record 1983 and 1985.

** Includes mixing and placing.

PVC = polyvinyl chloride
CPE = chlorinated polyethylene
EDPM = ethylene-propylene-diene-monomer

Table E.4

1985 Unit Costs for Pipe Installation

Item	Assumptions	Unit Cost	Source*
Drain Pipe			
PVC perforated underdrain	10-ft length, S.D.R. 35:		
	4 in.	\$2.16/ft	(2)
	6 in.	\$3.64/ft	(2)
	8 in.	\$4.56/ft	(2)
	10 in.	\$6.80/ft	(2)
	12 in.	\$8.40/ft	(2)
Corrugated steel or aluminum, perforated, asphalt coated	6 in., 18 ga	\$4.63/ft	(1)
	8 in., 16 ga	\$6.20/ft	(1)
	10 in., 16 ga	\$8.00/ft	(1)
Porous wall concrete underdrain, extra strength	6 in.	\$4.14/ft	(1)
	8 in.	\$5.80/ft	(1)
	10 in.	\$8.75/ft	(1)
Vitrified clay, extra heavy-duty strength, premium joints	4 in.	\$4.46/ft	(2)
	5 in.	\$5.35/ft	(2)
	6 in.	\$6.35/ft	(2)
	8 in.	\$8.50/ft	(2)
Filter and Envelope			
Filter fabric	Polypropylene, laid in trench	\$1.14-1.49/yd^2	(2)
Gravel envelope	Crushed bank run, screened 0.75-0.50-in.; in trench	\$9.20-10.55/yd^3	(1)
Backfill			
Dozer backfill, no compaction	Up to 300-ft haul, 900 yd^3/day	\$1.11/yd^3	(1)
Dozer backfill, air tamped	Up to 300-ft haul, 235 yd^3/day	\$5.45/yd^3	(1)
Compacted backfill, vibrating roller	6- to 12-in. lifts, 700 yd^3/day	\$1.54/yd^3	(1)
Compacted backfill, sheepsfoot roller	6- to 12-in. lifts, 650 yd^3/day	\$1.67/yd^3	(1)
Excavation			
Backhoe	3.5 yd^3 bucket	\$1.64/yd^3	(1)
Dragline	0.75 yd^3 bucket	\$3.00/yd^3	(1)
Wheel-mounted bucket loader	5 yd^3 bucket	\$0.84/yd^3	(1)

* Sources: (1) Godfrey (1984a), (2) Godfrey (1984b).

levels of existing ground-water contamination, and area of the country. Therefore, the costs for ground-water monitoring programs cannot be estimated until a ground-water investigation has been conducted and a plan has been developed.

Costs Summary. Cost of upland disposal of contaminated dredged material will vary according to specific site characteristics. Factors include ownership of the site, amount of site preparation necessary, distance from the dredge site (may include transportation method), and the amount of treatment and monitoring required both during and after disposal and capping. For Commencement Bay, weir construction is estimated at about $25,000. Upland sites in Commencement Bay that are in the elevation range of +8 to +12 MLLW may require that all diking materials be trucked to the site. At this elevation, the water table is near the surface and native soil may not be sufficient or suitable for dike materials. Granular fill adequate for diking materials is available from the gravel pits on the bluff north of the Hylebos Waterway. The estimated cost of importing materials and dike construction is $4 per cu yd.

Where existing ground elevation is higher because of previous fills, the existing surface material may be utilized for diking. Use of existing material would reduce the cost of diking to approximately $1 per cu yd. While coarser fill materials are easier to use for diking, finer soils that can be included in diking will reduce leakage of effluent water through the dike. An associated cost, though one not included in our analyses, involves the ultimate use of the land filled. If disposal can be designed to ultimately allow development to occur, at least some of the initial costs of disposal may be recoverable.

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APPENDIX F: DESCRIPTION OF PROPOSED DISPOSAL AREAS

The Dredged Material Alternative Selection Strategy (DMASS) is illustrated through application to the Totem Ocean Trailer Express (TOTE) project. This appendix summarizes site information on the alternative disposal sites evaluated for this project.

Open-water Disposal

Three open-water disposal sites are considered, although other areas in the bay have been used in the past.

1. Puyallup River Delta. This site is located 1/2-mile west of the mouth of the Puyallup River. Until 1972, it was the Department of Natural Resource's (DNR) designated open-water site. The site occupies the Puyallup River delta; surface radius of the former disposal site is 900 ft. Bottom elevation slopes from -28 ft MLLW to approximately -200 ft MLLW.

The site has a history of major slides from the delta into the deep water of Commencement Bay on about a 10-year frequency. Disposal of fine-grained sediment typical for Commencement Bay would increase the frequency of slides. Capping would be difficult, and slides could reexpose the contaminated material. Because the area is active, impacts on benthic communities would be short lived. However, it is located within the migratory paths of salmonids moving to and from the Puyallup River system; and Indian commercial net fishing occurs. Disposal may have to be scheduled to avoid times when juvenile salmonids are present and special restrictions may be necessary during the fishing season. Because of its location on the delta, a large volume of uncontaminated material is available nearby and could be used to cap contaminated dredged material at very low cost (dredging). It may be possible to place the contaminated sediments at the edge of the slide zone where the continuing accretion could further bury them.

2. Department of Natural Resources (DNR) Site. The site has been the DNR-designated open-water site for Commencement Bay since 1972; however, it is over 3 miles from the anticipated dredging sites. Surface radius of the site is 900 feet; water depths are in excess of 500 ft. Bottom topography is nearly level. The site has been used regularly for dredged material disposal since its designation and is known to be contaminated by a variety of compounds.

The depth would make accurate placement of the contaminated material and cap within the limits of the designated area difficult. Monitoring would be similarly difficult. However, the site has the capacity to receive all acceptable dredged material projected for the future dredging of Commencement Bay. Since the site has been used regularly in the past, contaminant levels at the site are higher than background levels. Therefore, disposal of contaminated material at the DNR site may be expected to have less biological impact than would disposal of contaminated material at an uncontaminated area. Also, the site's depth places it outside the feeding depths of salmonids and many commercial fishes.

3. Hylebos/Browns Point. This site is located midway between the mouth of Hylebos Waterway and Browns Point. Depths range between 100 and 200 ft. The site is a natural horseshoe-shaped depression; closing the fourth side with an underwater dike would provide a storage capacity of over 2.5 million cu yd. The site is within 2 miles of Hylebos, Blair, and Sitcum Waterways.

Relatively little is known of the site, so extensive investigations to characterize the site may be required. Local fishermen indicate that the area is popular for bottom fishing though success is unknown. While the depth is outside the normal feeding range of salmonids, the Puyallup Tribe indicates that the upper water column is seasonally used by drift netters. As the site has not been previously used for disposal, aquatic resources may be undisturbed and possibly significant use of the site would adversely affect these resources. However, past and present use of the water surface for extensive log booming may have affected the benthic community. Capacity of the site is sufficient for many years of disposal, allowing incremental diking. Diking the open end would allow more complete containment of contaminated material. This and the lesser depth (100 to 200 ft) would make capping and monitoring easier than at the existing DNR open-water site.

Upland Disposal

Concerns about upland disposal have been expressed by several entities. The Puyallup Tribe is concerned about the potential disposal of any contaminated material within the boundaries at their reservation. The Tacoma/Pierce County Department of Public Health has questions about the effects that upland disposal of contaminated dredged material may have on ground water and drainage systems and the possible burial of hazardous materials already existing on the site. The Port of Tacoma is concerned about the loss of real estate potential should sites be filled above the normal industrial grade elevation (+20 ft MLLW); and the port's leasers may express concerns about locating on or near contaminated material.

1. Puyallup Mitigation Site. This site is located north of the Puyallup River and east of Lincoln Avenue, approximately 1 mile from Sitcum and Milwaukee Waterways and 2 miles from the middle of Blair Waterway. The site has been previously filled with dredged material, and its current elevation is approximately +18 ft MLLW. Filling to +35 ft MLLW is contemplated; this would provide about 1 million cu yd capacity. Vegetation has reestablished, otherwise the site is vacant. The existing fill could be used to construct containment dikes. Slurry water from this site would be discharged into the Puyallup River.

The site has been proposed as a wetland creation site by the port as mitigation for filling of site No. 5 for the Sea-Land terminal development. The site would be excavated, and the Puyallup River dike would be breached to create freshwater wetlands. Presumable an alternative mitigation site would have to be located.

2. Port of Tacoma Site "D". This site is bounded by the Port of Tacoma Road on the northeast, the Union Pacific Railroad (UPRR) switchyard on the southeast, and Marshall Way on the northwest, within the area commonly known as the "Tacoma Tideflats." The site is a former dredged material disposal area and has been filled to approximately +16 ft MLLW. Filling of the site to +20 ft MLLW would provide capacity of 100,000 cu yd; fill to +35 ft MLLW would provide capacity of an additional 1,450,000 cu yd (total: 1,550,000 cu yd). The site is centrally located and within 1 mile from Hylebos, Blair, and Sitcum Waterways. The discharge path for this site is into the lower end of the Blair Waterway through an existing drainage canal.

The port has no current plans for developing the site and no prospective tenant, suggesting that the site may be available. Because the site has been filled in the recent past, its environmental value is judged to be relatively low.

3. Puyallup River/Railroad Site. This site is located on the south [illegible] of Interstate 5 (I-5), upstream from the I-5/Puyallup River bridge, and [illegible]

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FOR CONTAMINATED DREDGED MATERIAL(U) ARMY ENGINEER
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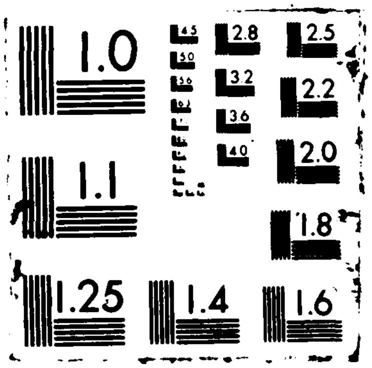
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situated between the UPRR and the Puyallup River. It is approximately 2 miles from the heads of Blair and Hylebos Waterways. Present elevation is approximately +9 ft MLLW. Filling the +80-acre site to +20 ft MLLW would provide capacity of 1.3 million cu yd; filling the site to +35 ft MLLW would provide capacity of an additional 2 million cu yd. One-third of the site has been identified as a wetland pasture; the remainder is under agricultural cultivation. Ownership is by the UPRR, although the former meandering river channel through the site is claimed by the Puyallup Tribe. Water from the site would be discharged into the Puyallup River.

The site has very large capacity, even without filling to +35 ft MLLW. Fill would eliminate approximately 25 acres of freshwater wetlands.

4. Port of Tacoma Site "E". This site is located southeast of the head of Blair Waterway and adjacent to the Tacoma Throughway. It is bounded by Work Road to the south and Franck Road to the east. The site is within 1 mile from Blair and Hylebos Waterways and has been used for dredged material disposal in the recent past. Current elevation of the site is +20 ft MLLW. Capacity for fill to +35 ft MLLW is 1.7 million cu yd. At the present time, the port has no tenant or plans to develop the site. The discharge path for this site would be through the existing drainage channel and creek and into the lower end of the Hylebos Waterway.

Filling the site would raise it above normal industrial level and reduce its land use value. As the site is only sparsely vegetated, its environmental value is judged to be relatively low.

5. Hylebos Creek Sites Nos. 1 and 2. These two sites are located east of 54th Avenue East on the north and south sides of 8th Street. Both sites lie within 1 mile of the head of Blair and Hylebos Waterways. Elevation both sites is approximately + 9 ft MLLW; site No. 1, to the north of 8th Street, is 25 acres and site No. 2, to the south, is 20 acres. Filled to +20 ft MLLW, capacity of site No. 1 is 450,000 cu yd and site No. 2 is 325,000 cu yd for a total capacity of 775,000 cu yd. Filling both sites to +35 feet MLLW would generate an additional 1 million cu yd capacity. The two sites are presently being cultivated for agriculture. The discharge path from these sites would be either into the small creek that runs between the sites and the hill to the west or via a new channel that connects with the existing drainage channel for disposal site "E."

Nearshore Disposal

All six nearshore disposal sites are located along or within Tacoma Harbor waterways.

1. Middle Waterway Site. Middle Waterway is located between City Waterway to the south and St. Paul Waterway to the north. The waterway has shoaled into the intertidal range at its inner end and is quite shallow throughout with an average elevation of -7 ft MLLW, although medium draft tugboats are still able to utilize the outer third of the waterway. The 27-acre site has a total capacity of 650,000 cu yd, of which 390,000 cu yd would be wet below +12 ft MLLW) and 260,000 cu yd would be dry. Users and adjacent landowners include Foss Towing, UPRR, St. Regis Paper Company, Paxport Mills, and others. Foss has indicated a desire to stay or to maintain its moorage at the outer end of the waterway. Paxport Mills, under recent Federal permit action, has placed a small fill along the waterway; mitigation of a resulting wetland loss was a condition of the permit. Ownership of the waterway is with the State of Washington.

Although the waterway is somewhat in decline, it is still a working waterway. Filling would adversely affect those businesses and industries along the waterway that still rely on water transportation for part or all of their operation. The site would be able to accept material dredged by any method.

2. Milwaukee Waterway. Milwaukee Waterway is located between the Puyaliup River to the south and Sitcum Waterway to the north. Wet capacity is estimated at 1,870,000 cu yd; dry capacity is 290,000 cu yd; total is 2,160,000 cu yd. The site has been recently acquired by the Port of Tacoma who has filed a permit application (PN 071-OYB-2-006175) to fill the waterway to accommodate Sea-Land's operations and to develop a container terminal facility. Although the waterway has been used by deep-draft navigation in the past, such use in recent years has been infrequent. The waterway is also the primary disposal site for the Corps of Engineers' proposed navigation improvements project for Blair and Sitcum Waterways. The site is zoned S-10 (Port Industrial) by the city of Tacoma. Contaminated materials are suspected to exist within the waterway.

The port would prefer to develop this site in the near future (2 years) rather than wait for Superfund results or for authorization of the Corps of Engineers' navigation improvements project. Otherwise, limitations are virtually identical to Middle Waterway, although there are currently fewer users of Milwaukee Waterway as a navigation waterway.

3. Blair Waterway Slips. The three slips are located on the south side of Blair Waterway and the outer end. The outer and middle slips are used for deep-draft navigation; the inner slip is presently used for shallow-draft moorage by commercial fishing vessels. The outer slip is owned by the State of Washington and the middle and inner slips are owned by the Port of Tacoma.

Average elevation of the 7-acre outer slip is -30 ft MLLW. The slip lies bayward of Pier No. 1 and would have to be diked along Commencement Bay. Total capacity is 892,000 cu yd, 825,000 cu yd wet and 67,000 cu yd dry.

The 8-acre middle slip lies between Piers No. 1 and 2 and has an average elevation of -30 ft MLLW. Total capacity is 945,000 cu yd, 868,000 cu yd wet and 77,000 cu yd dry.

The inner slip is 12 acres and has an average elevation of 13 ft MLLW. Total capacity for the slip is 600,000 cu yd, 484,000 cu yd wet and 116,000 cu yd dry.

The Port of Tacoma plans to fill these slips in the long term; however, at present they have no immediate need to fill the outer or middle slips. The port would like to fill the inner slip and had an approved Federal permit (issued in 1974, but currently expired) for this action. A condition of the permit required relocating the fishing fleet, and the port was unable to meet this condition. The port has indicated that they would prefer to see any filling completed in a relatively short time frame to maximize the industrial use of the site. The multiple sites provide for large capacity and allow a multiple cell system for effluent treatment. The area is heavily industrial, however, and lengthy filling could disrupt ongoing uses. The outer and middle slips would require dikes approximately 48 ft high. Construction of such structures would probably require staged construction over at least 2 years. Filling of the inner slip would displace the existing fishing fleet.

4. Blair Graving Dock. The site is located on the north side of Blair Waterway approximately 1,000 ft east of Lincoln Avenue. The site was excavated to -5 ft MLLW and used to construct the pontoons for the rebuilt Hood Canal Floating Bridge. The 700-ft by 500-ft rectangular site has a 200-ft-long opening onto Blair Waterway. Total capacity is 200,000 cu yd, 136,000 cu yd wet and 64,000 cu yd dry. The site is owned by the Port of Tacoma and is

currently under lease to the J.A. Jones Company; the lease expires in January 1986, at which time the port has the option of requiring the leasee to refill the site or to leave it as is. Filling of this site would displace the graving dock function from the bay.

5. Hylebos Waterway No. 1. The site is located on the north side of Hylebos Waterway, immediately west of the East 11th Street Bridge, and is bordered to the north by Marine View Drive. Average elevation over the 74-acre area is -10 ft MLLW; however, the site is a combination of subtidal and intertidal habitats containing the last tidal marsh in Commencement Bay. The site was the subject of a previous Federal permit application (PN 071-OYB-1-001200) that was withdrawn in 1978. Total capacity is calculated at 1,274,000 cu yd, of which 550,000 cu yd would be wet and 724,000 cu yd would be dry. The site is owned by the Port of Tacoma and is zoned S-11 (Industrial) by the city of Tacoma.

Strong objections to filling of this wetland are expected from the Puyallup Tribe and environmental agencies and interest groups. Mitigation for the loss would be difficult.

6. Hylebos Waterway No. 2. This site is located in the same approximate area as Hylebos Waterway No. 1 but is east of the bridge and inside the waterway. The site is bordered by Marine View Drive to the north and the Sound Refining Company to the east. Like Hylebos Waterway No. 1, the area is a combination of subtidal and intertidal habitat, sloping northward from the waterway to high ground along Marine View Drive, and is presently being used for log storage. Capacity of the site totals 300,000 cu yd, approximately 70,000 cu yd wet and 230,000 cu yd dry. The site is owned by the Sound Refining Company, which has held meetings in anticipation of filing for necessary permits to fill the site for plant expansion.

Limitations of this site are the same as for the Hylebos Waterway No. 1 site.

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