



## Disposal of Confined Dredged Material

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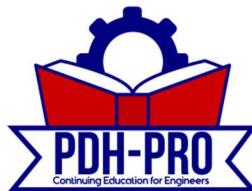
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CECW-EH-D  Engineer Manual 1110-2-5027	Department of the Army U.S. Army Corps of Engineers Washington, DC 20314-1000	EM 1110-2-5027
	Engineering and Design  CONFINED DISPOSAL OF DREDGED MATERIAL	
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US Army Corps  
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EM 1110-2-5027

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# Confined Disposal of Dredged Material

ENGINEER MANUAL

CEEC-EH-D

DEPARTMENT OF THE ARMY  
U. S. Army Corps of Engineers  
Washington, D. C. 20314-1000

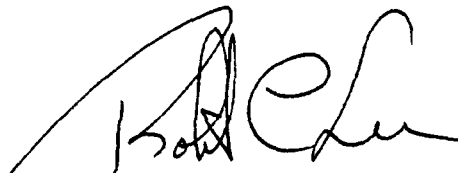
EM 1110-2-5027

Engineer Manual  
No. 1110-2-5027

Engineering and Design  
CONFINED DISPOSAL OF DREDGED MATERIAL

1. Purpose. This manual provides guidance for planning, designing, constructing, operating, and managing dredged disposal areas.
2. Applicability. This manual applies to all HQUSACE/OCE elements and field operating activities (FOA) having civil works responsibilities.
3. General. Subjects covered in this manual are field investigations, laboratory testing, containment area design, long-term capacity and management methods.

FOR THE COMMANDER:

A handwritten signature in black ink, appearing to read 'R. C. Lee', with a large, sweeping initial 'R'.

ROBERT C. LEE  
Colonel, Corps of Engineers  
Chief of Staff

Engineer Manual  
No. 1110-2-5027

Engineering and Design  
CONFINED DISPOSAL OF DREDGED MATERIAL

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## CHAPTER 1

### INTRODUCTION

1-1. Purpose. This manual provides guidance for planning, designing, constructing, operating, and managing confined dredged material disposal areas\* to retain suspended solids during disposal operations and to provide adequate storage volume for both short-term and long-term disposal needs.

1-2. Applicability. This manual applies to all field operating activities concerned with administering Corps dredging programs.

1-3. References. The references listed below provide guidance to personnel concerned with design, construction, operation, and management of dredged material containment areas.

- a. ER 200-2-2
- b. ER 1105-2-10
- c. ER 1105-2-20
- d. ER 1105-2-50
- e. ER 1110-2-1300
- f. EM 1110-1-1802
- g. EM 1110-2-1902
- h. EM 1110-2-1903
- i. EM 1110-2-1906
- j. EM 1110-2-1907
- k. EM 1110-2-1908
- l. EM 1110-2-1911
- m. EM 1110-2-2300
- n. EM 1110-2-5025

o. Hydraulics Design Criteria Sheets 224-1/2 to 224-1/4. Available from Waterways Experiment Station, P.O. Box 631, Vicksburg, MS 39180.

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\* The terms "confined disposal area," "confined disposal site," "diked disposal area," "containment area," and "confined disposal facility" all refer to an engineered structure for containment of dredged material.



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EM 1110-2-5025 is an overview of Corps dredging and dredged material disposal practice. This manual supplements EM 1110-2-5025 by providing detailed guidance for confined dredged material disposal.

1-4. Bibliography. Bibliographic references are indicated as needed in the text and are listed in Appendix A. The US Army Engineer Waterways Experiment Station (WES) reports listed in the Bibliography may be obtained from the Technical Information Center, US Army Engineer Waterways Experiment Station, PO Box 631, Vicksburg, MS 39180-0631. They are available for loan by request from the WES Technical Information Center Library. In addition, copies of the reports are available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

1-5. Background.

a. General. In fulfilling its mission to maintain, improve, and extend waterways and harbors, the US Army Corps of Engineers (CE) is responsible for the dredging and disposal of large volumes of dredged material each year. Dredging is a process by which sediments are removed from the bottom of streams, rivers, lakes, and coastal waters; transported via ship, barge, or pipeline; and discharged to land or water. Annual quantities of dredged material average about 300 million cubic yards\* in maintenance dredging operations and about 100 million cubic yards in new work dredging operations with the total annual cost now exceeding \$500,000,000. Much of this volume is placed in aquatic disposal sites, in wetlands creation or nourishment, or in unconfined disposal areas. Although no breakdown of these figures is routinely maintained, about 30 percent of the total maintenance volume, or 90 million cubic yards, is placed in diked disposal areas annually. This figure includes the majority of the maintenance for major ports along the Atlantic and gulf coasts and numerous harbors on the Great Lakes. The magnitude of confined dredged material disposal requires careful planning, design, construction, and management of containment areas that are compatible with future land-use goals and ensure environmental protection.

b. Scope.

(1) Confined disposal sites are engineered structures designed to provide required storage volume and to meet required effluent solids standards. This manual provides guidelines for designing, operating, and managing dredged material containment areas. These guidelines are applicable to the design of new containment areas as well as the evaluation of existing sites, and they include data collection and sampling requirements, description of testing procedures, and design, operational, and management procedures.

(2) The testing procedures described in this manual include column tests necessary for sedimentation design, chemical clarification for improvement of effluent quality, and consolidation tests for evaluating long-term storage capacity. Design procedures include the consideration of dredged material

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\* The US customary units of measurement are used in lieu of metric (SI) units for those cases common in dredging practice. Metric (SI) units are used in this report when consistent with standard usage.

sedimentation and consolidation/dewatering behavior and potential consolidation of foundation soils. Guidelines for containment area design for sedimentation were developed primarily for fine-grained material generated in maintenance dredging operations. Factors that improve containment area efficiency are presented and include weir design and location, effects of area size and shape, and use of interior spur dikes. Guidelines for containment areas during the dredging operation include weir operation and maintenance of adequate ponding depth. Guidelines for containment area management before, during, and after dredging operations to maximize sedimentation efficiency and long-term storage capacity are also presented. In addition, the manual contains guidance on the design of chemical clarification systems for removal of additional suspended solids that are not effectively eliminated by gravity settling. Guidance is also provided on the design of containment area dikes. Many of the design procedures in this manual have been incorporated into the Automated Dredging and Disposal Alternatives Management System (ADDAMS), a centralized computer-program and data management system (item 19).

(3) Although not specifically covered in this manual, guidelines have been developed for odor control, for mosquito and other insect control, and for minimizing the adverse visual impact of disposal areas and aspects of confined disposal for contaminated sediments. These factors should be considered in the earliest planning and design stages and carried through during construction and management phases. Information on these specialized topic areas is found in the Bibliography (items 9, 12, 17, 18, and 23).

c. Authority. The authority for implementing the planning, design, and operation and management approaches described in this manual is recognized in Section 148 of PL 94-587: Sec. 148:

The Secretary of the Army, acting through the Chief of Engineers, shall utilize and encourage the utilization of such management practices as he determines appropriate to extend the capacity and useful life of dredged material disposal areas such that the need for new dredged material disposal areas is kept to a minimum. Management practices authorized by this section shall include, but not be limited to, the construction of dikes, consolidation and dewatering of dredged material, and construction of drainage and outflow facilities.

Authority to implement management practices under Sec. 148 may be limited in some instances. If the disposal area is Federally owned, management practices can be pursued under Sec. 148. If the site is owned by others or if dikes are provided by others (such as the project sponsor), authority under Sec. 148 may be limited. Also, In some cases, the ownership of dredged material (once removed from the navigation channel) is in question. Current Corps policy on implementation of Sec. 148 should be determined on a case-by-case basis.

#### 1-6. Considerations Associated with Confined Dredged Material Disposal.

a. Diked containment areas are used to retain dredged material solids while allowing the carrier water to be released from the containment area. The two objectives inherent in the design and operation of a containment area are to provide adequate storage capacity to meet dredging requirements and to

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attain the highest possible efficiency in retaining solids during the dredging operation in order to meet effluent suspended solids requirements. These considerations are basically interrelated and depend upon effective design, operation, and management of the containment area.

b. The major components of a dredged material containment area are shown schematically in Figure 1-1. Constructed dikes form a confined surface area, and the dredged channel sediments are normally pumped into this area hydraulically. Both the influent dredged material slurry and effluent water can be characterized by suspended solids concentration, suspended particle size gradation, type of carrier water (fresh or saline), and rate of flow.

c. In some dredging operations, especially in the case of new work dredging, sand, clay balls, and/or gravel may be present. This coarse material (>No. 200 sieve) rapidly falls out of suspension near the dredge inlet pipe, forming a mound. The fine-grained material (<No. 200 sieve) continues to flow through the containment area with most of the solids settling out of suspension, thereby occupying a given storage volume. The fine-grained dredged material is usually rather homogeneous and is easily characterized.

d. The clarified water is usually discharged from the containment area over a weir. Effluent flow rate is approximately equal to influent flow rate for continuously operating disposal areas. Flow over the weir is controlled by the static head and the weir length provided. To promote effective

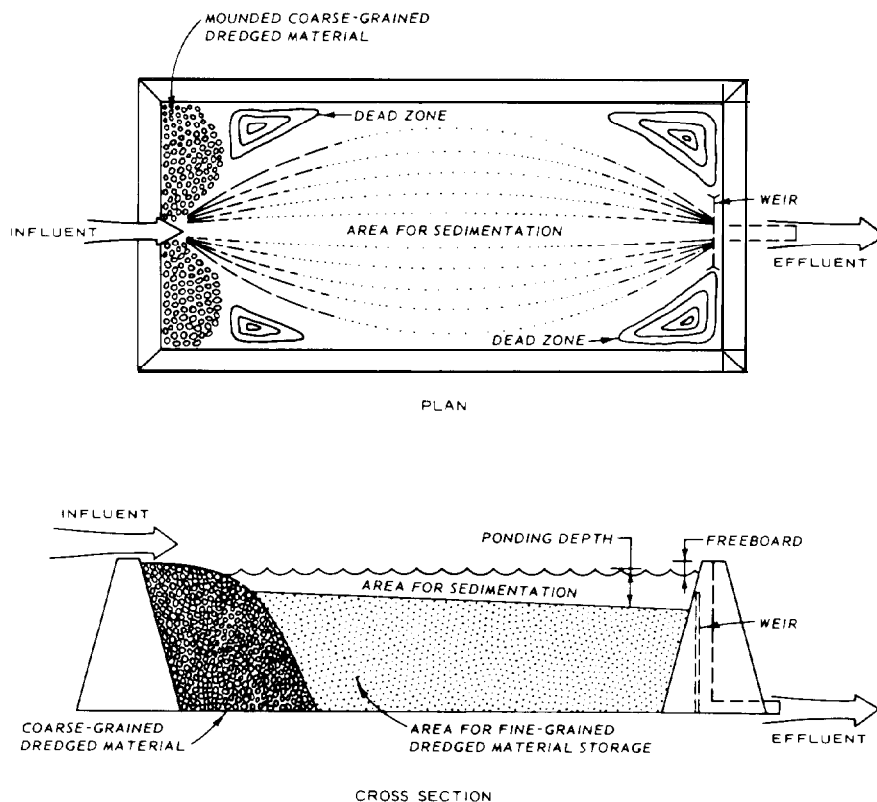


Figure 1-1. Conceptual diagram of a dredged material containment area

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sedimentation, ponded water is maintained in the area with the depth of water controlled by the elevation of the weir crest. The thickness of the dredged layer increases with time until the dredging operation is completed. Minimum freeboard requirements and mounding of coarse-grained material result in a ponded surface area smaller than the total surface area enclosed by the dikes. Dead spots in corners and other hydraulically inactive zones reduce the surface area effectively involved with the flow to considerably less than the total ponded surface area.

e. Effluent standards may be imposed as a requirement for water quality certification. Standards in terms of suspended solids or turbidity may be used. Procedures in this manual allow containment areas to be designed to meet such effluent standards.

f. In most cases, confined disposal areas must be used over a period of many years, storing material dredged periodically over the design life. Long-term storage capacity of these areas is therefore a major factor in design and management. Consolidation of the layers continues for long periods following disposal, causing a decrease in the volume occupied by the layers and a corresponding increase in storage capacity for future disposal. Once water is decanted from the area following active disposal, natural drying forces begin to dewater the dredged material, adding additional storage capacity. The gains in storage capacity are therefore influenced by consolidation and drying processes and the techniques used to manage the site both during and following active disposal operations.

## CHAPTER 2

## FIELD INVESTIGATIONS

2-1. General. Field investigations are necessary to provide data for containment area design. The channel must be surveyed to determine the volume of material to be dredged, and channel sediments must be sampled to obtain material for laboratory tests. Site investigations must be conducted to provide information for dike design and evaluation of potential foundation settlement, an important parameter in long-term storage capacity estimates. This chapter of the manual describes field investigations required to obtain the necessary samples for laboratory testing. The methods in common use for determining volumes of channel sediment to be dredged are well known and are not described in this manual. Basic considerations regarding sampling and volume determination are described in EM 1110-2-5025. The potential for the presence of contaminants should be evaluated when planning field investigations, and appropriate safety measures should be considered.

2-2. Channel Sediment Investigations.

a. Sample Type and Location.

(1) Samples of the channel sediments to be dredged are required for adequate characterization of the material and for use in laboratory testing. The level of effort required for channel sediment sampling is highly project-dependent. In the case of routine maintenance work, data from prior samplings and experience with similar material may be available, and the scope of field investigations may be reduced. For unusual maintenance projects or new work projects, more extensive field investigations will be required.

(2) For maintenance work, channel investigations may be based on grab samples of sediment. Since bottom sediments are in an essentially unconsolidated state, grab samples are satisfactory for sediment characterization purposes and are easy and inexpensive to obtain. Grab sampling may indicate relatively homogeneous sediment composition, segregated pockets of coarse- and fine-grained sediment, and/or mixtures. If segregated pockets are present, samples should be taken at a sufficient number of locations in the channel to adequately define spatial variations in the sediment character. In any case, results of grab sampling must allow estimation of the relative proportions of coarse- and fine-grained sediments present. Caution should be exercised in interpreting conditions indicated by grab samples since sediment surface samples do not indicate variation in sediment character with depth. For more detailed information, additional samples may be taken using conventional boring techniques.

(3) Water samples should be taken at several locations near the sediment-water interface in the area to be dredged. Subsequent salinity tests on these samples indicate whether the dredging will be done in a freshwater or saltwater environment. Potential changes in salinity because of tides or seasonal flooding should also be considered.

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(4) Samples of sediment taken by conventional boring techniques are normally required only in the case of new work dredging. Based on information gained from initial grab sampling, locations for borings should be selected. Samples should be taken from within the major zones of spatial variation in sediment type or along the proposed channel center line at constant spacing to define stratification within the material to be dredged and to obtain representative samples. Borings should be advanced to the full depth of anticipated dredging if possible. This is normally done on a routine basis for new work projects to indicate the type of material to be dredged and the degree of dredging difficulty, since this information is required for the dredging contractor to use as a basis for bidding on the project. Test pits using a clamshell dredge can also prove useful for accessing dredgability and can be used to obtain larger sample quantities.

(5) Vibracore samplers have also proved successful in obtaining core samples of sediments. The Vibracore sampler is not a standardized piece of equipment, but it usually consists of a core-barrel and a vibratory driving mechanism mounted on a four-legged tower guide and platform. The entire assembly is lowered to the sediment surface below the water by a crane/cable hoist system. After the device has been accurately positioned on the bottom, compressed air is supplied to the vibratory unit through flexible hoses extending from the floating plant down to the Vibracore. Upon application of the compressed air, the oscillating hammer (vibrator) propels the core-barrel into the subbottom materials. The Vibracore can be equipped with a penetration recording device that will provide a record of the penetration depth and time. After the core-barrel has been extended to its full length, the sampler is retracted from the sediment and returned to the floating plant deck. The removable plastic core-barrel containing the sample is then removed from the sampling device, and the ends are capped for sample preservation. Typically 3-inch-diameter cores of up to 20 feet in length are obtained; some devices may be modified to take samples of 30- or 40-foot lengths. This device is generally used to sample sands. It has also been used to sample some fine-grained materials.

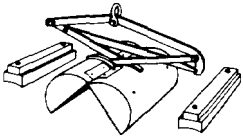
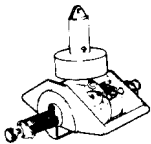
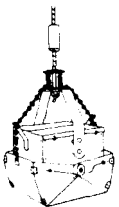


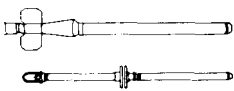
(6) Pertinent information regarding sediment samplers is summarized in Table 2-1. Grab samplers as described in Table 2-1 will allow retrieval of sufficient sediment to perform characterization tests and sedimentation and consolidation tests, if required.

b. Sample Quantity.

(1) The quantity of sediment samples to be collected should be determined by the designer, based on the requirements for the laboratory tests to be performed. A quantity of sediment sufficient to perform the necessary characterization tests and to provide some material for the composite sample for the column settling tests described in Chapter 3 should be collected from each established sampling point. If at all possible, the sampling efforts should be coordinated with other requirements for determining the presence of contaminants or for contaminant-related testing. In this case, appropriate procedures for sample collection, handling, and preservation should be followed. For grab samples, it is recommended that at least 5 gallons of sediment be collected at each sampling station. Five-gallon containers are generally recommended for collecting all grab samples; since most sampling

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Table 2-1  
Summary of Sediment Sampling Equipment

Sampler		Weight	Remarks
Peterson		39-93 lb	Samples 144-in. <sup>2</sup> area to a depth of up to 12 in., depending on sediment texture
Shipek		150 lb	Samples 64-in. <sup>2</sup> area to a depth of approximately 4 in.
Ekman		9 lb	Suitable only for very soft sediments
Ponar		45-60 lb	Samples 81-in. <sup>2</sup> area to a depth of less than 12 in. Ineffective in hard clay
Drag bucket		Varies	Skims an irregular slice sediment surface. Available in assorted sizes and shapes
Phlegar tube		Variable 17-77 lb; fixed in excess of 90 lb	Shallow core samples may be obtained by self-weight penetration and/or pushing from boat. Depth of penetration dependent on weight and sediment texture
Conventional soil samplers			Conventional soil samplers may be employed using barge- or boat-mounted drilling equipment. Core samples attainable to full depth of dredging

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will be performed from small motorboats, containers of this size are about the largest that can be handled efficiently. For core samples, a corncoring scheme must be developed, depending on the number of cores taken, size of cores, and nature of the material.

(2) A smaller sample of sediment should be collected from each fine-grained grab sample and placed in a small (about g-ounce) watertight jar for water content and specific gravity tests. Care should be taken to collect small sediment samples that are representative of the sediment sample as a whole. Similar procedures for core samples are standard soil sampling practice.

(3) After the characterization tests have been performed on samples from each sampling point, samples can be combined to meet requirements for the settling tests described in Chapter 3. Approximately 15 gallons of channel sediment is required to perform the column settling tests.

c. Sample Preservation.

(1) The laboratory tests described in this manual do not require sophisticated sample preservation measures. There are two requirements:

(a) Collect the samples in airtight and watertight containers.

(b) Place the samples in a cold room (6° to 8° C) within 24 hours after sampling until the organic content can be determined. If the organic content is above 10 percent, the samples should remain in the cold room until testing is complete; otherwise, the samples need not be stored in the cold room. The in situ water content of the small samples must be maintained. These samples should not be allowed to drain, nor should additional water be added when they are placed into the containers.

(2) All sample containers should be clearly identified with labels, and the sample crew should keep a field log of the sampling activity. Laboratory testing should be accomplished on the samples as soon as practicable after sampling.

2-3. Containment Area Investigations.

a. Field investigations must be performed at the containment area to define foundation conditions and to obtain samples for laboratory testing if estimates of long-term storage capacity are required. The extent of required field investigations is dependent upon project size and upon foundation conditions at the site. It is particularly important to define foundation conditions (including depth, thickness, extent, and composition of foundation strata) ground-water conditions, and other factors that may influence construction and operation of the site. For new containment areas, the field investigations required for estimating long-term storage capacity should be planned and accomplished along with those required for the engineering design of the retaining dikes as described in Chapter 6.

b. For existing containment areas, the foundation conditions may have been defined by previous subsurface investigations made in connection with



dike construction. However, previous investigations may not have included sampling of compressible soils for consolidation tests; in most cases, suitable samples of any previously placed dredged material would not be available. Field investigations must therefore be tailored to provide those items of information not already available.

c. Undisturbed samples of the compressible foundation soils can be obtained using conventional soil sampling techniques and equipment. If dredged material has previously been placed within the containment area, undisturbed samples must be obtained from borings taken within the containment area but not through existing dikes. The major problem in sampling existing containment areas is that the surface crust will not normally support conventional drilling equipment, and personnel sampling in these areas must use caution. Below the surface crust, fine-grained dredged material is usually soft, and equipment will sink rapidly if it breaks through the firmer surface. Lightweight drilling equipment, supported by mats, will normally be required if crust thickness is not well developed. In some cases, sampling may be accomplished manually if sufficient dried surface crust has formed to support crew and equipment. More detailed information regarding equipment use in containment areas may be found in Appendix I.

d. Water table conditions within the containment area must be determined in order to estimate loadings caused by placement of dredged material. This information must be obtained by means of piezometers, which may also be used for measurement of ground-water conditions during the service life of the area. Other desired instrumentation such as settlement plates may also be installed within the containment area for monitoring various parameters.

e. Additional information regarding conventional sampling techniques and equipment and development of field exploration programs is given in EM 1110-2-1907 and in Chapter 6 of this manual. Procedures for installation of piezometers and other related instrumentation are given in EM 1110-2-1908.

#### 2-4. Site Selection for Avoidance of Ground-Water Impacts.

a. As water percolates through in-place dredged material, leachate may be produced. This leachate water may be the result of precipitation or entrained water resulting from the dredging operation. Available data for the characterization of leachate produced from dredged material are very limited. Potential adverse water quality impacts will most likely be caused by the increases of chloride, potassium, sodium, calcium, total organic carbon, alkalinity, iron, and manganese. These factors should be considered even for dredged material that is considered uncontaminated. This is especially true if a saltwater dredged material may be placed over a freshwater aquifer.

b. Site location is an important, if not the most important, consideration in minimizing any adverse impact to underlying ground water. Selection of a technically sound site may reduce or eliminate the need for any restrictions or controls. Site characteristics affecting ground-water impacts are presented in Table 2-2. Site characteristics that are particularly important in the evaluation of ground-water impacts at potential upland disposal sites are discussed in the following paragraphs:

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Table 2-2

Site Characteristics Affecting Ground-water Impacts


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

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(1) 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, ground-water flow patterns, and climate.

(2) Topography. Topographic variables are important in evaluating surface drainage and run-on and runoff potential of the site. This information would be helpful in determining the amount of water that may be available to percolate through the in-place dredged material.

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

(4) Ground-water levels (equipotential surfaces). Seasonal maps of water table contours and piezometric surfaces, developed by analysis of ground-water monitoring well data, are important in predicting ground-water flow directions and hydraulic gradients, as these can vary greatly at upland or nearshore sites.

(5) Ground-water flow. Information on permeability and porosity of subsurface strata, combined with data on hydraulic gradients, is important in predicting ground-water flow velocities and direction.

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(6) Meteorology and climate. 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.

(7) Soil properties. An important variable in evaluating mobility of many metal contaminants is pH. 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 adverse ground-water impacts may result. 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. Soil type (e.g., clay, till, sand, fractured bedrock) is a major variable affecting rates and routes of ground-water migration.

(8) Potential ground-water receptors and sensitive ecological environments. Ground-water and surface water usage, especially downgradient of the site, is important in evaluating adverse impacts. Size of population and nature of ecological resources downgradient of the site are also important variables in determining adverse impacts.

c. Examples where site location alone can be used to reduce or eliminate adverse impacts to ground water include:

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

(2) Selection of sites to avoid aquifer recharge areas that can minimize potential ground-water contamination concerns. Another consideration associated with site location is that some fine-textured dredged material tends to form its own liner as particles settle with percolation drainage water; however, it may require considerable time for self-sealing to develop. For this reason, if an artificial liner is considered useful, a temporary liner subject to gradual deterioration with time may be adequate in many cases.

## CHAPTER 3

## LABORATORY TESTING

3-1. General.

a. Laboratory tests as described are required primarily to provide data for sediment characterization, containment area design, and long-term storage capacity estimates. The laboratory tests and procedures described in this chapter include standard tests that generally follow procedures found in Standard Methods (item 2) and EM 1110-2-1906. A flowchart illustrating the complete laboratory testing program for sediment samples is shown in Figure 3-1. Sediment characteristics and requirements for settling data and for long-term storage capacity estimates will dictate which laboratory tests are required.

b. The required magnitude of the laboratory testing program is highly project dependent. Fewer tests are usually required when dealing with a relatively homogeneous material and/or when data are available from previous tests and experience. This is frequently the case in maintenance work. For unusual maintenance projects where considerable variation in sediment properties is apparent from samples or for new work projects, more extensive laboratory testing programs are required. Laboratory tests should always be performed on representative samples selected using sound engineering judgment. The potential presence of contaminants should be evaluated when planning a laboratory testing program, and appropriate safety measures should be considered.

c. In some cases, recurring maintenance dredging is performed on given channel reaches. Laboratory test data from previous sampling efforts may be available. Under such conditions, sediment characterization tests may be the only laboratory testing required. Additional settling tests or consolidation tests are not required if it has been satisfactorily determined by prior testing that the settling and consolidation properties of the sediment to be dredged have not changed.

3-2. Sediment Characterization Tests.

a. General. A number of sediment characterization tests are required before the tests essential to design can be performed. Visual classification will establish whether the sediment sample is predominantly fine-grained (more than half <No. 200 sieve) or coarse-grained (more than half >No. 200 sieve). Tests required on fine-grained sediments include natural water content, Atterberg limits (LL), organic content, and specific gravity. The coarse-grained sediments require only grain size analyses. Results of these tests can be used to classify the sediments according to the Unified Soil Classification System (USCS) (item 33).

b. Salinity. Near-bottom water samples from the area where water will be mixed with sediment during the dredging or pump-out operation (usually dredging site water) should be tested for salinity. In estuarine environments, the salinity may vary with depth, flow, wind, tidal cycle, and season. Therefore, it is important to know the expected range of salinity during the dredging project. If the dredging site water is saline (>1 part per

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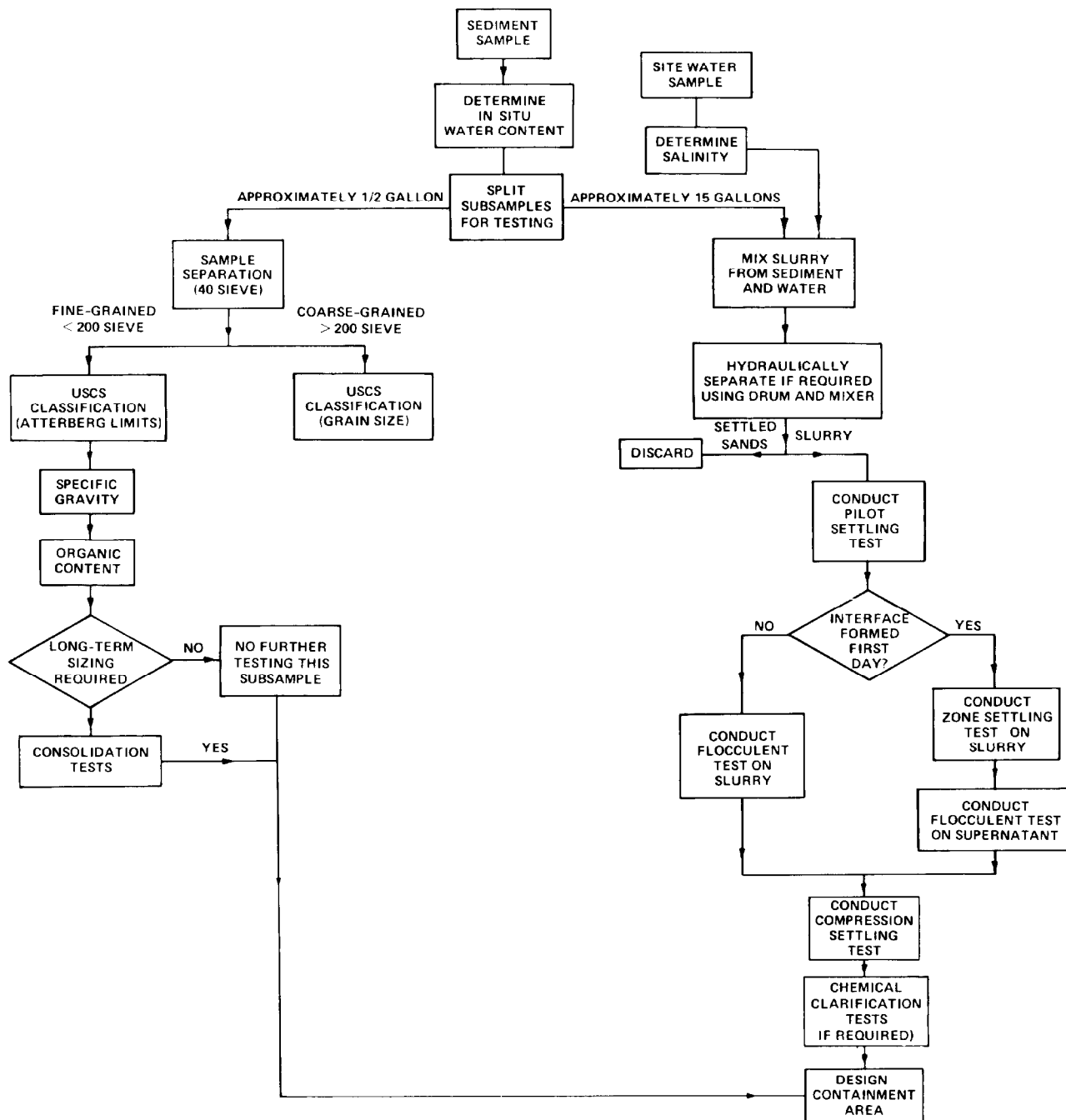


Figure 3-1. Flowchart depicting laboratory testing program for sediment samples

thousand), water gathered during the field investigation or reconstituted salt water should be used when additional water is required in all subsequent characterization tests and in the settling tests. Salinity may be measured in two ways:

(1) Conductivity. The salinity may be measured directly by a salinity-conductivity meter that electronically converts temperature-adjusted electrical conductivity into salinity.

(2) Dissolved solids or nonfiltrable residue. A detailed procedure is presented in Standard Methods for the Examination of Water and Wastewater (item 2). Briefly,

(a) Filter water through a filter that has a pore size of 1 micron or less.

(b) Pipette a known volume (about 25 millilitres) into a weighed dish and evaporate the sample 4 to 6 hours in a drying oven at 103° to 105° C.

(c) Cool the dish in a desiccator and then weigh immediately.

(d) Salinity (in parts per thousand) is equal to the residue (in milligrams) divided by the sample (in millilitres).

c. Water Content. Water content\* is an important factor used in sizing dredged material containment areas. Water content determinations should be made on representative samples from borings or grab samples of fine-grained sediment obtained in the field investigation phase. The water content of the sample should be determined prior to sample homogenization and separation as described below. The detailed test procedure for determining the water content is found in Appendix I of EM 1110-2-1906. The water content is expressed on a dry weight basis as follows:

$$w = \frac{W_w}{W_s} \times 100 \text{ percent} \quad (3-1)$$

where\*\*

w = water content, percent\*

$W_w$  = weight of water in sample, grams

$W_s$  = weight of solids in sample, grams

d. Solids Concentration.

(1) General. The suspended solids concentration is the most frequently measured parameter in the laboratory procedures. This measurement is made during preparation of slurries and suspensions and during evaluation of settling characteristics, treatment effectiveness, etc. Three methods may be

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\* It should be noted that the term "water content" as used in this manual refers to the engineering water content commonly used in geotechnical engineering and may exceed 100 percent.

\*\* For convenience, symbols and unusual abbreviations are listed and defined as appropriate throughout the text.

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used to measure suspended solids: evaporation, filtration, and centrifugation. Each is applicable under different circumstances. Evaporation (direct drying) measures total solids, i.e., the sum of both suspended and dissolved solids. The dissolved solids concentration, if significant, must be measured separately and subtracted from the total solids concentration. Filtration directly measures suspended solids. Centrifugation is a blend of the other two methods. It attempts to measure suspended solids by measuring the total solids after washing the dissolved solids out of a known volume of sample. The procedures outlined below are adapted from the methods given in Palermo, Montgomery, and Poindexter (item 26). In practice, there has been confusion concerning the method of reporting suspended solids. The terms "concentration in grams per litre," "percent solids by weight," "percent solids by volume," and "percent solids by apparent volume" have been used. These methods of reporting suspended solids concentration are discussed and compared in Table 3-1. The relationship of percent suspended solids by weight and volume, concentration in grams per litre, and water content is illustrated in Figure 3-2. Figure 3-2 does not account for salinity in the sample. Suspended solids concentration in grams per litre or milligrams per litre is used throughout this manual. If suspended solids determinations are to be made on samples with a solids concentration of 1 gram per litre or less, the centrifugation or the filtration method should be used. The total solids method or

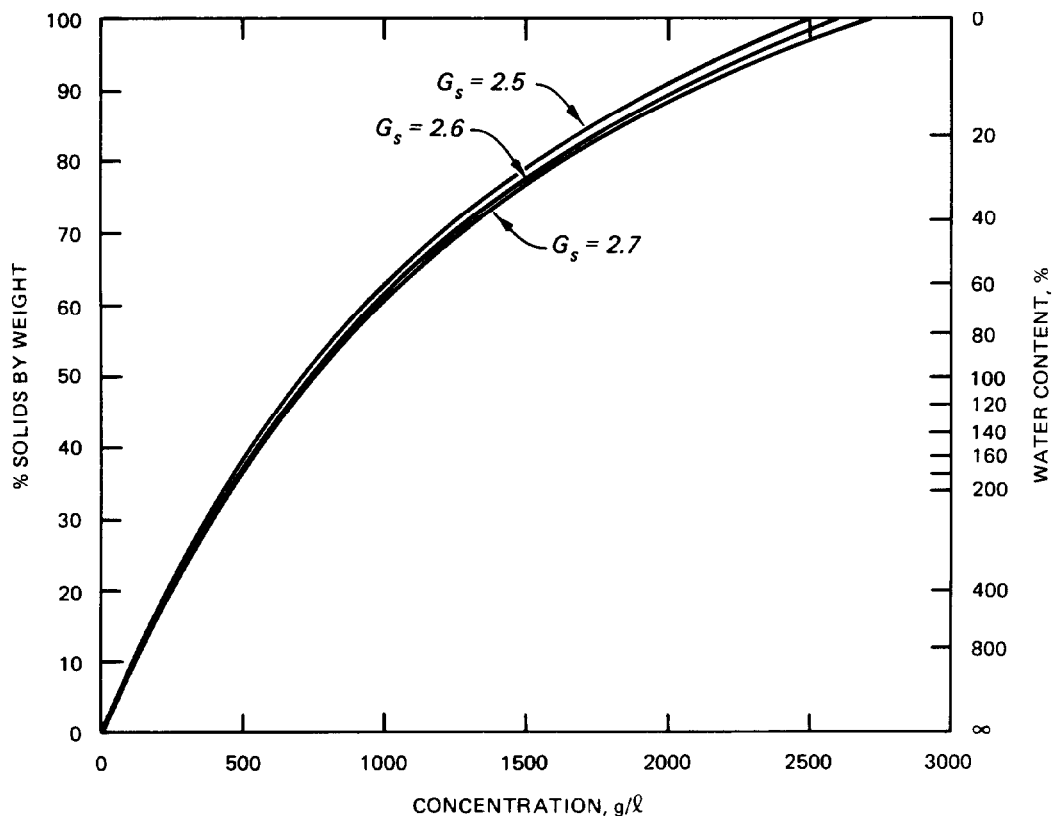
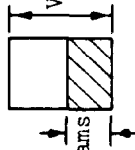
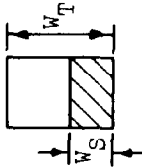
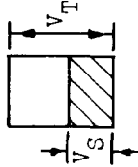
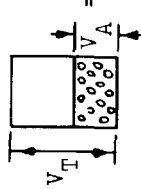


Figure 3-2. Relationship of concentration in percent solids by weight, percent solids by volume, concentration in grams per litre, and water content

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Table 3-1  
Methods of Reporting Suspended Solids

Method of Reporting Suspended Solids	Weight-Volume Relationship	Method of Computation	Remarks
<u>Preferred Method</u>			
grams per litre or milligrams per litre	 $V_T = 1 \text{ litre}$ $W_S, \text{ grams}$	$S = \frac{W_S}{V_T}$	Common method for reporting dissolved chemical concentrations. Best method for engineering purposes
<u>Other Methods</u>			
percent by weight	 $W_T$ $W_S$	$S = \frac{W_S}{W_T} 100$	Easy to determine by laboratory test. Does not require value for specific gravity
percent by volume	 $V_T$ $V_S$	$S = \frac{V_S}{V_T} 100$	Easy to determine by laboratory test. Requires determination of percent by weight and value for specific gravity
percent by apparent volume	 $V_T$ $V_A$ $V_I$ $V_T = V_S + V_I$	$S = \frac{V_A}{V_T} 100$	Apparent volume determined by settled solids for a bottle or flask. No standardized procedure available. Void ratio of settled solids varies with type of sediment. Can lead to errors because of nonstandard test. Not recommended. Value is meaningless in engineering calculations
Note: $W_S$ = oven-dry weight of solid particles $V_T$ = total volume $W_T$ = total weight $V_S$ = volume of solid particles $V_A$ = apparent volume of settled solids $V_I$ = volume of interstitial water			



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the centrifugation method should be used for slurries with solids concentrations of 1 gram per litre or more.

(2) Definitions and conversions.

(a) The percent of total solids by weight is the weight of solids both nonfiltrable and filtrable (both dissolved and suspended) in a sample divided by the weight of the sample.

$$\%S = \frac{W_s}{W_t} (100 \text{ percent}) \quad (3-2)$$

where

$\%S$  = percent total solids by weight, percent

$W_t$  = total weight of sample, grams

(b) The percent of suspended solids by weight is the weight of solids less the weight of dissolved solids in a sample divided by the weight of the sample.

$$\%SS = \frac{W_s - \frac{(W_w \text{ Sal})}{1,000}}{W_t} (100 \text{ percent}) \quad (3-3)$$

where

$\%SS$  = percent suspended solids by weight, percent

Sal = salinity, parts per thousand

(c) Solids concentration is the weight of solids (dissolved and suspended) in a sample divided by the volume of sample.

$$C_s = \frac{W_s}{V_t} \quad (3-4)$$

where

$C_s$  = solids concentration, grams per litre

$V_t$  = sample volume, litre

(d) Suspended solids concentration is the weight of suspended solids in a sample divided by the volume of sample.

$$C = \frac{W_{ss}}{V_t} \quad (3-5)$$

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where

C = suspended solids concentration, grams per litre

$W_{ss}$  = weight of suspended solids in sample, grams

=  $W_s - [W_w (\text{Sal}/1,000 \text{ parts per thousand})]$

(e) The percent of suspended solids by weight may be converted to concentrations in units of grams per litre by the following formula:

$$C = \frac{(1,000 \text{ g/l}) G_s \left[ 1 + \left( \frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right]}{G_s \left[ \left( \frac{100\%}{\%SS} \right) - 1 \right] + \left[ 1 + \left( \frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right]} \quad (3-6a)$$

where

$G_s$  = specific gravity of suspended solids particles

(f) Suspended solids concentrations presented in units of grams per litre may be converted to percent of suspended solids by the following formula:

$$\%SS = \frac{100\% G_s \left( \frac{C}{1,000 \text{ g/l}} \right)}{G_s \left( \frac{C}{1,000 \text{ g/l}} \right) + \left[ G_s - \left( \frac{C}{1,000 \text{ g/l}} \right) \right] \left[ 1 + \left( \frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right]} \quad (3-6b)$$

(g) Suspended solids concentrations can be calculated from total solids concentrations by the following equations if the salinity is known and the total solids concentration is presented in percent of solids by weight.

$$\%SS = \%S - \left[ (100\% - \%S) \left( \frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right] \quad (3-6c)$$

$$\%S = \frac{\%SS + 100\% \left( \frac{\text{Sal}}{1,000 \text{ ppt}} \right)}{1 + \left( \frac{\text{Sal}}{1,000 \text{ ppt}} \right)} \quad (3-6d)$$

$$C_{ss} = \frac{(1,000 \text{ g/l}) G_s \left[ 1 + \left( \frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right]}{\left[ 1 + \left( \frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right] + G_s \left\{ \left[ \left( \frac{\%S}{100\%} \right) \left( 1 + \frac{\text{Sal}}{1,000 \text{ ppt}} \right) - \left( \frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right] \right\}} \quad (3-6e)$$

(3) Total solids method. This test is used when the suspended solids concentration is large, compared to dissolved solids. It may be used in other cases where the dissolved solids or salinity is known or measured separately. To ensure accuracy, the test should generally be used only for a suspension with a suspended solids concentration greater than 1 gram per litre. These steps should be followed:

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- (a) Obtain tared weight of a sample dish.
- (b) Thoroughly mix sample and pour into sample dish.
- (c) Weigh dish and sample and place in drying oven at 105° C until sample has dried to a constant weight (about 4 to 6 hours).
- (d) Cool in desiccator and then weigh immediately.
- (e) Calculate suspended solids concentration C , in grams per litre, as follows:

$$C = \frac{W_{ss} (1,000 \text{ g/l})}{\left(\frac{W_{ss}}{G_s}\right) + W_w} \quad (3-7)$$

from before

$$W_{ss} = W_s - [W_w (\text{Sal}/1,000 \text{ parts per thousand})]$$

$$W_s = [(\text{weight of dry sample and dish}) - (\text{weight of dish})]$$

Sal = salinity, parts per thousand, or dissolved solids, grams per litre; if unknown in freshwater environments, use zero

$G_s$  = specific gravity of solids; use 2.67 if unknown

$W_w$  = [(weight of wet sample and dish, grams) - (weight of dry sample and dish, grams)]

(4) Filtration method. This method should be used for suspensions having suspended solids concentrations of less than 1.0 gram per litre. Any quantitative filtering apparatus using a filter paper that has a pore size of 1 micron or less can be used for the test. The two most common setups use either a Gooch crucible with a glass fibre filter paper or a membrane filter apparatus. These steps should be followed:

- (a) Weigh the filter.
- (b) Filter a measured volume of the sample. The volume should be sufficient to contain 5 milligrams of suspended solids.
- (c) Filter 10 millilitres of distilled water twice to wash out dissolved solids.
- (d) Place the filter in a drying oven at 105° C until the sample has dried to constant weight (usually 1 to 2 hours).
- (e) Cool in a desiccator and weigh.
- (f) Calculate suspended solids concentration C , in grams per litre, as follows:

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$$C = \frac{[(\text{weight of filter and dry solids, grams}) - (\text{weight of filter, grams})] (1,000 \text{ millilitres per litre})}{(\text{volume of sample, millilitres})} \quad (3-8)$$

(5) Centrifugation method. This method is recommended for samples from saltwater environments that have a suspended solids concentration greater than 1 gram per litre. It is particularly useful when the dissolved solids concentration or salinity is unknown but is expected to be significant (greater than 10 percent of the suspended solids concentration). This method is preferable to the total solids method when the dissolved solids concentration is several times greater than the suspended solids concentration. These steps should be followed:

(a) Centrifuge a measured volume of sample until the liquid and solids have separated, yielding clear supernatant (several minutes should be sufficient).

(b) Pour off the supernatant, being careful not to lose any of the solids.

(c) Resuspend the settled solids in distilled water by diluting the sample to its initial volume.

(d) Repeat steps (a) through (c) twice to wash out all dissolved solids.

(e) Pour the sample into a preweighed dish and then wash all remaining solids from the centrifuge tube into the dish, using distilled water.

(f) Place the dish in a drying oven at 105° C until the sample has dried to constant weight (usually 4 to 6 hours).

(g) Cool in a desiccator and weigh.

(h) Calculate suspended solids concentration C, in grams per litre, as follows:

$$C = \frac{[(\text{weight of dish and dry solids, grams}) - (\text{weight of dish, grams})] \times 1,000 \text{ millilitres per litre}}{(\text{volume of sample, millilitre})} \quad (3-9)$$

(6) Correlation of suspended solids with turbidity. In some cases, effluent quality standards are specified in terms of turbidity, an optical property. Relationships between suspended solids concentration and turbidity are sediment-specific and can be determined only by preparing a correlation curve. The correlation curve is developed by determining turbidity and suspended solids concentration of samples prepared over a sufficiently wide range of concentrations.

#### e. Sample Compositing and Separation.

(1) Following determination of in situ water content, the sediment sample(s) must be homogenized, split, and possibly separated into coarse- and

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fine-grained fractions prior to further testing. Sediment characterization tests such as plasticity, grain size determination, specific gravity and organic content may be performed on grab samples from each of several sampling locations. Other tests, such as consolidation and settling tests, should be performed on an appropriately composited and homogenized sample. The need for and methods of compositing are highly project-dependent, but should be aimed toward producing a sample for testing that is representative of the material to be dredged. If composite samples are to be used for further testing, they must be thoroughly mixed. Samples for settling tests (approximately 15 gallons) may require addition of some water to aid in mixing.

(2) Sediment character as determined from in situ samples is not indicative of dredged material behavior after dredging since the fine-grained (<No. 200 sieve) fraction will undergo natural segregation within the containment area and will behave independently of the coarse-grained (>No. 200 sieve) fraction. Therefore, the relative percentage (dry weight basis) of coarse- and fine-grained material should be determined by separation of a small portion of the sample using a No. 200 sieve and following procedures generally described in EM 1110-2-1906.

(3) If the coarse-grained fraction is less than 10 percent by dry weight, the sediment sample is considered to be fine grained and is treated as though all the material passed the No. 200 sieve; separation for further characterization tests is not required. If the coarse-grained fraction is greater than 10 percent by dry weight, the entire sample should be separated into coarse- and fine-grained fractions prior to further testing. Separation can be accomplished for small sample volumes (e.g., those intended for classification or consolidation testing) by using the No. 200 sieve as described above. However, the larger sample volume required for sedimentation tests makes the use of a sieve impractical. For such volumes, slurry (sediment plus water) can be thoroughly mixed in a large barrel and then allowed to separate by differential settling. After initial mixing is stopped, coarse material will quickly accumulate on the bottom. The slurry remaining above the coarse material can be pumped into a second barrel, where it can be remixed and loaded into the testing column.

(4) In conducting the various tests and during sample separation and preparation activities, it will be necessary to make up slurries of various solids concentrations. In doing so, it is advisable to begin the testing sequence with slurry of higher concentration and add the required volume of water to obtain the desired lower concentration. The following simple relationship is useful in calculating the volume of additional water required:

$$C_1 V_1 = C_2 V_2 \quad (3-10)$$

where

$C_1$  and  $C_2$  = solids concentrations

$V_1$  and  $V_2$  = slurry volumes (water plus solids)

f. Grain Size Analyses. Grain size analyses should be performed on coarse-grained samples or on the coarse-grained fraction of samples that are mixtures of coarse- and fine-grained material. These analyses are used to classify the coarse-grained portion of the sediments. The fine-grained

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material (passing the No. 200 sieve) should be used in the other characterization and consolidation tests if required. Grain size analyses should follow the procedures contained in EM 1110-2-1906. Hydrometer analyses can be used to define the grain size distribution of the fine-grained fraction if desired.

g. 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. 200 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.

h. Organic Content. 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-gram sample at 105° C until there is no further weight loss (usually 4 to 6 hours).

(2) Place it in a desiccator to cool for 15 minutes.

(3) Weigh the sample and place it in the oven at 440° C for 4 hours.

(4) Place it in the desiccator to cool for 15 minutes.

(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.

i. Specific Gravity. Values for the specific gravity of solids for fine-grained sediments 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.

j. USCS Classification. When classifying sediment samples, the fine-grained portion that passes the No. 200 sieve should be classified separately from the coarse-grained portion retained on the No. 200 sieve, regardless of which fraction comprises the greatest percentage by weight. Additional information regarding the USCS classification may be found in WE'S Technical Memorandum No. 3-357 (item 33).

3-3. Settling Tests. Dredged material placed in disposal areas by hydraulic dredges or pumped into disposal areas by pump-out facilities enters the disposal area as a slurry (mixture of dredged solids and dredging site water). Settling refers to those processes in which the dredged material slurry is separated into supernatant water of low solids concentration and a more

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concentrated slurry. Laboratory sedimentation tests provide data for designing the containment area to meet effluent suspended solids criteria and to provide adequate storage capacity for the dredged solids.

a. Settling Processes.

(1) Settling types. The settling process can be categorized according to four basic classifications: discrete settling where the particle maintains its individuality and does not change in size, shape, or density during the settling process; flocculent settling where particles agglomerate during the settling period with a change in physical properties and settling rate; zone settling where the flocculent suspension forms a lattice structure and settles as a mass, the high solids concentration partially blocks the release of water and hinders settling of neighboring particles, and a distinct interface between the slurry and the supernatant water is exhibited during the settling process; and compression settling where settling occurs by compression of the lattice structure. All of the above sedimentation processes may occur simultaneously in a disposal area, and any one may control the design of the disposal area.

(2) Governing factors. Discrete settling describes the sedimentation of coarse particles. The important factors governing the sedimentation of fine-grained dredged material are the initial concentration of the slurry, salinity of the carrier water, and the flocculating properties of the solid particles. Because of the high influent solids concentration and the tendency of fine-grained particles to flocculate, either flocculent or zone settling behavior normally describes sedimentation in containment areas. Sedimentation of freshwater sediments at slurry concentrations of 100 grams per litre can generally be characterized by flocculent settling properties. As slurry concentrations or salinity is increased, the sedimentation process may be characterized by zone settling properties. Compression settling occurs in the lower layers of settled material for both the flocculent and zone settling cases. As more settled material accumulates, excess pore pressures develop in the lower layers and further consolidation occurs as water is expelled and the excess pore pressures dissipate.

(3) Zone versus flocculent settling as a function of salinity. The tendency of a fine-grained dredged material slurry to settle by zone or flocculent behavior in the initial stages of settling is strongly influenced by the presence of salt as a coagulant. If salinity is less than 1 part per thousand, indicative of freshwater conditions, flocculent processes normally describe the initial settling, and no clearly defined interface is seen. If salinity is greater than 1 part per thousand, indicative of brackish or salt-water conditions, zone settling processes normally describe the initial settling, and a clear interface between the clarified supernatant water and the more concentrated slurry is evident. For the zone settling case, some of the fine particles remain in the supernatant water as the interface falls. Flocculent processes then describe the settling of these fine particles from the supernatant.

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b. Testing Equipment and Procedures.

(1) Test objective. The objective of running settling tests on sediments to be dredged is to define their settling behavior in a dredged material containment area. The tests provide numerical values for the design criteria that can be projected to the size and design of the containment area. Procedures for computer-assisted plotting and reduction of settling column data are available as discussed in Chapter 8.

(2) Settling column. The settling column shown in Figure 3-3 should be used for dredged material settling tests. The column is constructed of 8-inch-diameter Plexiglas tubing and can be sectioned for easier handling and cleaning. Ports are provided for extraction of samples at various depths during sampling. A bottom-mounted airstone is also provided for agitation and mixing of slurries in the column by using compressed air. Shop drawings of the column with bills of materials are shown in Appendix B.

(3) Samples. Samples used to perform settling tests should consist of fine-grained (<No. 200 sieve) material. Any coarse-grained (>No. 200 sieve) material present in the sample would normally be hydraulically separated when the sample is mixed 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 gallons of sediment is usually required for the tests. Water used to mix the slurries can be taken from the proposed dredging site or can be prepared by mixing tap-water and salt to the known salinity of the dredging site water.

(4) Pilot test. A pilot test conducted in a graduated cylinder (4 litres is satisfactory) is a useful method for determining if flocculent or zone process will describe the initial settling. The pilot test should be run at a slurry concentration of approximately 150 grams per litre. 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 3-4. 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 in the 8-inch column. If no break in the curve is evident, the material has begun 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 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.

(5) Required number of column loadings for tests. Three types of settling tests in the 8-inch column may be needed to fully define the settling properties of the dredged material. However, in most cases the 8-inch



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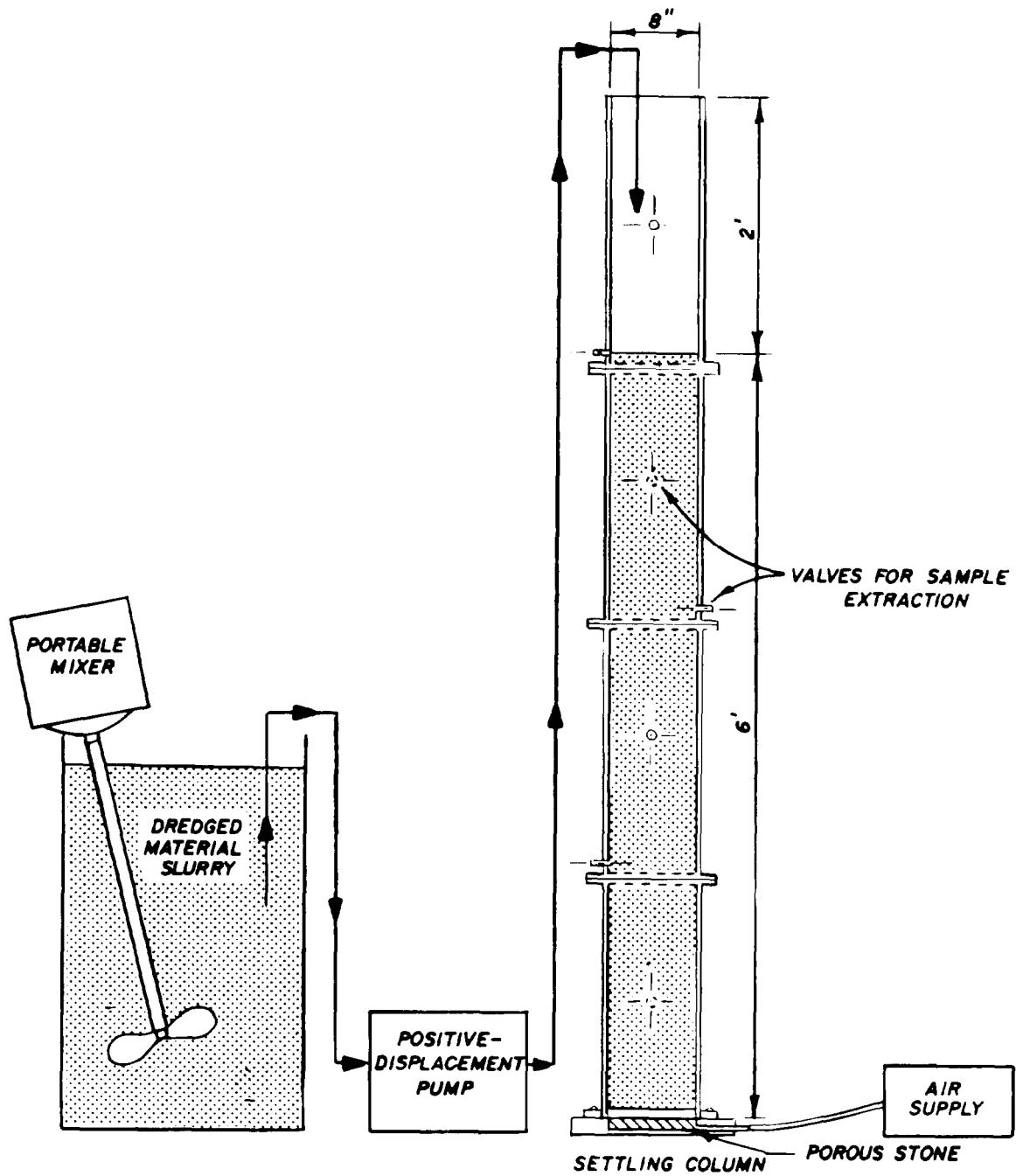


Figure 3-3. Schematic of apparatus for settling tests

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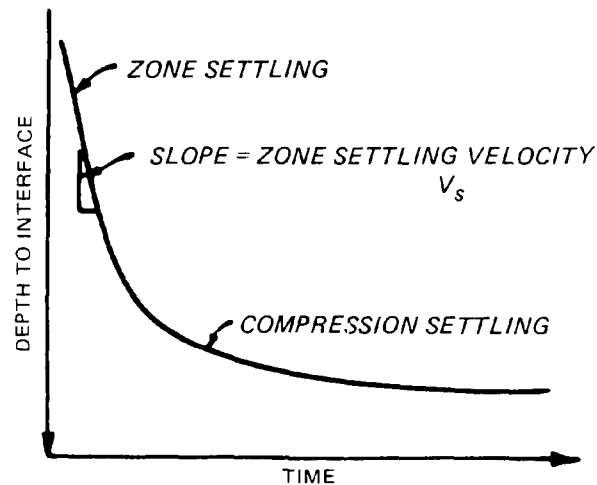


Figure 3-4. Conceptual plot of interface height versus time

settling column used for the settling tests needs to be loaded with slurry only 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 at the end of the disposal operation. 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. A zone settling test is required to define the minimum surface area needed for effective zone settling. 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 all purposes.

c. 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 described 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 for the flocculent settling process can be obtained using the following procedure:

(a) A settling column such as shown in Figure 3-3 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 feet. The column should be at least 8 inches in diameter with sample ports at 0.5 foot 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 a suspended solids concentration  $C$  equal to the expected concentration of the dredged material influent  $C_1$ . The

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slurry should be mixed in a container with sufficient volume to fill the test column. Field studies indicate that for maintenance dredging of fine-grained material, the disposal concentration will average about 150 grams per litre. This concentration should be used in the test if better data are not available.

(c) Pump or pour the slurry into the test column using compressed air or mechanical agitation to maintain a uniform concentration during the filling period.

(d) When the slurry is completely mixed in the column, cut off the compressed air or mechanical agitation 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 first 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 hours, etc., until the end of the test. As a rule, a 50-millilitre sample should be taken from each port. Continue the test until an interface can be seen near the bottom of the column and the suspended solids concentration in the fluid above the interface is 1 gram per litre. Test data are tabulated and used to plot a concentration profile diagram as shown in Figure 3-5. Examples are shown in Appendix C.

(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 the beginning 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 hours, 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 than 1 gram per litre, and filtration will be required to determine the concentrations. The data should be expressed in milligrams per litre for these samples. Tabulate the data and plot a concentration profile diagram as shown in Figure 3-5. In reducing the data for this case, the concentration of the first port sample taken above the falling interface is considered the initial concentration  $C_0$ . Examples are shown in Appendix C.

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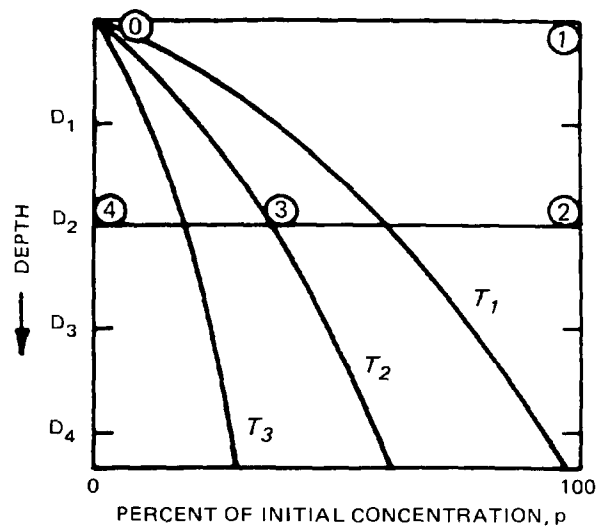


Figure 3-5. Conceptual concentration profile diagram

d. Zone Settling Test.

(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 velocity settling zone of the curve is the zone settling velocity, which is a function of the initial test slurry concentration. This test is required if the material exhibits an interface within the first day. The test should be run at the expected influent slurry concentration, or the highest expected to persist for several hours if a range is expected.

(2) Information required to design a containment area for the zone settling process can be obtained by using the following procedure:

(a) A settling column such as shown in Figure 3-3 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-litre 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 minute.

(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 curve of depth to interface versus time as shown in Figure 3-4. It is important to take enough readings to clearly define this curve.

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(d) Continue the readings until sufficient data are available to define the maximum point of curvature of the depth to interface versus time plot. The test may require from 8 to 48 hours to complete.

(e) Calculate the zone settling velocity  $v_s$  as the slope of the constant velocity settling zone, as shown in Figure 3-4 (straight-line portion of curve). The velocity should be in feet per hour.

(f) 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 the zone settling test 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 log of concentration versus log of time in the compression settling range as shown in Figure 3-6 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) Information required to design a containment area for the compression settling process can be obtained using the following procedures:

(a) Tabulate the interface height  $H_t$  for various times of observation during the 15-day test period.

(b) Calculate concentrations for various interface heights as follows:

$$C = \frac{C_o H_i}{H_t} \quad (3-11)$$

where

$C$  = slurry concentration at time  $t$  , grams per litre

$C_o$  = initial slurry concentration, grams per litre

$H_i$  = initial slurry height, feet

$H_t$  = height of interface at time  $t$  , feet

Neglect solids in the water above the interface to simplify calculations.

(c) Plot concentration versus time on log-log paper as shown in Figure 3-6.

(d) Draw a straight line through the data points.

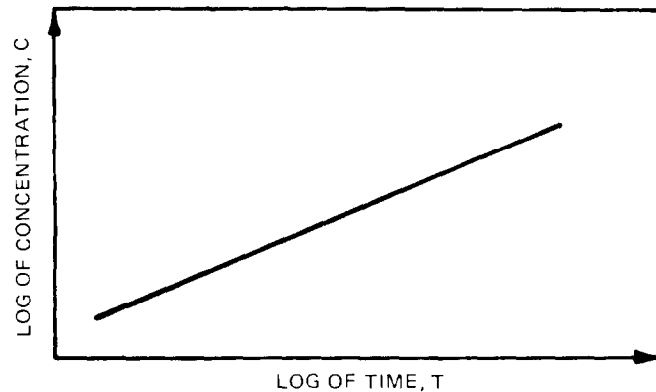


Figure 3-6. Conceptual time versus concentration plot

#### 3-4. Chemical Clarification Tests.

a. General. If for a given disposal area, gravity sedimentation does not remove sufficient suspended solids to meet effluent standards, chemical clarification may be required. This may be especially true when a freshwater sediment with a significant clay fraction is dredged. The effluents from such sites may contain several grams per liter of suspended solids after gravity settling prior to chemical clarification.

##### b. Jar Tests.

(1) Jar tests have traditionally been used to evaluate the effectiveness of various flocculants under a variety of operating conditions for water treatment, and these procedures have been applied to the disposal of dredged material. Jar tests are used to provide information on the most effective flocculant, optimum dosage, optimum feed concentration, effects of dosage on removal efficiencies, effects of concentration of influent suspension on removal efficiencies, effects of mixing conditions, and effects of settling time.

(2) The general approach used in the jar test procedures is as follows:

(a) Using site-specific information on the sediment, dredging operation, containment areas, and effluent requirements, select mixing conditions, suspension concentration, settling time, and polymers for testing. Test a small number (four to six) of polymers that have performed well on similar dredged material.

(b) Prepare stock suspension of sediment.

(c) The tests should be run on 2-grams-per-litre suspensions of sediment, which is a typical concentration for effluents from a well-designed containment area for freshwater clay sediments. If good removals are obtained at low dosages (10 milligrams per litre of polymer or less), then select the most cost-effective polymer. If good removals are not obtained, examine the

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polymer under improved mixing and settling conditions and test the performance of other flocculants.

(d) After selecting a polymer and its optimum dosage, examine the effect of polymer-feed concentration over the range of sediment concentrations of 1 to 30 grams per litre, typical concentrations found in the field, at the optimum dosage.

(e) Determine the dosage requirements for the expected range of suspended solids concentrations to be treated at the primary weir.

(f) Examine the effects of the range of possible mixing conditions on the required dosage of flocculant for a typical suspension.

(g) Examine the effects of settling time on the removal of suspended solids from a suspension of average suspended solids concentration using the selected dosage and likely mixing conditions.

(3) The purpose of the approach described is to select an effective polymer for a suspension of a standard suspended solids concentration, 2 grams per litre, which is a typical effluent solids concentration. In this manner, the effectiveness and dosage requirements of various polymers are easy to compare. The other test variables are set to simulate anticipated field conditions. After a polymer is selected, other variables are examined: polymer-feed concentration, solids concentration of suspension to be treated, mixing, and settling time. The approach may be changed to fit the needs and conditions of the specific study. Detailed jar test procedures are found in Appendix E.

3-5. Consolidation Testing. Determination of containment area long-term storage capacity requires estimates of settlement due to self-weight consolidation of newly placed dredged material and due to consolidation of compressible foundation soils. Consolidation test results must be obtained, including time-consolidation data, to estimate the average void ratios at completion of 100 percent primary consolidation.

a. Consolidation tests for foundation soils should be performed as described in EM 1110-2-1906.

b. Controlled-rate-of-strain tests or fixed-ring consolidometers should be used for consolidation testing of sediment samples because of their fluid-like consistency. The only major modifications for the conventional fixed-ring testing procedure concern the sample preparation and the method of loading. Detailed procedures are found in Appendix D.

## CHAPTER 4

### CONTAINMENT AREA DESIGN FOR RETENTION OF SOLIDS AND INITIAL STORAGE

#### 4-1. General.

a. This chapter presents guidelines for designing a new containment area for suspended solids retention and for evaluating the suspended solids retention potential of an existing containment area. Intermittent dredging, with higher costs, may be required if dredging flow rates exceed the solids retention capacity of a disposal area. This condition can be avoided by following the design guidelines in this chapter. 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 space and volume for retaining the solids within the containment area through settling and providing storage capacity of dredged solids for a single dredged material disposal operation. 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 assure adequate retention of solids. Guidance is also presented in this chapter for the design of weirs for the release of ponded water and for chemical clarification systems for additional removal of suspended solids.

b. 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 resuspend solids and increase effluent solids concentration. The settling process, with proper design and operation, will normally provide removal of fine-grained dredged material down to a level of 1 to 2 grams per litre in the effluent for freshwater conditions. The settling process will usually provide removal of fine-grained dredged material down to a level of several hundred milligrams per litre or lower for saltwater conditions. 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.

c. The generalized flowchart shown in Figure 4-1 illustrates the design procedures presented in the following paragraphs. These steps were adapted from procedures used in water and wastewater treatment and are based on field and laboratory investigations on sediments and dredged material at active dredged material containment areas. The procedures in this chapter are presented in the manner required to calculate the minimum required disposal area geometry for a given inflow rate (dredge size) and dredged volume. The same procedures would be used in reverse fashion to calculate a maximum flow rate (dredge size) allowable for a given disposal area geometry. Numerical examples of both approaches are presented in Appendix C. Procedures for computer-assisted design for sedimentation and initial storage are available as discussed in Chapter 8.



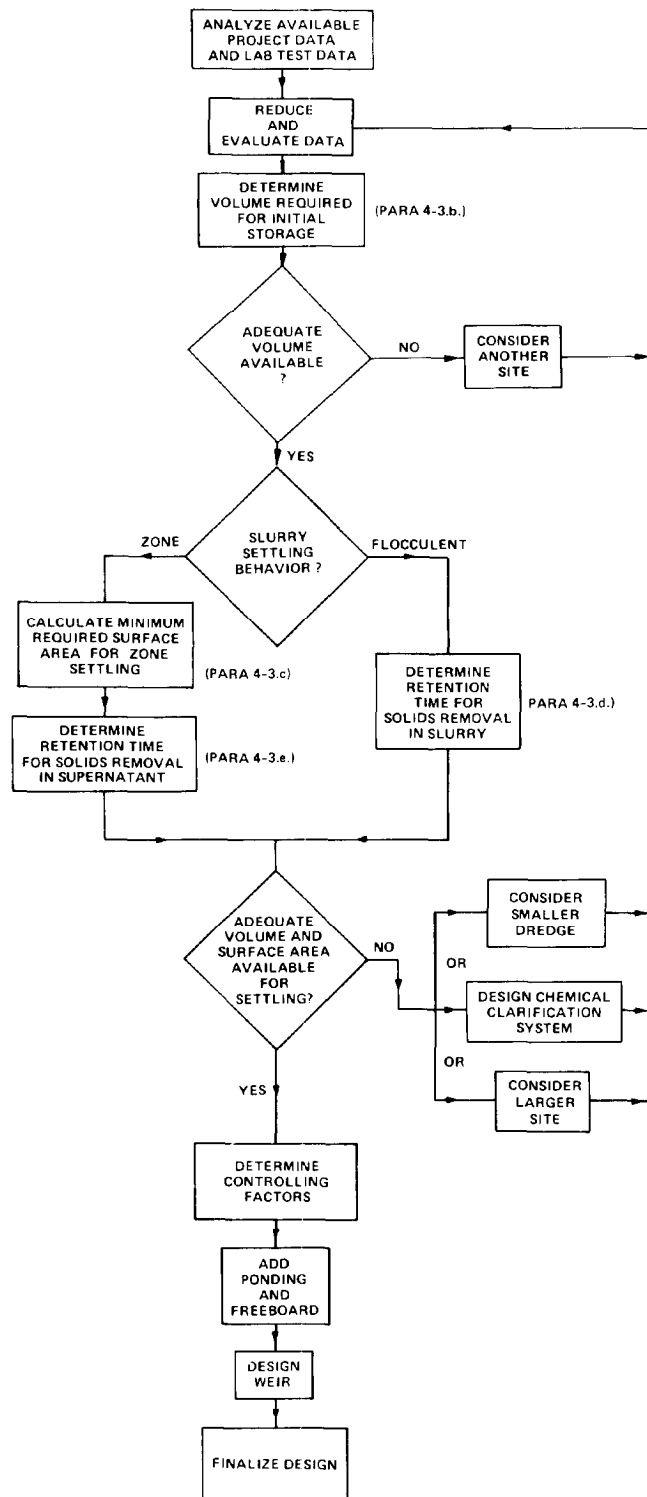


Figure 4-1. Flowchart of design procedure for settling and initial storage

#### 4-2. Data Requirements.

a. General. The data required to use the design guidelines are obtained from field investigations (Chapter 2), laboratory testing (Chapter 3), project-specific operational constraints, and experience in dredging and disposal activities. The types of data required are described in the following paragraphs.

b. In Situ Sediment Volume. The initial step in any dredging activity is to estimate the total in situ channel volume of sediment to be dredged  $V_c$ . Sediment quantities are usually determined from routine channel surveys.

c. Physical Characteristics of Sediments. Field sampling and sediment characterization should be accomplished according to the laboratory tests described in Chapters 2 and 3 of this manual. Adequate sample coverage is required to provide representative samples of the sediment. Also required are in situ water contents of the fine-grained maintenance sediments. 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:

$$e_i = \frac{wG_s}{S_D} \quad (4-1)$$

where

$e_i$  = in situ void ratio of sediment

$w$  = water content of the sample, percent

$G$  = specific gravity of sediment solids

$S_D$  = degree of saturation, percent (equal to 100 percent for sediments)

A representative value for 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. The volume of sand  $V_{sd}$  can be estimated as a percentage of the total volume  $V_c$  to be dredged by using the percent coarser than No. 200 sieve. The in situ volume of fine-grained sediment  $V_i$  is equal to  $V_c - V_{sd}$ .

d. 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 experience. If no data on past experience are available, Figure 4-2, 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 for dredging in sand (item 32). Additional guidance on dredge production rates is found in ER 1110-2-1300. For hopper dredge

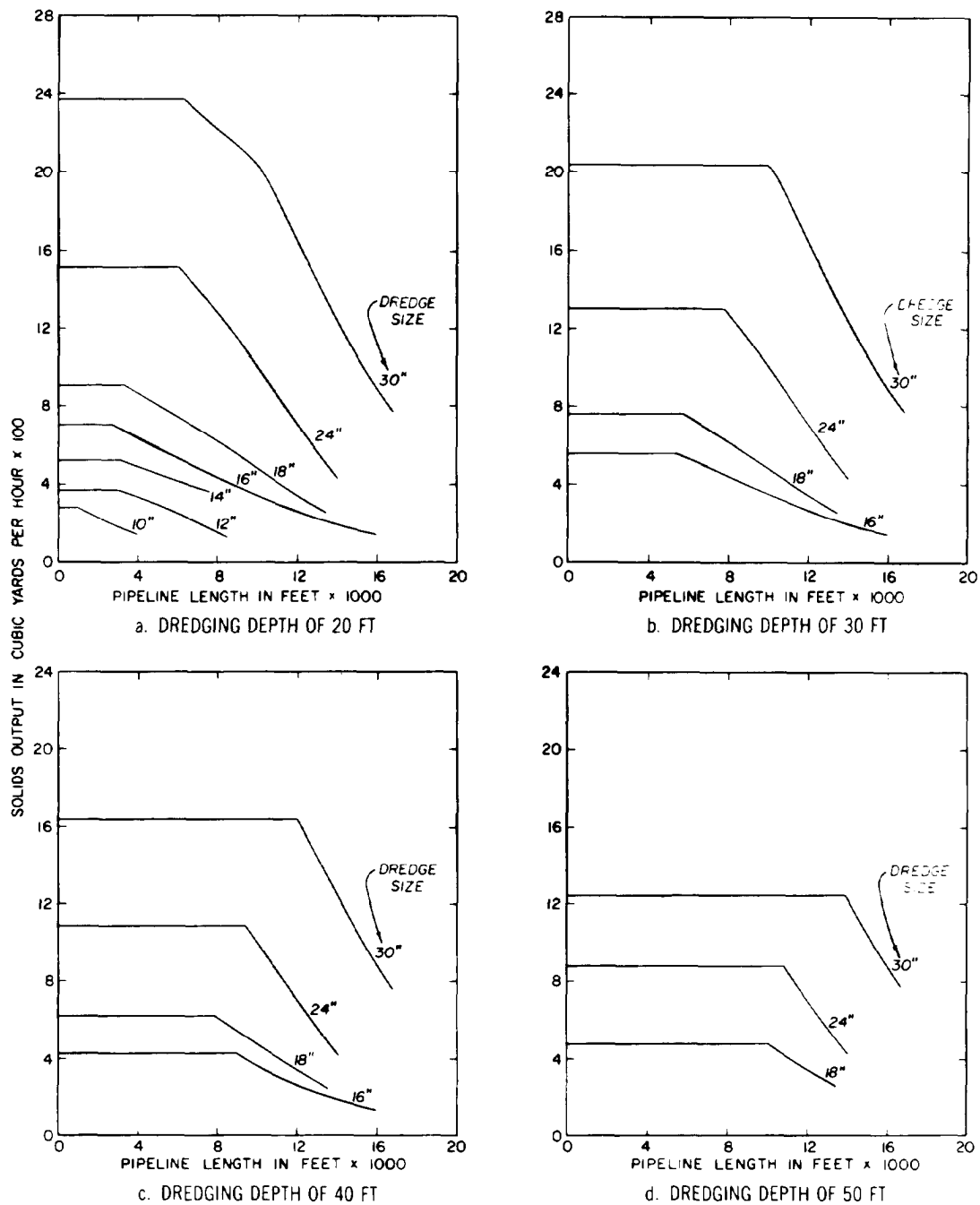


Figure 4-2. Relationships among solids output, dredge size, and pipeline length for various dredging depths

or barge pump-out operations, 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), and time required to complete the disposal activity. For hydraulic pipeline dredges, -if no other data are available, an influent suspended solids concentration  $C_i$  of 150 grams per litre (14 percent by weight) should be used for design purposes. The influent flow rate  $Q_i$  can be estimated using the following tabulation or from other available data:

Discharge Pipeline Diameter, in.	Discharge Rate (for Flow Velocity of 15 ft/sec) *	
	cfs	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 divide by 15.

e. Laboratory Settling Test Data. The guidelines for sedimentation tests are given in Section 3-3. Depending on the results of the sedimentation tests, the dredged material slurry will settle by either zone processes (common for saltwater sediments) or flocculent processes (common for freshwater sediments). Regardless of the salinity, flocculent processes govern the concentration of solids in the effluent.

#### 4-3. Sedimentation Basin Design.

a. Selection of Minimum Average 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 an average ponding depth in estimating the residence time necessary for effective settling. A minimum average ponding depth of 2 feet should be used for the

design. If the design objective is to minimize the surface area required, selection of a deeper ponding depth may be desirable. If conditions will allow for the greater ponding depth throughout the operation, the greater value can be used. For most cases, constant ponding depth can be maintained by raising the pond surface as settled material accumulates in the containment area by raising the elevation of the weir crest.

b. Calculation of Volume for Initial Storage.

(1) General. Containment areas must be designed to meet volume requirements for a particular disposal activity. The total volume required in 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. 200 sieve) material must be determined separately since this material behaves independently of the fine-grained (<No. 200 sieve) material.

(2) 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 test described in Chapter 3. This design parameter is required both for estimating initial storage requirements and for determining minimum required surface areas for effective zone settling. The following steps can be used to estimate  $C_d$  from the compression settling test.

(a) Estimate the time of dredging by dividing the dredge production rate into the volume of sediment to be dredged. Use Figure 4-2 for estimating the dredge production rate if no specific data are available from past dredging activities. (Note that curves in Figure 4-2 were developed for sand.) The total time required for dredging should allow for anticipated downtime.

(b) Enter the concentration versus time plot as shown in Figure 4-3 and determine the concentration at a time  $t$  equal to one-half the time required for the disposal activity determined in step (a).

(c) The value computed in step (b) is the design solids concentration  $C_d$ . Examples are shown in Appendix C.

(3) Volume estimation. The volume computed in the following steps is the volume occupied by dredged material in the containment area immediately after the completion of a particular disposal activity. This value is critical in determining the dike height requirements for the containment area. The volume is not an estimate of the long-term needs for multiple-disposal activities. Estimates for long-term storage capacity can be made using the procedures outlined in Chapter 5. 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 initial storage is the only consideration (this is expected to be an exceptional case).

(a) Compute the average void ratio of the fine-grained dredged material in the containment area at the completion of the dredging operation using the

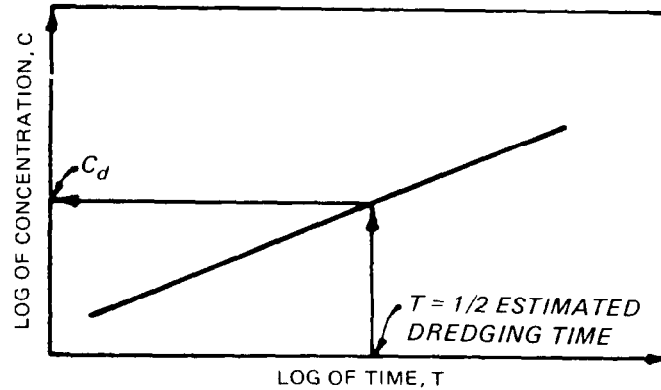


Figure 4-3. Conceptual time versus concentration plot

design concentration  $C_d$  determined in 4-3.b. Use the following equation to determine the void ratio:

$$e_o = \frac{G_s \gamma_w}{C_d} - 1 \quad (4-2)$$

where

$e_o$  = average void ratio of the dredged material in the containment area at the completion of the dredging operation

$\gamma_w$  = density of water, grams per litre (normally 1,000 grams per litre)

(b) Compute the volume of the fine-grained channel sediments after disposal in the containment area:

$$V_f = V_i \left[ \frac{e_o - e_i}{1 + e_i} \right] + 1 \quad (4-3)$$

where

$V_f$  = volume of the fine-grained dredged material after disposal in the containment area, cubic feet

$V_i$  = volume of the fine-grained channel sediments, cubic feet

$e_i$  = average void ratio of the in situ channel sediments

(c) Compute the volume required to store the dredged material in the containment area:

$$V = V_f + V_{sd} \quad (4-4a)$$

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where

$V$  = total volume of the dredged material in the containment area at the end of the dredging operation, cubic feet

$V_{sd}$  = volume of sand (use 1:1 ratio), cubic feet

(d) If there are limitations on the surface area available for disposal or if an existing disposal site is being evaluated, check whether 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  $H_{dm(max)}$  using the following equation:

$$H_{dm(max)} = H_{dk(max)} - H_{pd} - H_{fb} \quad (4-4b)$$

where

$H_{dk(max)}$  = maximum allowable dike height due to foundation conditions, feet

$H_{pd}$  = ponding depth, feet

$H_{fb}$  = freeboard (minimum of 2 feet can be assumed), feet

Compute the minimum surface area that could be used to store the material:

$$A_{ds} = \frac{V}{H_{dm(max)} (43,560)} \quad (4-4c)$$

where

$A_{ds}$  = design surface area for storage, acres

If  $A_{ds}$  is less than the available surface area, then adequate volumetric storage is available at the site.

#### c. Calculation of Minimum Surface Area for Effective Zone Settling.

(1) General. 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 describes 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.

(2) Compute area required for zone settling. The minimum surface area determined according to the following steps should provide removal of fine-grained sediments so that suspended solids levels in the effluent do not exceed several hundred milligrams per litre. The area is required for the zone settling process to remove suspended solids from the surface layers at

the rate sufficient to form and maintain a clarified supernatant that can be discharged.

(a) Determine the zone settling velocity  $v_s$  at the influent suspended solids concentration  $C_i$  as described in paragraph 3-3.d.

(b) Compute area requirements as

$$A_z = \frac{Q_i (3600)}{v_s} \quad (4-5)$$

where

$A_z$  = containment surface area requirement for zone settling, square feet  
 $Q_i$  = influent flowrate in  $\text{ft}^3/\text{sec}$   
 3600 = conversion factor hours to seconds  
 $v_s$  = zone settling velocity at influent solids concentration  $C_i$ , feet per hour

(c) Multiply the area by a hydraulic efficiency correction factor HECF to compensate for containment area inefficiencies:

$$A_{dz} = \frac{(\text{HECF})A_z}{43,560} \quad (4-6)$$

where

$A_{dz}$  = design basin surface area for effective zone settling, acres  
 HECF = hydraulic efficiency correction factor (determined as described in 4-3.g.)  
 $A_z$  = area determined from Equation 4-5, square feet

#### d. Calculation of Required Retention for Flocculent Settling.

(1) 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.

(2) Sediments in a dredged material containment area are composed 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 sediments and flocs. Therefore, flocculent settling of dredged sediments is dependent on the ponding depth as well as the properties of the particles. For this reason, it is important that settling tests be performed with column heights corresponding to ponding depths expected under field conditions.



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(3) The concentration of suspended solids in the effluent will depend on the total depth at which fluid is withdrawn at the weir, which is related to the hydraulic characteristics of the weir structure. The depth of withdrawal is equivalent to the depth of ponded water for weir configuration and flow rates that are normally encountered in containment areas. For this reason, the term "ponding depth" is used interchangeably with withdrawal zone in this manual in the context of effluent quality evaluations.

(4) Evaluation of the sedimentation characteristics of a sediment slurry exhibiting flocculent settling is accomplished as discussed in Chapter 3. The design steps to determine the required retention time for a desired effluent quality are as follows:

(a) Calculate the removal percentage at the selected minimum average ponding depth  $H_{pd}$  for various times using the concentration profile plot as shown in Figure 3-5. As an example, the removal percentage for  $H_{pd} = \text{depth } d_2$  and time  $t_2$  is computed as follows:

$$R = \frac{\text{Area right of profile}}{\text{Area total}} (100) = \frac{\text{Area } 0, 1, 2, 3, 0^*}{\text{Area } 0, 1, 2, 4, 0} (100) \quad (4-5)$$

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 the selected ponding depth as a function of time.

(b) Plot the solids removal percentages versus time as shown in Figure 4-4.

(c) Mean detention times can be selected from Figure 4-4 for various solids removal percentages. Select the residence time  $T_d$  that gives the desired removal percentage.

(d) The required mean residence time  $T_d$  should be multiplied by an appropriate hydraulic efficiency correction factor HECF to compensate for the fact that containment areas, because of inefficiencies, have field mean detention times less than theoretical (volumetric) detention times. The HECF is determined as described in 4-3.g. The basin volumetric or theoretical residence time is estimated as follows:

$$T = \text{HECF } T_d \quad (4-8)$$

where T is the volumetric or theoretical residence time and  $T_d$  is selected from Figure 4-4.

(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

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\* These numbers correspond to the numbers used in Figure 3-5 to indicate the area boundaries for the total area down to depth  $d_2$  and the area to the right of the line for  $t_2$ .

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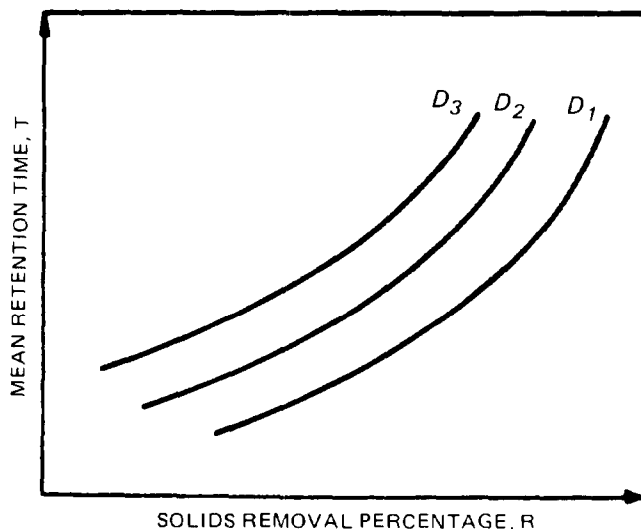


Figure 4-4. Conceptual plot of solids removal versus time for slurries exhibiting flocculent settling

2 grams per litre. For this case, the selection of a required residence 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 residence time for an effluent suspended solids standard is more appropriate. Examples are shown in Appendix C.

e. Calculation of Required Retention Time for Flocculent Settling in Supernatant Water.

(1) Data analyses. For slurries exhibiting zone settling, flocculent settling behavior describes the process occurring in the supernatant water above the interface. Therefore, a flocculent data analysis procedure as outlined in the following paragraphs is required. The steps in the data analysis are as follows:

(a) Use the concentration profile diagram as shown in Figure 3-5 to graphically determine percentages removed,  $R$ , for the various time intervals and for the minimum ponding depth. 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.

(b) Compute the percentages remaining as follows:

$$P = 100 - R \quad (4-9)$$

(c) Compute values for the average suspended solids concentration in the supernatant at each time of extraction as follows:

$$C_t = P_t C_o \quad (4-10)$$

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where

$C_t$  = suspended solids concentration at time  $t$  , milligrams per litre

$P_t$  = percentage remaining at time  $t$

$C_o$  = initial concentration in the supernatant, milligrams per litre

(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 Figure 4-5. An exponential curve fitted through the data points is recommended.

(2) 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 able to be achieved in the field, assuming little or no resuspension of settled material. The relationship in Figure 4-5 can also be used to determine the required retention time to meet a standard for effluent suspended solids. For dredged material slurries exhibiting flocculent settling behavior, the concentration of particles in the ponded water is 1 gram per litre 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. 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) A standard for effluent suspended solids  $C_{eff}$  must be met considering anticipated resuspension under field conditions. A corresponding maximum concentration under quiescent laboratory conditions is calculated as:

$$C_{col} = \frac{C_{eff}}{RF} \quad (4-11)$$

where

$C_{col}$  = Maximum suspended solids concentration of effluent as estimated from column settling tests, milligrams suspended solids per litre of water

$C_{eff}$  = Suspended solids concentration of effluent considering anticipated resuspension, milligrams suspended solids per litre of water

RF = Resuspension factor selected from Table 4-1

Table 4-1 summarizes recommended resuspension factors based on comparisons of suspended solids concentrations as predicted from column settling tests and field data from a number of sites with varying site conditions.

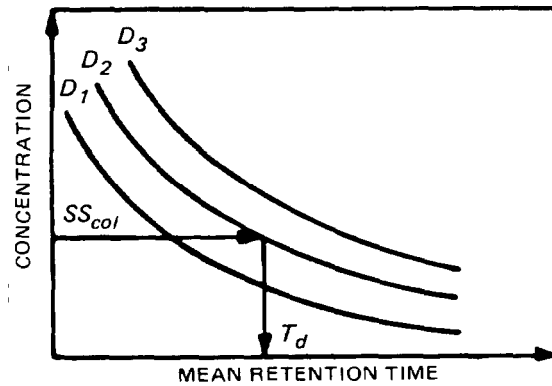


Figure 4-5. Conceptual plot of supernatant suspended solids concentration versus time from column settling test

Table 4-1

Recommended Resuspension Factors for the Zone Settling Case  
for Various Poned Areas and Depths

<u>Anticipated Poned Area</u>	<u>Anticipated Average Poned Depth</u>	
	<u>less than 2 feet</u>	<u>2 feet or greater</u>
Less than 100 acres	2.0	1.5
Greater than 100 acres	2.5	2.0

(b) Using Figure 4-5, determine the required minimum mean residence time corresponding to  $C_{col}$ .

(c) As in the case for flocculent settling of the entire slurry mass, the mean residence time should be increased by an appropriate hydraulic efficiency factor HECF using Equation 4-8. The resulting minimum volumetric or theoretical residence time  $T$  can be used to determine the required disposal area geometry.

f. Computation of Design Surface Area for Flocculent Settling. The design surface area for flocculent settling can be calculated as follows:

$$A_{df} = \frac{T Q_1}{H_{pd} (12.1)} \quad (4-12)$$

where

- $A_{df}$  = design surface area for flocculent settling, acres
- $T$  = minimum mean residence time, hours
- $Q_i$  = average inflow rate, cubic feet per second
- $H_{pd}$  = average ponding depth, feet
- 12.1 = conversion factor acre-feet per cubic feet per second to hours

g. Estimation of Hydraulic Efficiency Correction Factor.

(1) 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  $T_d$  for given flow rate and ponding conditions and the theoretical residence time  $T$  are related by a hydraulic efficiency correction factor as follows:

$$T_d = \frac{T}{(HECF)} \quad (4-13)$$

where

- $T_d$  = mean residence time, hours
- $T$  = theoretical residence time, hours
- HECF = hydraulic efficiency correction factor (HECF > 1.0) defined as the inverse of the hydraulic efficiency,  $T_d/T$ .

(2) The hydraulic efficiency correction factor HECF can be estimated by several methods. The most accurate estimate is that made from dye tracer studies to determine  $T_d$  at the actual site under operational conditions at a previous time, with the conditions similar to those for the operation under consideration (see Appendix J). This approach can be used only for existing sites.

(3) Alternatively, the ratio  $T_d/T = 1/HECF$  can be estimated from the equation:

$$\frac{T_d}{T} = 0.9 \left[ 1 - \exp \left( -0.3 \frac{L}{W} \right) \right] \quad (4-14)$$

where  $L/W$  is the length-to-width ratio of the proposed basin. The  $L/W$  ratio can be increased greatly by the use of internal spur dikes, resulting in a higher hydraulic efficiency and a lower required total area.

h. Determination of Disposal Area Geometry. Previous calculations have provided minimum required surface area for storage  $A_{ds}$ , a minimum required surface area for zone settling (if applicable)  $A_{dz}$ , and a minimum required surface area for flocculent settling  $A_{df}$ . 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 of dike stability (See Chapter 6).

(1) Select the design surface area. Select the design surface area  $A_d$  as the largest of  $A_{ds}$ ,  $A_{dz}$ , and/or  $A_{df}$ . If  $A_d$  exceeds the real estate available for disposal, consider a smaller flow rate (dredge size), deeper average ponding depth, chemical clarification, or an alternate site, and repeat the design. If the surface area for an existing site exceeds  $A_d$ , the existing surface area may be used for  $A_d$ .

(2) Compute height of the dredged material and dikes. The following procedure should be used:

(a) Estimate the thickness of the dredged material at the end of the disposal operation:

$$H_{dm} = \frac{V}{A_d} \quad (4-15)$$

where

$H_{dm}$  = thickness of the dredged material layer at the end of the dredging operation, feet

$V$  = volume of dredged material in the basin, cubic feet (from Equation 4-4)

$A_d$  = design surface area, square feet (as determined above)

(b) Add the ponding depth and freeboard depth to  $H_{dm}$  to determine the required containment area depth (dike height):

$$H_{dk} = H_{dm} + H_{pd} + H_{fb} \quad (4-16)$$

where

$H_{dk}$  = dike height, feet

$H_{pd}$  = average ponding depth, feet (a minimum of 2 feet is recommended)

$H_{fb}$  = freeboard above the basin water surface to prevent wave overtopping and subsequent damage to confining earth dikes, feet (a minimum of 2 feet is recommended)

4-4. Weir Design and Operation. The purpose of the weir structure is to regulate the release of ponded water from the containment area. Proper weir design and operation can control resuspension and withdrawal of settled solids.

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## a. Guidelines for Weir Design.

(1) 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 assumptions that the design of the containment area has provided sufficient area and volume for sedimentation and that short-circuiting is not excessive.

## (2) 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 minimum depth of the withdrawal zone, which will prevent scouring settled material. The withdrawal zone is the area through which fluid is removed for discharge over the weir as shown in Figure 4-6. The size of the withdrawal zone affects the approach velocity of flow toward the weir and is generally equal to the depth of ponding.

(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 the containment area, flow concentrations of varying degree occur near the weir, resulting in higher local velocities and 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 necessary to discharge a given flow without significantly entraining settled material is illustrated by the nomograph in Figure 4-7.

(3) 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 operating line in the lower portion of the nomograph based on the governing settling behavior of the dredged material slurry (zone or flocculent).

(b) Construct horizontal lines at the design inflow rate  $Q_i$  and the ponding depth expected at the weir as shown in the key in Figure 4-7. This ponding depth may be larger than the average ponding depth for large containment areas as the result of a slope taken by the settling material. The ponding depth at the weir may be estimated by using the following equation:

$$H_{pd(weir)} = H_{pd} + 1/2 Lps (0.001) \quad (4-17)$$

where

$H_{pd(weir)}$  = estimated ponding depth at the weir, feet

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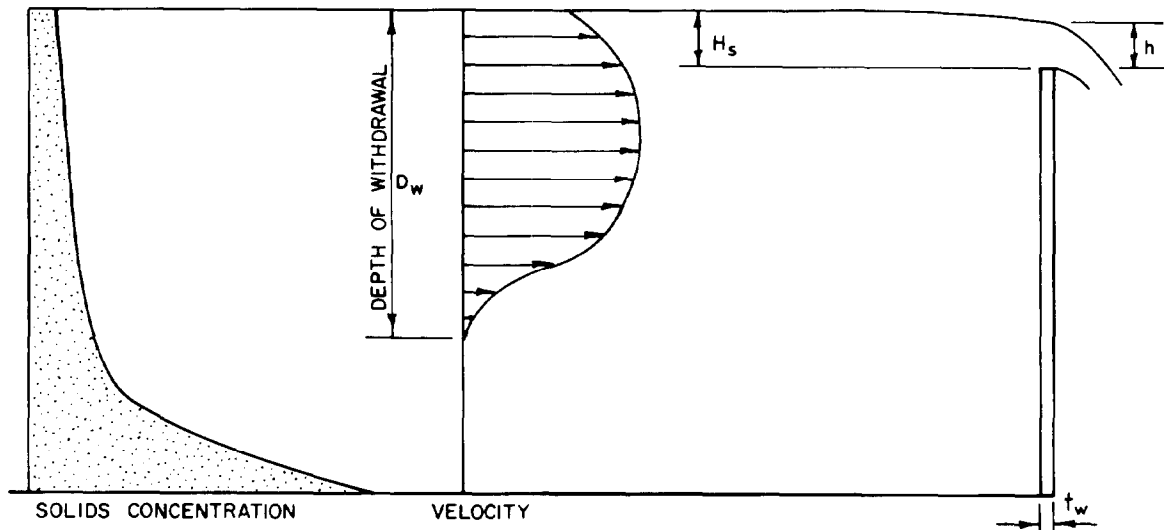


Figure 4-6. Conceptual illustration of withdrawal depth and velocity profile

$H_{pd}$  = average ponding depth, feet

$L_{ps}$  = length of ponded surface between inflow point and weir, feet

(c) Construct a vertical line from the point of intersection of the horizontal ponding depth line and the selected operating line of the nomogram. The required effective weir length is found at the intersection of the vertical line and the horizontal design flow line. An example is shown in the key in Figure 4-7.

(d) Determine the number of weir structures, the physical dimensions of each, and the 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 may be required to prevent resuspension at the weir as the containment area is filled. An illustrative problem is given in Appendix C.

#### (4) Effect of weir type.

(a) Rectangular weirs. Rectangular weirs are the commonly used weir type and may consist of a rectangular wood- or metal-framed inlet(s) 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 Figure 4-8a.



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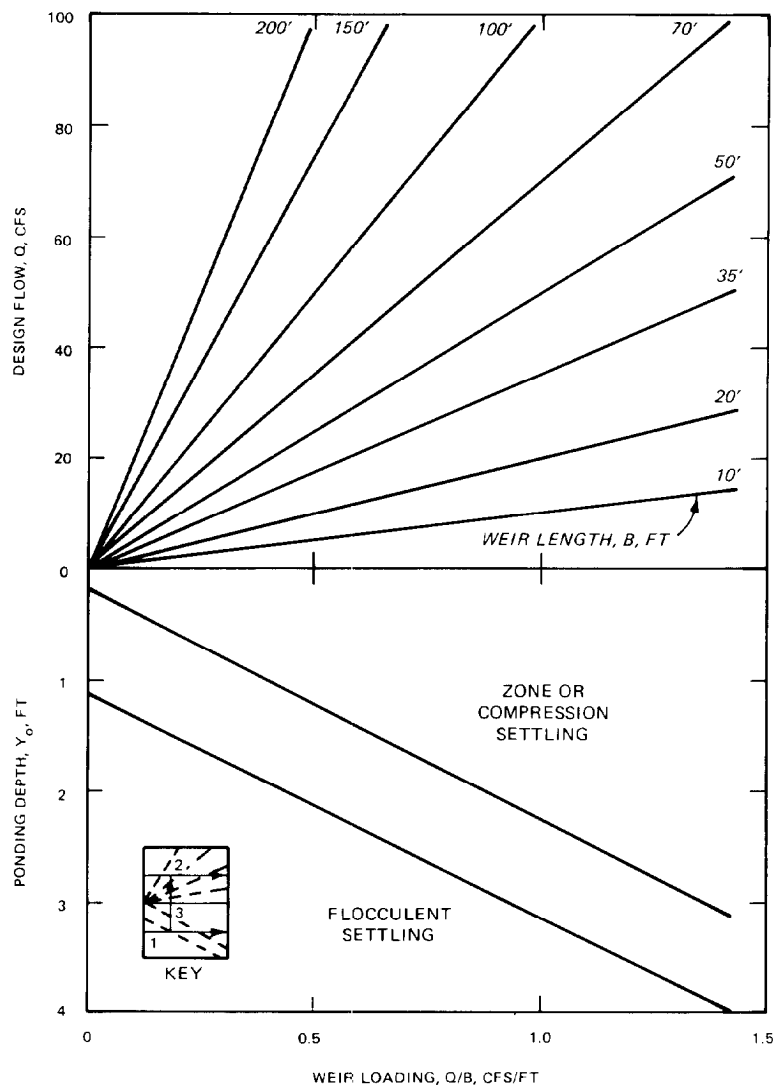
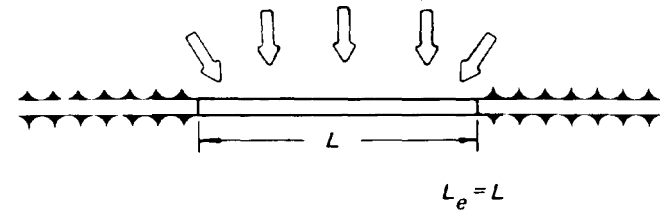


Figure 4-7. Weir design nomograph

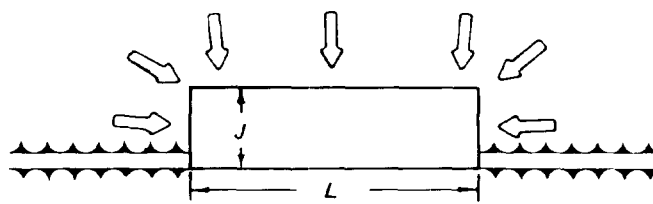
(b) Jutting weirs. A modified form of the rectangular weir is the jutting weir (see Figure 4-8b). It is possible to achieve a greater effective weir length using a jutting weir since the effective length  $L_e$  equals  $L + 2J$  as shown in Figure 4-8b.

(c) 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 withdrawal depth for the rectangular weir in Figure 4-8a would be the same as that for the polygonal weir in Figure 4-8c 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



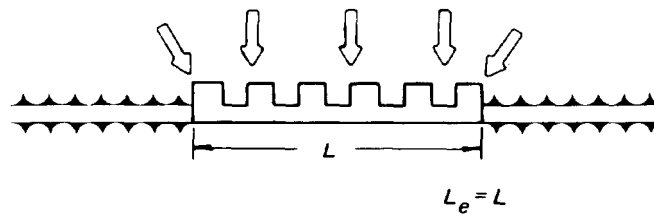
$$L_e = L$$

a. RECTANGULAR WEIR



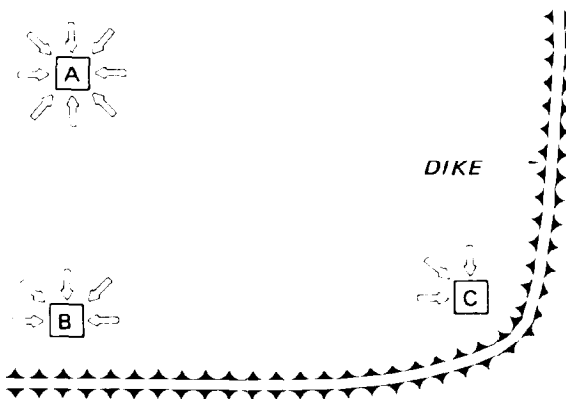
$$L_e = L + 2J$$

b. JUTTING RECTANGULAR WEIR



$$L_e = L$$

c. POLYGONAL WEIR



d. SHAFT WEIRS

Figure 4-8. Effective lengths of various weir types

because of the greater cost and the marginal improvement of effluent quality realized when using such a weir.

(d) 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 Figure 4-8d. 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 Figure 4-8d, 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 Figure 4-8 may not be optimal since it is far from the dike and will require a longer pipe than Location B.

(e) Converting weir length. 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:

$$L_s = \frac{L_e}{n} \quad (4-18)$$

where  $n$  is the number of effective sides of a shaft-type weir. A side is considered effective if it is at least  $1.5 L_s$  feet 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.

(5) Structural design. Weirs should be structurally designed to withstand anticipated loadings at maximum ponding elevations. Considerations should be given to uplift forces, potential settlement, access, corrosion protection, and potential piping beneath or around the weir. Additional information regarding structural design of weirs is found in WES TR D-77-9 (item 16). Outlet pipes for the weir structure must be designed to carry flows in excess of the flow rate for the largest dredge size expected. Larger flow capacity of the outlet pipes may be needed if an emergency release of ponded water is required.

b. Weir Operation.

(1) Weir boarding.

(a) 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 board heights should range in size from 2 to 10 inches, and thickness should be sufficient to avoid excessive bending as the result of the pressure of the ponded water.

(b) Weir boarding should be determined based on the desired ponding elevation as the dredging operation progresses. Small boards (e.g., 2 inches) should be placed at the top of the weir 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 4-9 shows the recommended weir boarding used for a minimum ponding depth of 2 feet.

(2) Operational guidelines for weirs. Some basic guidelines for weir operation are given below:

(a) If the weir and the disposal site are properly designed, intermittent dredging operation should not become necessary unless the required ponding depth cannot be maintained.

(b) While the weir is in operation, floating debris should be periodically removed from the front of the weir to prevent larger withdrawal flows at greater depths.

(c) If multiple weirs or a weir with several sections is used in a basin, the crests of all weirs or weir sections should be maintained at equal elevations, in order to prevent local high velocities and resuspension in front of the weir with lower elevation.

(d) 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.

(e) The weir may be controlled in the field by using the head over the weir as an operational parameter since the actual volumetric flow over the weir cannot easily be measured.

(3) 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 crest thickness  $t_w$  is less than two-thirds the depth of flow over the weir  $h$  as seen in Figure 4-6. The ratio of depth of flow over the weir to the static head  $h/H_s$  equals 0.85 for rectangular sharp-crested weirs. Other values for the ratio of depth of flow to static head for various weir configurations may be found in the Handbook of Applied Hydrology (item 7). 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:

$$H_s = \left[ 0.3 \frac{Q}{L} \right]^{2/3} \quad (4-19)$$

and

$$h = 0.85 H_s \quad (4-20)$$

where

$H_s$  = static head above the weir crest, feet

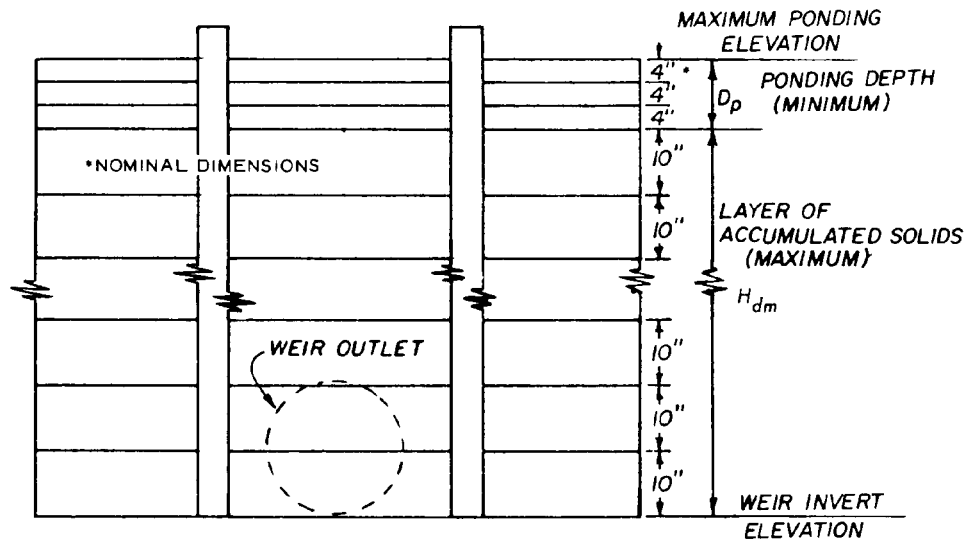


Figure 4-9. Recommended boarding configuration

$Q$  = flow rate, cubic feet per second ( $Q = Q_i = Q_e$  for continuous operation)

$Q_e$  = clarified effluent rate, cubic feet per second

$L$  = weir crest length, feet

$h$  = depth of flow over the weir crest, feet

These relationships are shown graphically in Figure 4-10. If a given flow rate is to be maintained, Figure 4-10 can be used to determine the corresponding head and depth of flow. If the head in the basin exceeds this value, additional weir boards can be added, or the dredge can be operated intermittently 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 parameter. The operator need not be concerned with head over the weir if effluent suspended solids concentrations are acceptable.

(4) Weir operation for undersized basins. If the basin is undersized and/or inefficient settling is occurring in the basin, added residence time and reduced approach velocities are needed to achieve efficient settling and to avoid resuspension, respectively. Added residence 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 residence 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.

(5) 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-inch 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

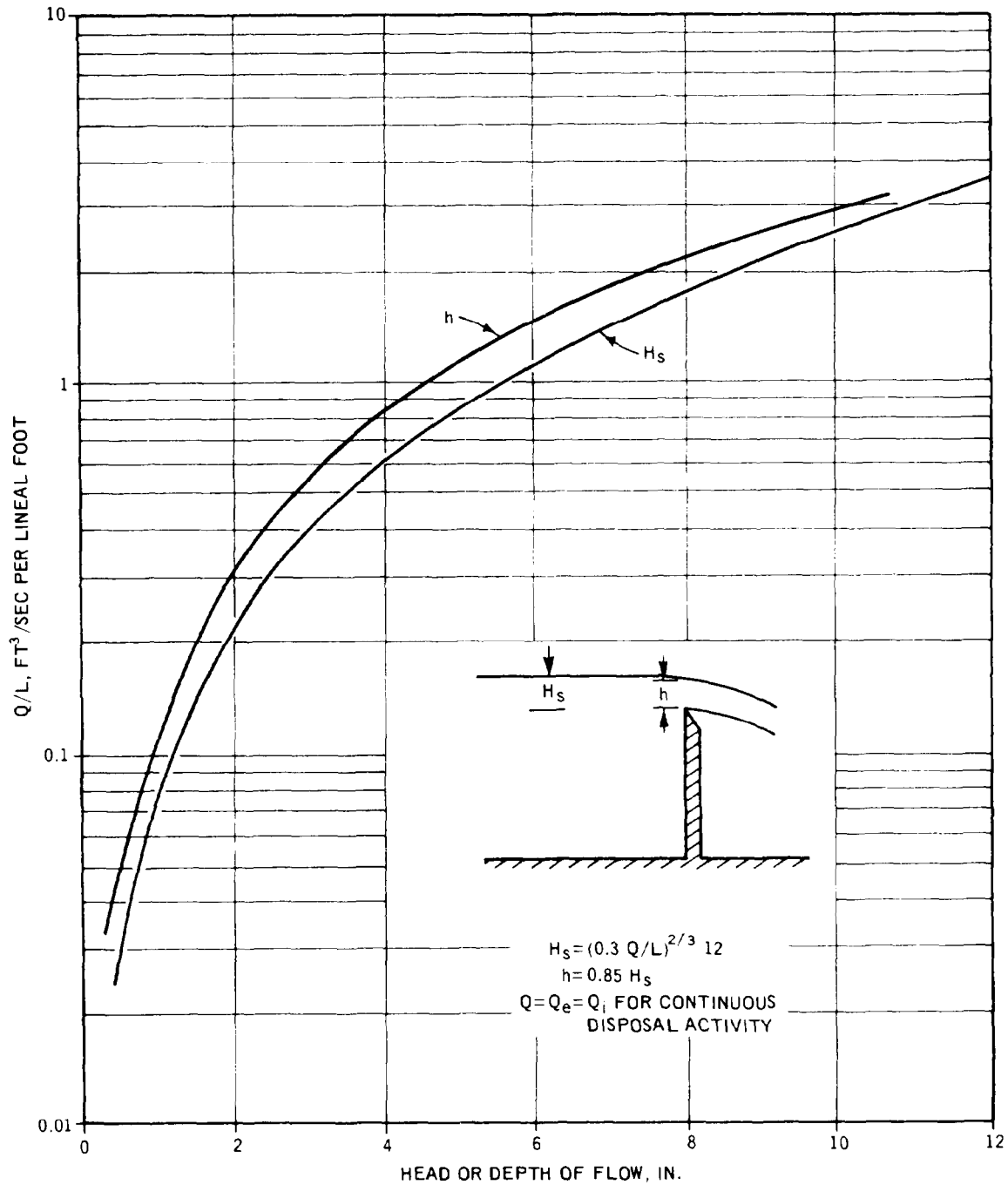


Figure 4-10. Relationship of flow rate, weir length, and head

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water level is drawn down close 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, allowing low flow for slow removal of surface water.

4-5. Design of Chemical Clarification Systems. Pipeline injections of chemicals for clarification into the dredge inflow pipeline have shown only limited effectiveness and require much higher dosages of chemicals. This section therefore presents only the design procedures for chemical clarification of primary containment area effluents. The design is composed of three subsystems: the polymer feed system including storage, dilution, and injection; the weir and discharge culvert for mixing; and the secondary basin for settling and storage. The treatment system should be designed to minimize equipment needs and to simplify operation. Detailed procedures and examples are presented in Appendix G.

## CHAPTER 5

## LONG-TERM STORAGE CAPACITY OF CONTAINMENT AREAS

5-1. Factors Affecting Long-Term Storage Capacity.

## a. General.

(1) In order that the maximum benefits can be derived from areas constructed for the confined disposal of dredged material, the design and operation plan must accurately account for the long-term increase in storage capacity in containment areas resulting from decreases in the height of dredged fill deposited. The height of the dredged fill decreases by three natural processes: sedimentation, consolidation, and desiccation. Sedimentation is a relatively short-term process, whereas consolidation and desiccation are long-term processes. Design of containment areas for effective sedimentation was discussed in Chapter 4. This chapter presents guidelines for estimating long-term containment area storage capacity, considering both dredged material consolidation and dewatering (evaporative drying). The storage capacity is defined as the total volume available to hold additional dredged material and is equal to the total unoccupied volume minus the volume associated with ponding requirements and freeboard requirements. The estimation of long-term storage capacity is an important consideration for long-term planning and design of new containment areas or evaluation of the remaining service life of existing sites.

(2) After dredged material is placed within a containment area, it undergoes sedimentation and self-weight consolidation, resulting in gains in storage capacity. The placement of dredged material also imposes a loading on the containment area foundation; therefore, additional settlement may result from consolidation of compressible foundation soils. Settlement due to consolidation is therefore a major factor in the estimation of long-term storage capacity. Since the consolidation process is slow, especially in the case of fine-grained materials, it is likely that total settlement will not have taken place before the containment area is required for additional placement of dredged material. Settlement of the containing dikes may also significantly affect the available storage capacity and should be considered. Once a given active dredging operation ends, the ponded surface water required for settling is decanted, exposing the dredged material surface to desiccation (evaporative drying). This process can further add to long-term storage capacity and is a time-dependent and climate-dependent process. Active dewatering operations such as surface trenching can speed the natural dewatering process. A conceptual diagram illustrating these processes is shown in Figure 5-1.

(3) Guidelines for estimation of gains in long-term capacity due to settlement within the containment area are based on the fundamental principles of consolidation theory modified to consider the self-weight consolidation behavior of newly placed dredged material. The guidelines are presented in the following paragraphs; illustrative examples are found in Appendix F.



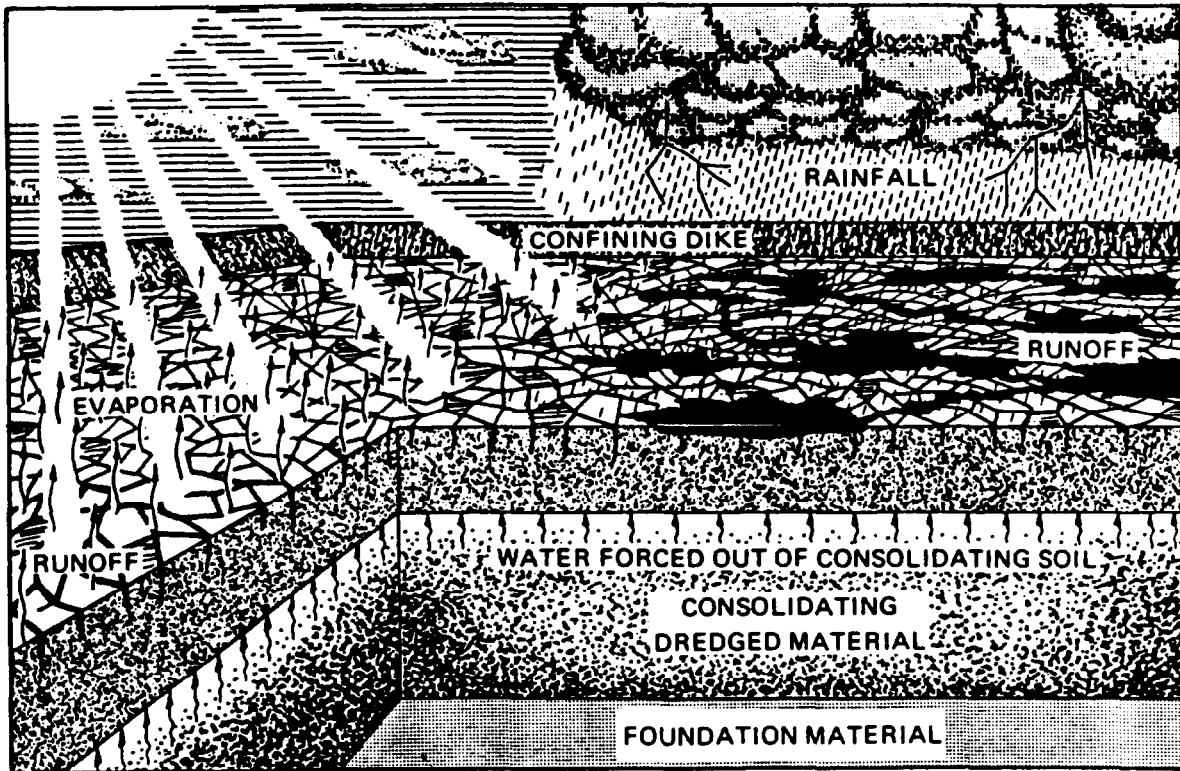


Figure 5-1. Conceptual diagram of dredged material consolidation and dewatering processes.

b. Dredged Material Consolidation. Three types of consolidation may occur in dredged material containment areas. These are primary consolidation, secondary consolidation, and consolidation resulting from desiccation.

(1) Primary consolidation. The Terzaghi standard theory of one-dimensional consolidation has received widespread use among geotechnical engineers and continues to be the first choice for estimation of settlements. The Terzaghi or "small strain theory" has received widespread application for consolidation problems in which the magnitude of settlement is small in comparison to the thickness of the consolidating layer. In contrast to the small strain theory, a "finite strain theory" for one-dimensional consolidation is better suited for describing the large settlements common to the primary consolidation of soft fine-grained dredged material. Calculation techniques are discussed in 5-2.

(2) Secondary consolidation. The process of secondary consolidation or "creep" refers to the rearrangement of soil grains under load following completion of primary consolidation. This process is not normally considered in settlement analyses and is not considered in this manual.

(3) Desiccation consolidation. There are basically two phenomena that control the amount of consolidation caused by desiccation of fine-grained dredged material. The first is the evaporation of water from the upper

sections of the dredged material. The resulting reduction in its moisture content causes a reduction in void ratio or volume occupied due to the negative pore water pressure induced by the drying. This can be referred to as the dewatering process and is discussed in 5-1.c.

(4) Consolidation in underlying material. An additional process influencing settlement involves the primary consolidation in underlying material when the free water surface is lowered. As the water surface moves downward, the unit weight acting on lower material changes from buoyant unit weight to effective unit weight. The material below the new water level is therefore subjected to an additional surcharge.

c. Dredged Material Dewatering Processes.

(1) General process description.

(a) Desiccation of dredged material is basically removal of water by evaporation and transpiration. In this report, plant transpiration is considered insignificant due to the recurrent deposition of dredged fill and is therefore disregarded. Evaporation is mainly controlled by such variables as radiation heating from the sun, convective heating from the earth, air temperature, ground temperature, relative humidity, and wind speed.

(b) However, other factors must also be taken into account. For instance, the evaporation efficiency is normally not a constant but some function of depth to which the layer has been desiccated and also is dependent on the amount of water available for evaporation.

(c) It is practical to make desiccation calculations on a monthly basis because of the availability of long-term monthly average rainfall and pan evaporation data. Rainfall and pan evaporation data have been tabulated and published in climatic summaries by the US Weather Bureau for many areas of this country. Tables of average monthly rainfall for select stations are available from the National Oceanic and Atmospheric Administration (NOAA) (item 25). Maps of monthly pan evaporation are presented in Appendix H. In the absence of more site-specific data, these sources can be used for specification of climatic data.

(2) Evaporative stages.

(a) Evaporative drying of dredged material leading to the formation of a desiccated crust is a two-stage process. The removal of water occurs at differing rates during the two stages as shown in Figure 5-2. The first stage begins when all free water has been decanted or drained from the dredged material surface. The void ratio at this point  $e_{\infty}$  corresponds to zero-effective stress as determined by laboratory sedimentation and consolidation testing. This initial void ratio has been empirically determined to be at a water content of approximately 2.5 times the Atterberg liquid limits (LL) of the material.

(b) First-stage drying ends and second stage begins at a void ratio that may be called the "decant point or saturation limit"  $e_{SL}$ . The  $e_{SL}$  of

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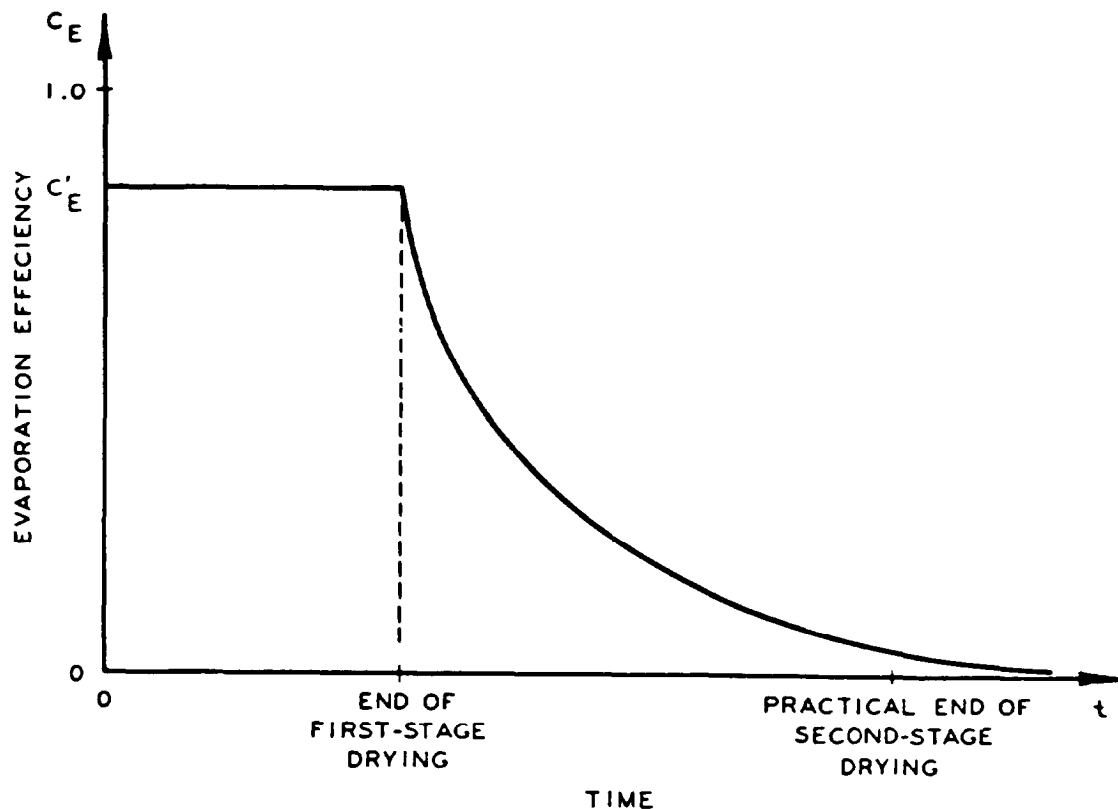


Figure 5-2. Dredged material evaporative efficiency as a function of time

typical dredged material has been empirically determined to be at a water content of approximately 1.8 LL.

(c) Second-stage drying will be an effective process until the material reaches a void ratio that may be called the "desiccation limit" or  $e_{DL}$ . When the  $e_{DL}$  reaches a limiting depth, evaporation of additional water from the dredged material will effectively cease. Any additional evaporation will be limited to excess moisture from undrained rainfall and that water forced out of the material as a result of consolidation of material below the crust. The  $e_{DL}$  of typical dredged material may roughly correspond to a water content of 1.2 plastic limit (PL). Also associated with the  $e_{DL}$  of a material is a particular percentage of saturation that probably varies from 100 percent to something slightly less, depending on the material.

#### 5-2. Estimation of Long-Term Storage Capacity.

a. Data Requirements. The data required to estimate long-term storage capacity include the consolidation and desiccation properties of the fine-grained dredged material, the consolidation properties of compressible foundation soils, and project data. Any system of units is permissible as long as

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the dimensions are consistent. For example, if layer thickness is in feet and time is in days, then permeability must be in feet per day. The data required are as follows:

- (1) Compressible foundation characteristics.
  - (a) Specific gravity of the soil solids.
  - (b) Initial thickness of the compressible foundation.
  - (c) Relationship between the void ratio and the effective stress.
  - (d) Relationship between the void ratio and the permeability.
- (2) Fine-grained dredged material characteristics.
  - (a) Specific gravity of the soil solids.
  - (b) Thickness of the initial material deposit.
  - (c) Initial void ratio of the deposit.
  - (d) Unit weight of water.
  - (e) Relationship between the void ratio and the effective stress.
  - (f) Relationship between the void ratio and the permeability.
  - (g) Filling sequence, including average thickness of deposit, time of disposal, and estimated time until the material is exposed to evaporative drying.
  - (h) Elevation of a permanent water table.
  - (i) Void ratio corresponding to the end of maximum evaporation.
  - (j) Void ratio at the end of effective material drying.
  - (k) Efficiency of surface runoff drainage in the area.
  - (l) Monthly average pan evaporation values.
  - (m) Monthly average rainfall values.
  - (n) Average pan-to-field evaporation coefficient.
  - (o) Percent saturation of the material when dried to the desiccation limit, including the desiccation crack volume.
  - (p) Maximum thickness of the dried crust.

(3) Incompressible foundation characteristics.

(a) Void ratio at the upper surface.

(b) Permeability at the upper surface.

(c) Drainage path length.

(d) Elevation of the upper surface.

b. Storage Capacity-Time Relationship.

(1) The estimated time-settlements due to dredged material consolidation and dewatering and foundation consolidation may be combined to yield a time-total settlement relationship for a single lift as shown in Figure 5-3.

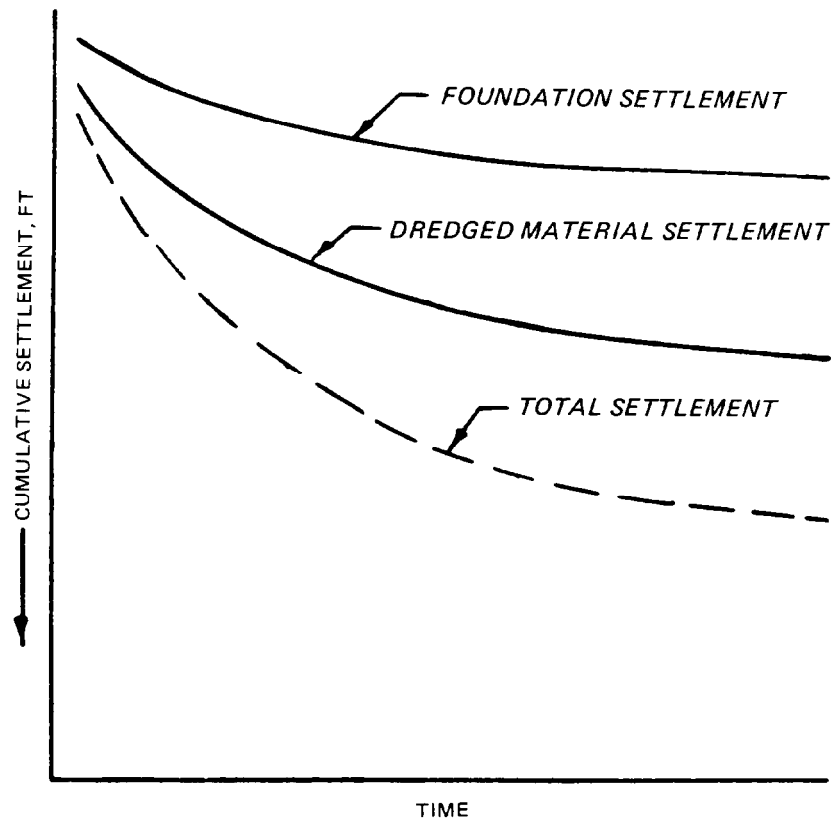


Figure 5-3. Illustrative time-consolidation relationships

These data are sufficient for estimation of the remaining capacity in the short term. However, if the containment area is to be used for long-term placement of subsequent lifts, a projected plot of dredged material surface height versus time should be developed. This plot can be developed using time-settlement relationships for sequential lifts combined as shown in

Figure 5-4. Such data may be used for preliminary estimates of the long-term service life of the containment area.

(2) The maximum dike height as determined by foundation conditions or other constraints and the containment surface area will dictate the maximum available storage volume. The increases in dredged material surface height during the dredging phases and the decreases during settlement phases correspond to respective decreases and increases in remaining containment storage capacity, shown in Figure 5-5. Projecting the relationships for surface height or for remaining capacity to the point of maximum allowable height or exhaustion of remaining capacity, respectively, will yield an estimate of the containment area service life. Gains in capacity due to anticipated dewatering or material removal should also be considered in making the projections.

(3) The complex nature of the consolidation and desiccation relationships for multiple lifts of compressible dredged material and the changing nature of the resulting loads imposed on compressible foundation soils may result in errors in projections of remaining storage capacity over long time periods. Accuracy can be greatly improved by updating the estimates every few years using data from newly collected samples and laboratory tests. Observed field behavior should also be routinely recorded and used to refine the projections.

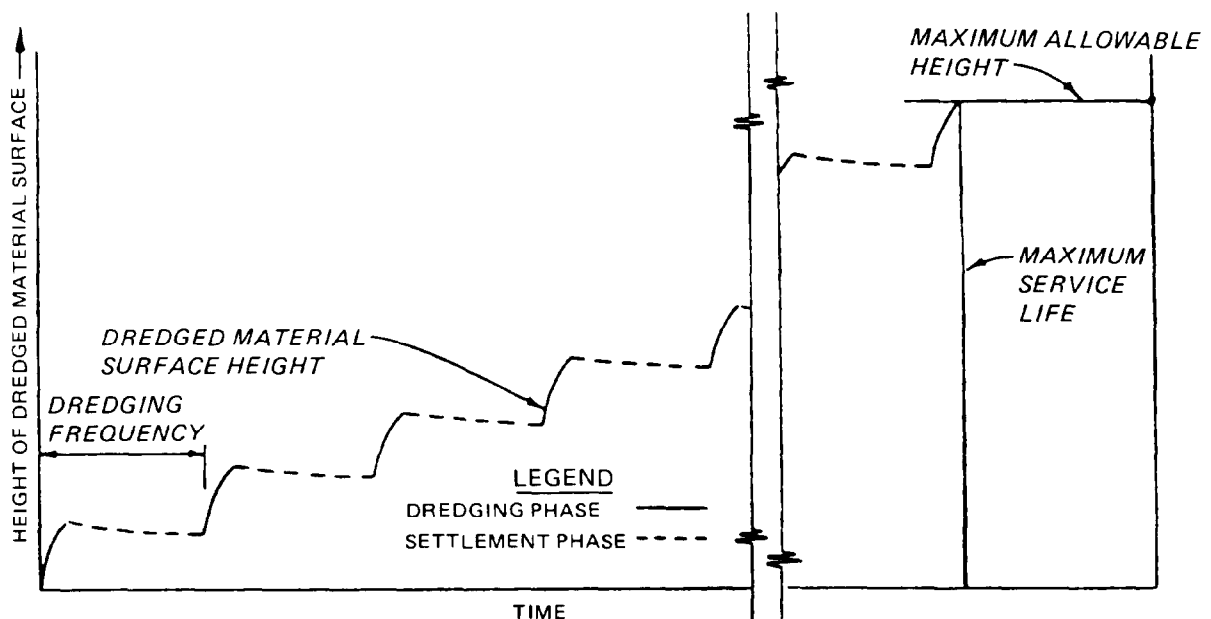


Figure 5-4. Projected surface height for determination of containment area service life

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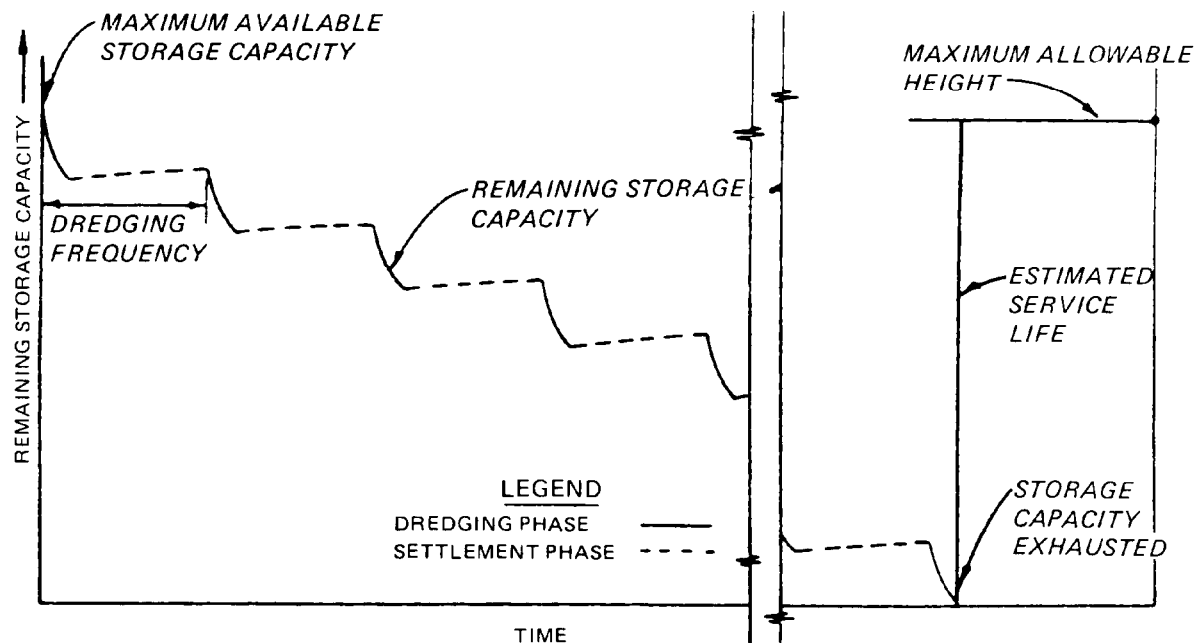


Figure 5-5. Projected storage capacity for determination of containment area service life

c. Overview of Estimation Techniques.

(1) Small strain versus finite strain consolidation.

(a) The most applicable procedure for estimating consolidation in soft dredged material is the finite strain consolidation theory. The magnitude of consolidation as determined by small strain techniques is equivalent to that determined by the finite strain technique. However, the time rate of consolidation is overly conservative for small strain in that the rate of consolidation as predicted is slow when compared to field behavior. Details on the theoretical background for the finite strain theory are given in WES TR D-83-1 and TR D-85-4 (items 5 and 6).

(b) The advantages of using the finite strain technique for the estimation of dredged material consolidation settlement are summarized in Table 5-1. The technique accounts for the nonlinearity of the void ratio, permeability, and coefficient of consolidation relationships that must be considered when large settlements of a layer are involved. Hand calculations using the finite strain approach have been developed and are presented in this manual. However, the technique is more easily applied using a computer program.

(2) Empirical methods for estimating desiccation behavior. Empirical equations for estimating the settlement of a dredged material layer due to desiccation and the thickness of dried crust were developed for the purpose of determining feasibility and benefits of active dewatering operations (item 14). The empirical relationships have been refined (Item 6) to consider the two stage process of desiccation and the overall water balance

Table 5-1

Comparison of Small Strain and Finite Strain Consolidation Techniques

<u>Consideration</u>	<u>Finite strain</u>	<u>Small strain</u>
Range of void ratios	Very large	Very small
Self-weight	Included	Not included
Void ratio/effective stress relationship	Nonlinear	Linear
Void ratio/permeability relationship	Variable	Constant

relationships that exist within a dredged material disposal area. The interaction of the desiccation process with dredged material consolidation due to self-weight has been incorporated in computer programs for estimating long-term storage capacity. The refined empirical relationships can be easily applied in determining the benefits of dewatering programs and provide increased accuracy in storage capacity evaluations.

(3) Hand calculation versus computer solution.

(a) The use of computer models can greatly facilitate the estimation of storage capacity for containment areas. Although the computations for simple cases can be easily and quickly done by hand, the analyses often require computations for a multiyear service life with variable disposal operations and possibly material removal or dewatering operations occurring intermittently throughout the service life. These complex computations can be done more efficiently using a computer model.

(b) The use of computer models holds added advantage when considering the additional settlements that occur as the result of dredged material desiccation (dewatering). The estimation of desiccation behavior can also be done by means of hand calculations; however, the interaction between desiccation and consolidation cannot be handled by direct hand computation, but instead would require cumbersome iterative calculations. A computer program is well suited to handle the calculations of both consolidation and desiccation and the interaction between the two processes.

(c) Methods of hand calculation for finite strain consolidation and desiccation are presented in Appendix F. These calculations are manageable for estimation of settlements in one dredged material layer. However, if storage capacity estimates must be made for multiple disposal operations, the use of computer programs is recommended.



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d. Computer Solutions for Consolidation and Desiccation.

(1) The recommended computer model for use in predicting the long term capacity of disposal areas is documented in the Automated Dredging and Disposal Alternatives Management System (ADDAMS) described in Chapter 8 of this manual. The program is entitled "Primary Consolidation and Desiccation of Dredged Fill (PCDDF)" and incorporates the concepts described in this chapter. Theoretical documentation, description of solution techniques, and a user guide are available (item 6). An expanded user guide with plotting routines for results is found in the ADDAMS instruction report (item 19).

(2) Examples of the results obtained using the PCDDF model are shown in Figures 5-6 and 5-7. These are plots of dredged material surface elevation versus time for several cases including multiple layers deposited at varying times. Field data collected at the respective sites are also shown for comparison.

5-3. Dredged Material Dewatering Operations.

a. General.

(1) Surface trenching for improved drainage and use of underdrains are the only technically feasible and economically justifiable dewatering techniques for dredged material containment areas. The use of underdrains has been successfully applied on a small scale; however, their use in large disposal areas has not been proven economical as compared with surface drainage techniques. Accordingly, this section describes only techniques recommended for improvement of surface drainage through trenching. Guidance for application of underdrains is found in WES Technical Report DS-78-11 (item 14).

(2) Four major reasons exist for dewatering fine-grained dredged material placed in confined disposal areas:

(a) Promotion of shrinkage and consolidation, leading to creation of more volume in the existing disposal site for additional dredged material.

(b) Reclamation of the dredged material into more stable soil form for removal and use in dike raising, other engineered construction, or other productive uses, again creating more available volume in the existing disposal site.

(c) Creation of stable fast land at a known final elevation and with predictable geotechnical properties.

(d) Benefits for control of mosquito breeding.

b. Conceptual Basis for Dewatering by Progressive Trenching. The following mechanisms were found to control evaporative dewatering of fine-grained dredged material placed in confined disposal areas:

(1) Establishment of good surface drainage allows evaporative forces to dry the dredged material from the surface downward, even at disposal area locations where precipitation exceeds evaporation (negative net evaporation).

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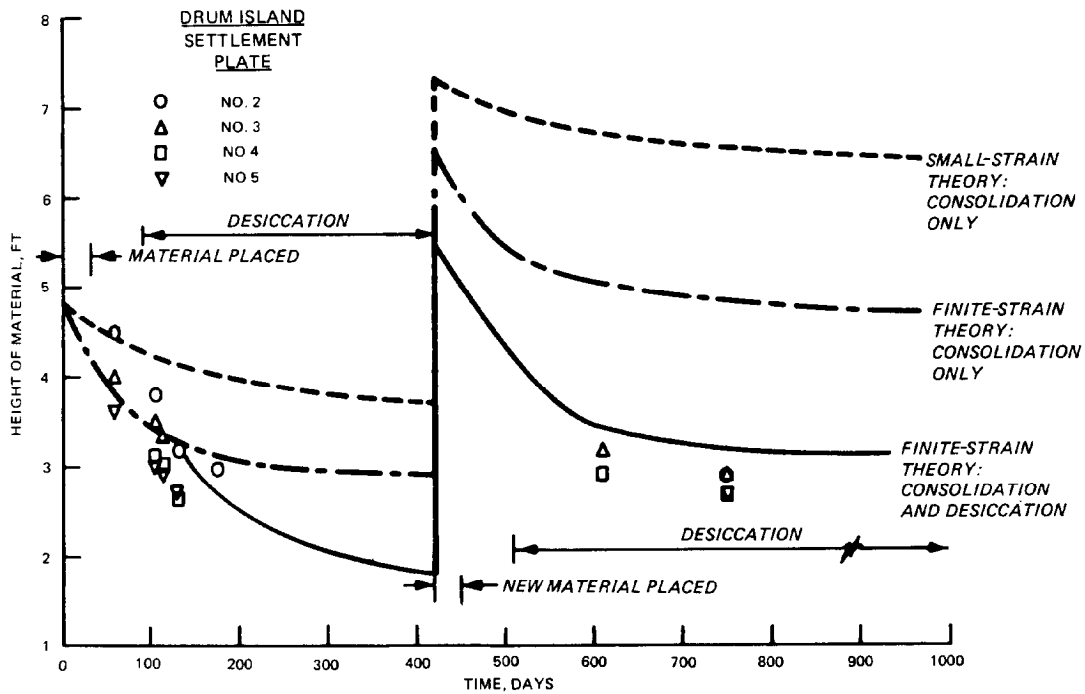


Figure 5-6. Measured and predicted material heights at Drum Island

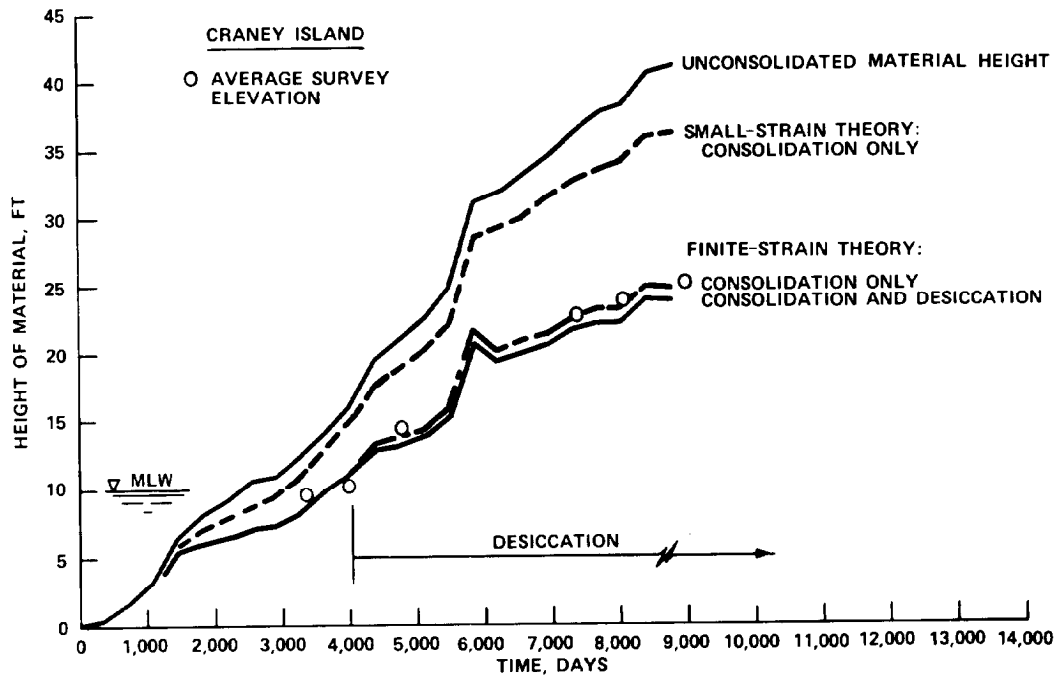


Figure 5-7. Measured and predicted material heights at Craney Island

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(2) The most practical mechanism for precipitation removal is by runoff through crust desiccation cracks to surface drainage trenches and off the site through outlet weirs.

(3) To maintain effective drainage, the flow-line elevation of any surface drainage trench must always be lower than the base of crust desiccation cracks; otherwise, ponding will occur in the cracks. As drying occurs, the cracks will become progressively deeper.

(4) Below the desiccation crust, the fine-grained subcrust material may be expected to exist at water contents at or above the liquid limit (LL). Thus, it will be difficult to physically construct trenches much deeper than the bottom of the adjacent desiccation crust.

(5) To promote continuing surface drainage as drying occurs, it is necessary to progressively deepen site drainage trenches as the water table falls and the surface crust becomes thicker; thus, the name "progressive trenching" was developed for the concept.

(6) During conduct of a progressive trenching program, the elevation difference between the internal water table and the flow line of any drainage trench will be relatively small. When the relatively low permeability of fine-grained dredged material is combined with the small hydraulic gradient likely under these circumstances, it appears doubtful that appreciable water can be drained from the dredged material by gravity seepage. Thus, criteria for trench location and spacing should be based on site topography so that precipitation is rapidly removed and ponding is prevented, rather than to achieve marked drawdown from seepage.

c. Effects of Dewatering. The net observable effects of implementing any program of dewatering by improved surface drainage will be as follows:

- (1) Disappearance of ponded surface water.
- (2) Runoff of the majority of precipitation from the site within a few hours.
- (3) Gradual drying of the dredged material to more stable soil form.
- (4) Vertical settlement of the surface of the disposal area.
- (5) Ability to work within the disposal area with conventional equipment.

d. Initial Dewatering (Passive Phase).

(1) Once the disposal operation is completed, dredged material usually undergoes hindered sedimentation and self-weight consolidation (called the "decant phase"), and water will be brought to the surface of the consolidating material at a faster rate than can normally be evaporated. During this phase, it is extremely important that continued drainage of decant water and/or precipitation through outlet weirs be facilitated. Weir flow-line elevations may have to be lowered periodically as the surface of the newly placed dredged

material subsides. Guidelines for appropriate disposal site operation during this passive dewatering phase, to maximize decant and precipitation water release while maintaining appropriate water quality standards, are described in Chapter 7.

(2) Once the fine-grained dredged material approaches the decant point water content, or saturation limit as described previously, the rate at which water is brought to the surface will gradually drop below the climatic evaporative demand. If precipitation runoff through site outflow weirs is facilitated, a thin drying crust or skin will form on the newly deposited dredged material. The thin skin may be only several hundredths of a foot thick, but its presence may be observed by noting small desiccation cracks that begin to form at 3- to 6-foot intervals, as shown in Figure 5-8. Once the dredged material has reached this consistency, active dewatering operations may be initiated.

e. Dewatering by Progressive Trenching.

(1) Three procedures have been found viable to initiate active dredged material dewatering by improved surface drainage, once the material has achieved consistency conditions shown in Figure 5-8: periodic perimeter



Figure 5-8. Surface of fine-grained dredged material at the earliest time when surface trenching should be attempted; initial cracks are spaced at 3- to 6-foot intervals, and the surface water content approaches  $1.8 \times LL$

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trenching by dragline, with draglines working initially from perimeter dikes and subsequently from berms established inside the perimeter dikes; periodic interior site trenching; or a combination of these two methods. This section presents information necessary to properly conduct dewatering operations by these procedures. Only the last two procedures will result in total site dewatering at the maximum rates. The first procedure would have, in many instances, an effective interior dewatering rate considerably less than the predicted maximum rate, though the exact lower rate would be highly site-specific.

(2) Perimeter dragline trenching operations.

(a) Construction of trenches around the inside perimeter of confined disposal sites is a procedure that has been used for many years to dewater and/or reclaim fine-grained dredged material. In many instances, the purpose of dewatering has been to obtain convenient borrow for use in perimeter dike raising activities. Draglines and backhoes have been found to be adaptable to certain activities because of their relatively long boom length and/or method of operation and control. The perimeter trenching scheme should be planned carefully so as not to interfere with operations necessary for later dewatering or other management activities.

(b) When initiating dragline trenching operations, the largest size, longest boom length dragline that can be transported efficiently to the disposal site and can operate efficiently on top of disposal site dikes should be obtained. Operations should begin at an outflow weir location, where the dragline, operating from the perimeter dike, should dig a sump around the weir extending into the disposal area to maximum boom and bucket reach. The very wet excavated material is cast against the interior side of the adjacent perimeter dike. It may be necessary to board up the weir to prevent the very wet dredged material from falling into the weir box during the sump-digging operation. A localized low spot some 1 or 2 inches in elevation below the surrounding dredged material can be formed. Once the sump has been completed, weir boards should be removed to the level of the dredged material, and, if necessary, handwork should be conducted to ensure that any water flowing into the sump depression will exit through the outflow weir.

(c) Once the sump has been completed, the dragline should operate along the perimeter dike, casting its bucket the maximum practicable distance into the disposal area, dragging material back in a wide shallow arc to be cast on the inside of the perimeter dike. A wide shallow depression 1 to 2 inches lower than the surrounding dredged material will be formed. The cast material will stand on only an extremely shallow (1 vertical on 10 horizontal or less) slope. A small dragline should be able to accomplish between 200 and 400 linear feet of trenching per working day.

(d) Dredged material near the ditch edge will tend to dry slightly faster than material located farther out in the disposal site, with resulting dredged material shrinkage giving a slight elevation gradient from the site interior toward the perimeter trenches, also facilitating drainage (Figure 5-9). In addition, desiccation crack formation will be more pronounced near the drainage trenches, facilitating precipitation runoff through the cracks to the perimeter trenches.

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Figure 5-9. Shallow initial perimeter trench constructed by dragline operating from perimeter dike

(e) Once appreciable desiccation drying has occurred in the dredged material adjacent to the perimeter trench and the material cast on the interior slope of the perimeter dike has dried, the perimeter trenches and weir sumps should be deepened. The exact time between initial and secondary trench deepening will vary according to the engineering properties of the dredged material and existing climatological conditions, ranging from 2 or 3 weeks during hot, dry summer months up to 8 or 10 weeks in colder, wetter portions of the year. Inspection of the existing trenches is the most reliable guideline for initiating new trench work, since desiccation cracks 1 or 2 inches deep should be observed in the bottom of existing trenches before additional trenching is begun. Depending on the size of the disposal area, relative costs of mobilization and demobilization of dragline equipment, and the relative priority and/or need for dewatering, it may prove convenient to employ one or more draglines continuously over an interval of several months to periodically work the site. A second trenching cycle should be started upon completion of an initial cycle, a third cycle upon completion of the second cycle, etc., as needed.

(f) During the second trenching, wide shallow trenches with a maximum depth of 2 to 6 inches below the surface of adjacent dredged material can be constructed, and sumps can be dug to approximately 8 to 12 inches below surrounding dredged material. These deeper trenches will again facilitate more rapid dewatering of dredged material adjacent to their edges, with resulting shrinkage and deeper desiccation cracks providing a still steeper drainage flow gradient from the site Interior to the perimeter trenches.

(g) After two or perhaps three complete periodic perimeter dragline trenching cycles, the next phase of the trenching operation may be initiated. In this phase, the dragline takes the now dry material placed on the interior

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of the perimeter dike and spreads it to form a low berm adjacent to the dike inside the disposal area. The dragline then moves onto this berm, using single or double mats if required and using the increased digging reach now available, and widens and extends the ditch into the disposal site interior, as shown in Figure 5-10. The interior side of the ditch is composed of material previously dried, and a ditch 12 to 18 inches deep may be constructed, as shown in Figure 5-11. Material excavated from this trench is again cast on the interior slope of the perimeter dike to dry and be used either for raising the perimeter dike or for subsequent berming farther into the disposal area.

(h) After two or more additional periodic trench deepenings, working from the berm inside the disposal area, trenches up to 3 to 5 feet deep may be completed. Trenches of this depth will cause accelerated drying of the dredged material adjacent to the trench and produce desiccation cracks extending almost the entire thickness of the adjacent dredged material, as shown in Figure 5-12. A well-developed perimeter trench network leading to outflow weirs is now possible, as shown in Figure 5-13, and precipitation runoff is facilitated through gradual development of a network of desiccation cracks which extend from the perimeter trenches to the interior of the site.

(i) Once a perimeter trench system such as that shown in Figure 5-13 is established, progressive deepening operations should be conducted at less frequent intervals, and major activity should be changed from deepening perimeter trenches and weir sumps to that of continued inspection to make sure that the ditches and sumps remain open and facilitate free drainage. As a desiccation crack network develops with the cracks becoming wider and deeper, precipitation runoff rate will be increased and precipitation ponding in the site interior will be reduced. As such ponding is reduced, more and more evaporative drying will occur, and the desiccation crack network will propagate toward the



Figure 5-10. Small dragline on mats working on berm deepens shallow perimeter drainage trench



Figure 5-11. Construction of ditch 12 to 18 inches deep with excavated material cast on interior slope of perimeter dike



Figure 5-12. Desiccation crust adjacent to perimeter  
3- to 5-foot-deep drainage trench





Figure 5-13. A well-developed perimeter trenching system, Morris Island Disposal Site, Charleston District

disposal area interior. Figure 5-13 is a view of the 500-acre Morris Island Disposal Site of the Charleston District, where a 3-foot lift of dredged material was dewatered down to approximately a 1.7-foot thickness at the perimeter over a 12-month period by an aggressive program, undertaken by the District, of site drainage improvement with dragline perimeter trenching. Figure 5-14 shows the 12-inch desiccation crust achieved at a location approximately 200 yards from the disposal area perimeter. The dredged material was a CH clay with an LL over 100. However, despite the marked success with perimeter trenching, a close inspection of Figure 5-13 shows that ponded water still exists in the site interior.

### (3) Interior trenching.

(a) Riverine utility craft. The high water content of dredged material during the initial dewatering stages requires the use of some type of amphibious or low-ground-pressure equipment for construction of trenches in the site interior. The Riverine Utility Craft (RUC), an amphibious vehicle using twin screws for propulsion and flotation, can successfully construct shallow trenches in fine-grained dredged material shortly after formation of a thin surface crust. It can also be effective in working with other equipment in constructing sump areas around outflow weirs for collection of surface water. The RUC was initially developed in the 1960's as a reconnaissance vehicle for military applications and was used on an experimental basis for trenching operations. RUC vehicles have since been successfully applied in dewatering operations in the Mobile, Charleston, and Norfolk Districts for both trenching and surveying/sampling applications. Even though this vehicle is perhaps the only tool that can be used to construct shallow trenches in dredged material



Figure 5-14. Desiccation crust achieved in highly plastic clay dredged material 200 yards into disposal area by perimeter trenching over 12-month period

with little or no developed surface crust, its potential use in dewatering operations is limited. The RUC is susceptible to maintenance problems because of the nature of the drive train and frame, which were not designed for heavy use in trenching operations on a production basis. The nonavailability of RUC vehicles limits their potential widespread use for routine dewatering operations. Only two vehicles are available Corps-wide. Also, field experience has shown that the early stages of evaporative dewatering and crust development occur at acceptable rates considering only the natural drying processes, perhaps aided by perimeter trenching as described previously. Once a surface crust of 4 to 6 inches has developed, more productive trenching equipment as described in the following paragraphs can be used.

(b) Rotary trenchers. The use of trenching equipment with continuously operating rotary excavation devices and low-ground-pressure chassis is recommended for routine dewatering operations. This type of equipment has been used successfully in dewatering operations in the Savannah District and in the other numerous locations along the Atlantic Coast for mosquito control. The Charleston, Norfolk, and Philadelphia Districts have also used this equipment for dewatering operations. The major features of the equipment include a mechanical excavation implement with cutting wheel or wheels used to cut a trench up to 3 feet deep. The low-ground-pressure chassis may be tracked or rubber tired. The major advantage of rotary trenchers is their ability to

continuously excavate while slowly moving within the containment area. This allows them to construct trenches in areas where the use of dragline or back-hoe equipment would cause mobility problems. Photographs of tracked and rubber-tired trenchers are shown in Figures 5-15 and 5-16. The excavating wheels can be arranged in configurations that create hemispherical or trapezoidal trench cross sections and can throw material to one or both sides of the trench. The material is spread in a thin layer by the throwing action, which allows it to dry quickly and prevents the creation of a windrow which might block drainage to the trench. Photographs of the excavating devices, ongoing trenching operations, and configuration of constructed trenches are shown in Figures 5-17 through 5-22. Based on past experience, an initial crust thickness of 4 to 6 inches is required for effective mobility of the equipment. This crust thickness can be easily formed within the first year of dewatering effort if surface water is effectively drained from the area, assisted by perimeter trenches constructed by draglines operating from the dikes. A suggested scheme for perimeter and interior trenching using a combination of draglines and a rotary trencher or other suitable equipment is shown in Figure 5-23.

(c) Trench spacing. The minimum number of trenches necessary to prevent precipitation ponding on the disposal area surface should be constructed. These trenches should extend directly to low spots containing ponded water. However, the greater the number of trenches per unit of disposal site area, the shorter the distance that precipitation runoff will have to drain through desiccation cracks before encountering a drainage trench. Thus, closely spaced trenches should produce more rapid precipitation runoff and may slightly increase the rate of evaporative dewatering. Conversely, the greater the number of trenches constructed per unit of disposal site area, the greater the cost of dewatering operations and the greater their impact on subsequent dike raising or other borrowing operations. However, the rotary trenchers have a relatively high operational speed, and it is therefore recommended that the maximum number of drainage trenches be placed consistent with the specific trenching plan selected. Trench spacings of 100 to 200 feet have normally been used. If topographic data are available for the disposal site interior, they may be used as the basis for preliminary planning of the trenching plan.

(d) Parallel trenching. The most common trench pattern would employ parallel trenching. A complete circuit of the disposal area with a perimeter trench is joined with parallel trenches cut back and forth across the disposal area, ending in the perimeter trench. Spacing between parallel trenches can be varied as described above. A parallel pattern is illustrated in Figure 5-22. A schematic of a parallel trenching pattern with radial combinations is shown in Figure 5-23.

(e) Radial trenching pattern. Small disposal areas or irregularly-shaped disposal areas may be well suited for a radial trenching pattern for effective drainage of water to the weir structures. The radial patterns should run parallel to the direction of the surface slopes existing within the area. Radial trenching patterns can also be used to provide drainage from localized low spots to the main drainage trench pattern. When the disposal area is extremely large in areal extent or when interior cross dikes or other obstructions exist within the disposal area, sequential sets of radial trenches may be constructed, with the sets farthest into the disposal area



Figure 5-15. Rubber-tired rotary trencher



Figure 5-16. Track-mounted rotary trencher used in mosquito control activities



Figure 5-17. View of hemispherical rotary trenching implement

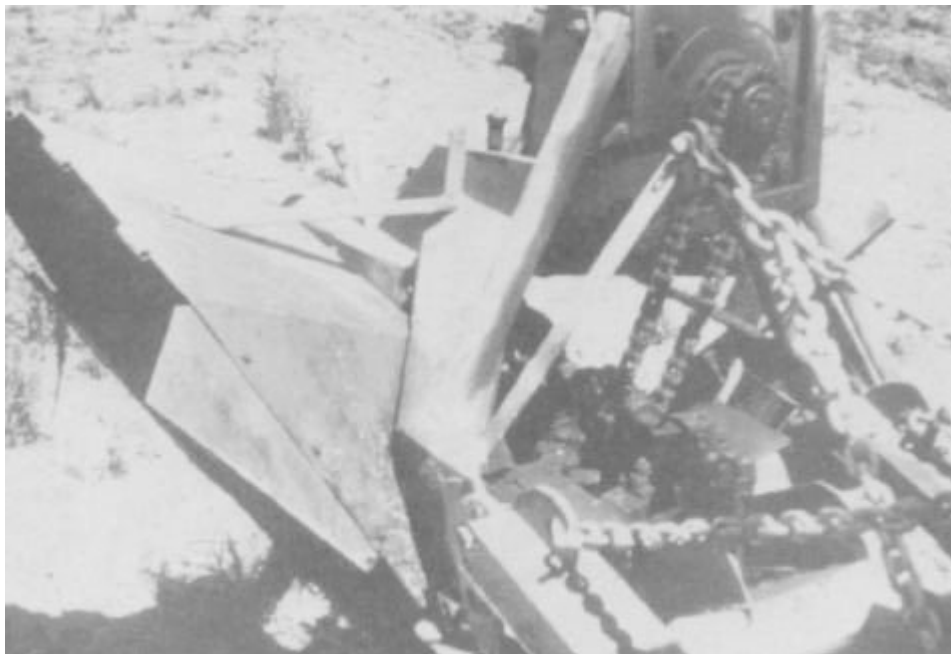


Figure 5-18. View of the trapazodial rotary trenching implement



Figure 5-19. View of rotary trenching device in operation



Figure 5-20. General view of trenches formed  
by rotary trencher

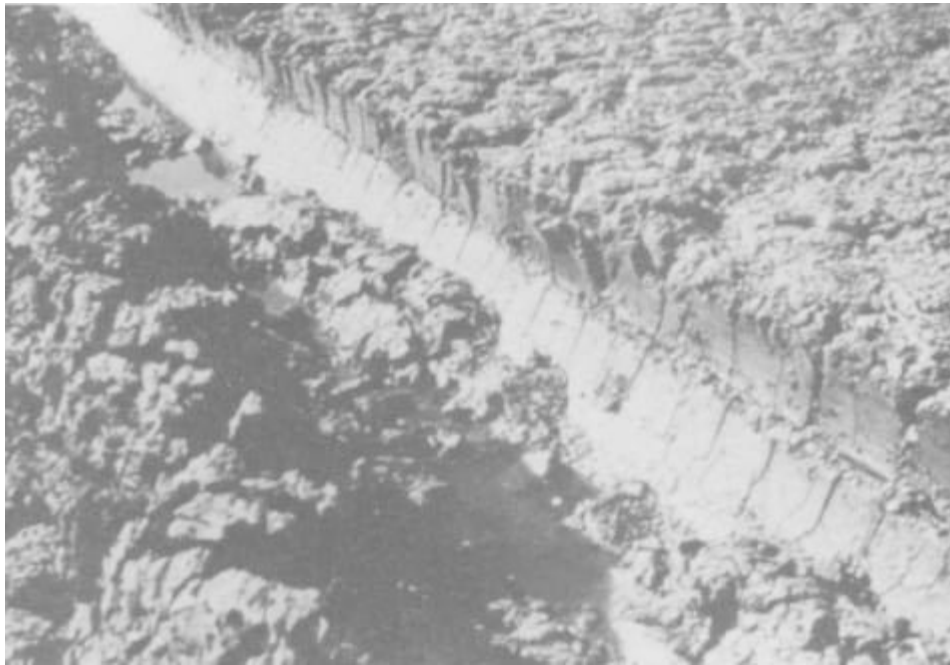


Figure 5-21. Closeup view of trenches formed by rotary trencher



Figure 5-22. General view of confined disposal area showing parallel trenches in place

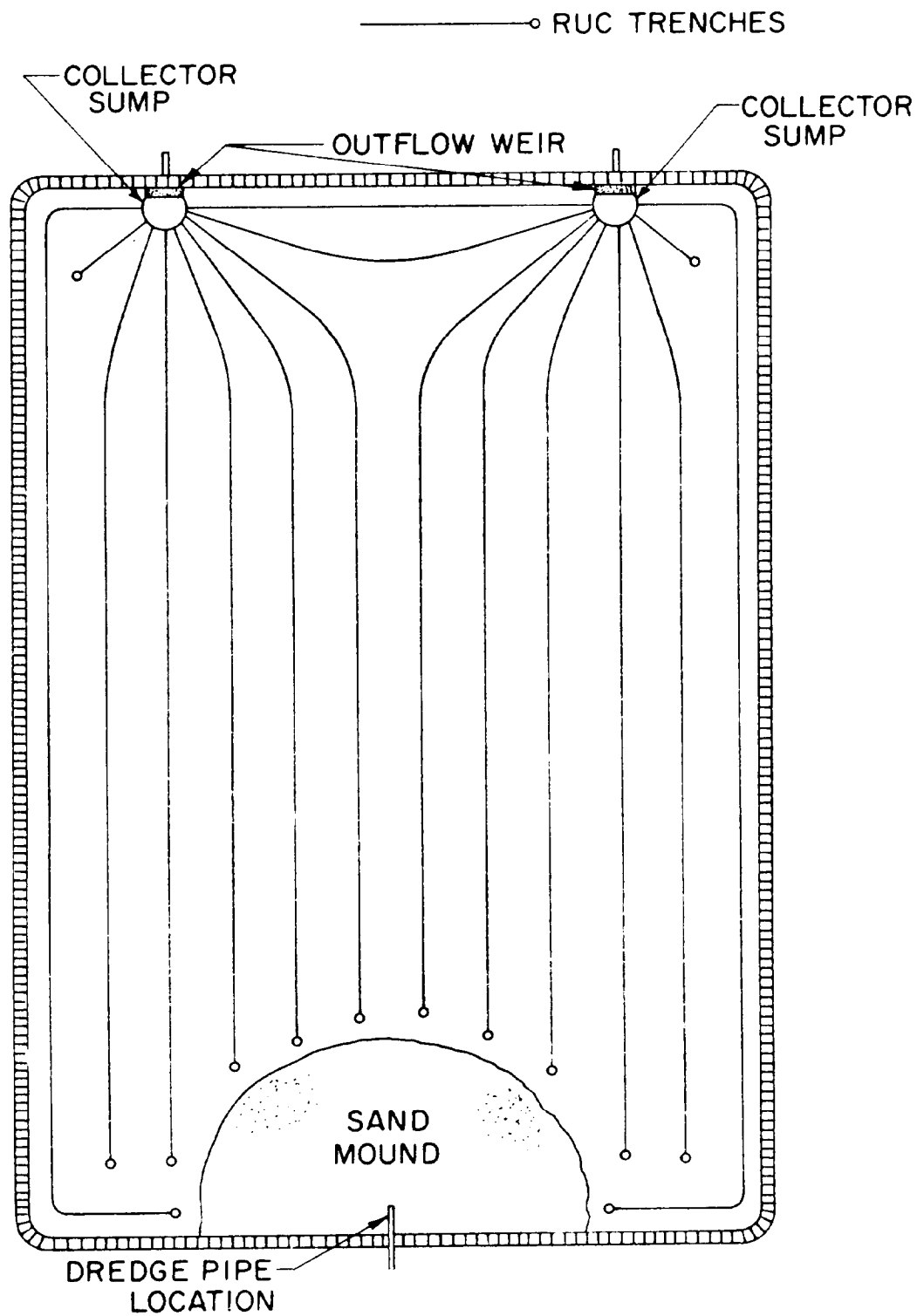


Figure 5-23. Combination radial-parallel trenching scheme



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interior acting as collectors funneling into one of the radial trenches extending from the outflow weir. This sequential radial trenching procedure is shown in Figure 5-24, as constructed in the South Blakely Island Disposal Site of the Mobile District.



Figure 5-24. Aerial view of sequential radial trenching procedure used when interior cross dikes are encountered, South Blakely Island Disposal Site of the Mobile District

## CHAPTER 6

DESIGN AND CONSTRUCTION OF DIKES FOR CONTAINMENT  
OF DREDGED MATERIAL

6-1. Purpose. Containment dikes are retaining structures used to form confined disposal facilities. They consist primarily of earth embankments and can be constructed in upland or nearshore areas or on nearshore islands. The principal objective of a dike is to retain solid particles and pond water within the disposal area while at the same time allowing the release of clean effluent to natural waters. The location of a containment 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 containment dikes are generally dictated by containment capacity requirements, availability of construction materials, and prevailing foundation conditions.

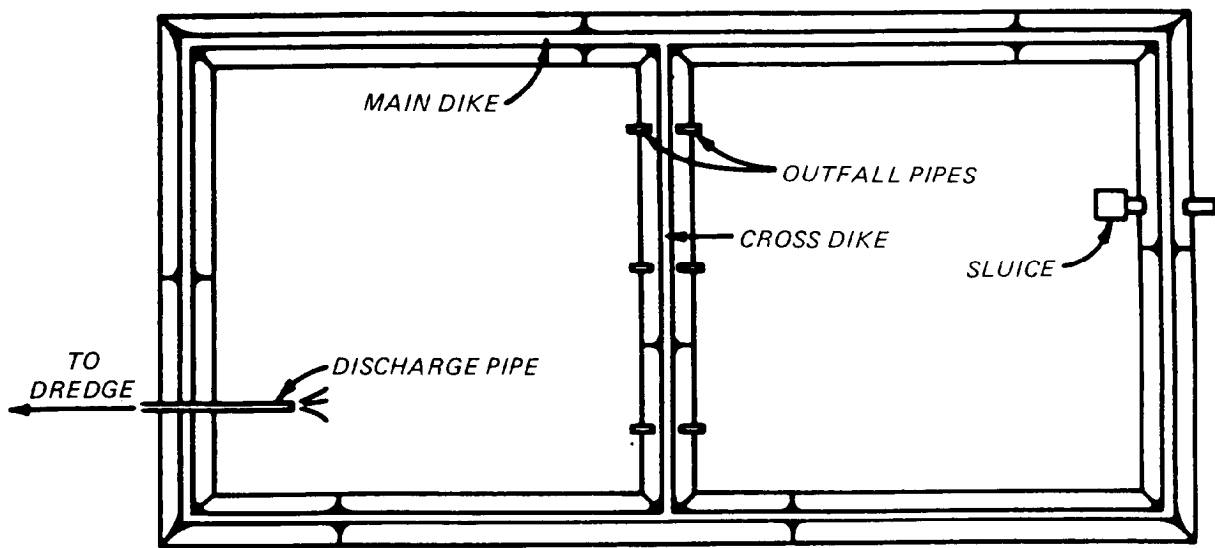
## a. Types of Containment Dikes.

(1) Main dike. The 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 chapter applies to the main dike. The main dike and two other type dikes, cross and spur dikes, which serve primarily as operational support structures for the main dike, are shown in Figure 6-1.

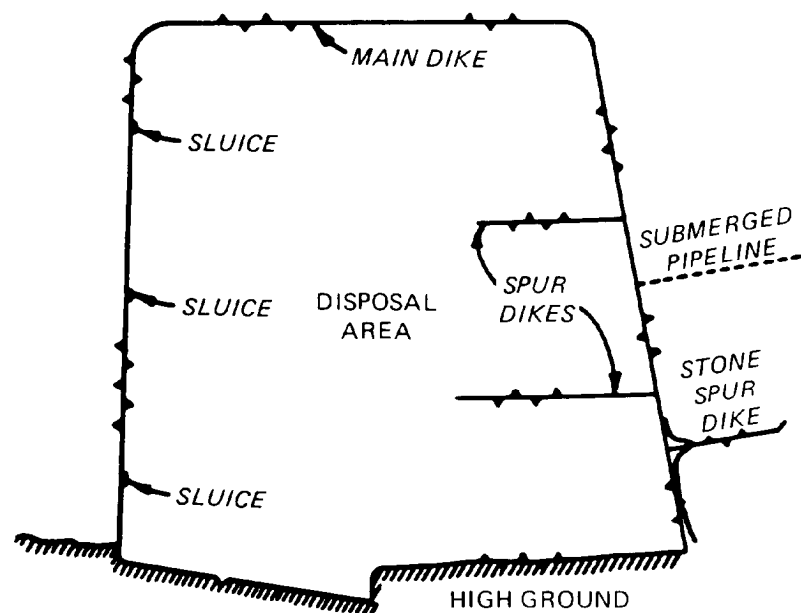
(2) Cross dike. A cross or lateral dike (Figure 6-1) is placed across the interior of the containment area connecting two sides of the main dike. This permits the use of one area as an active disposal area while another area may be used solely for dewatering. Another use of cross dikes is to separate the facility 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. A cross dike can also be used with a Y-discharge line to divide an area into two or more areas, each receiving a portion of the incoming dredged material.

(3) Spur dike. Spur or finger dikes protrude into, but not completely across, the disposal area from the main dike as shown in Figure 6-1. 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 coalescence of the two dredged material inputs and thereby discouraging an otherwise large quantity of slurry from reaching flow velocities necessary for channelization.

b. Factors affecting design. The engineering design of a dike includes selection of location, height, cross section, material, and construction method. The selection of a design and construction method are dependent on project constraints, foundation conditions, material availability, and availability of construction equipment. The final choice will be a selection among feasible alternatives.



a. DIKED DISPOSAL AREA WITH CROSS DIKE



b. DIKED DISPOSAL AREA WITH SPUR DIKES

Figure 6-1. Examples of cross and spur dikes

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(1) Project constraints. Several constraints on design are placed by the overall project needs. Available construction time and funding are always factors. The location, height, and available space for the containment dike are usually dictated by project requirements that are discussed elsewhere in this manual. The design factor of safety against structural failure is usually specified. Environmental safety and aesthetics must be considered.

(2) Foundation conditions. The lateral and vertical distribution of shear strength, compressibility, permeability, and stratification of potential foundation materials are major factors in dike design.

(3) Availability of materials. All potential sources of construction materials for the embankment should be characterized according to location, type, index properties, and ease of recovery. Available disposal sites are often composed in the near-surface of soft clays and silts of varying organic content. Since economical dike construction normally requires the use of material from inside the disposal area and/or immediately adjacent borrow areas, initial dike heights may be limited, or it may be necessary to use rather wide embankment sections, expensive foundation treatment, or expensive construction methods.

(4) Availability of equipment. Although common earthwork equipment is generally available, the specialized equipment for the soft soils desirable for use at containment sites may not be available to meet the project schedule, or the mobilization cost may be excessive. Less expensive alternatives should then be considered.

c. Construction Methods. Each type of construction method has characteristics that can strongly affect dike design. Transportation of the soil material to be placed in the dike section is either by hauling, casting, or dredging. The soil is then compacted, semicompacted, or left uncompacted. The selection of a construction method, even though based on economics, must also be compatible with available materials, available equipment, geometry of the final dike section, and environmental considerations.

6-2. Foundation Investigation. The extent to which the site investigation(s) and design studies are carried out is dependent, in part, on the desired margin of safety against failure. This decision will usually be made by the local design agency and is affected by a number of site-specific factors. Table 6-1 lists some general factors, based on engineering experience, that can be used as general guidelines in the planning stage of a project.

a. Foundation Exploration. The purpose of the foundation exploration is similar to that for the containment area as defined in Section 2-3, i.e., to define dike foundation conditions including depth, thickness, extent, composition, and engineering properties of the foundation strata. The exploration is made in stages, each assembling all available information from a given source prior to the planning and start of the next, more expensive stage. The usual sequence of the foundation exploration is shown in Table 6-2.

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Table 6-1  
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.

Additional guidance on the number, depth, and spacing of exploratory and/or final phase borings is given in WES TR D-77-9 (item 16), EM 1110-2-2300, ASCE Manual No. 56 (item 3), and various geotechnical engineering textbooks. Geo-physical exploration methods are described in EM 1110-1-1802.

b. Field and Laboratory Tests. Field soils tests are often made during exploratory boring operations. Commonly used field tests are given in Table 6-3. Disturbed samples from exploratory and final phase borings are used for index properties tests. Samples from undisturbed sample borings are used in laboratory tests for engineering properties. Commonly used laboratory tests are given for fine-grained soils in Table 6-4 and for coarse-grained soils in Table 6-5. Additional guidance on field soil sampling methods is given in EM 1110-2-1907 and on laboratory soils testing in EM 1110-2-1906.

### 6-3. Construction Materials.

#### a. Acceptable Materials.

(1) Almost any type of soil material is acceptable (even though not the most desirable) for construction of a retaining dike, with the exception of very wet fine-grained soils and those containing a high percentage of organic

Table 6-2  
Stages of Field Investigation

Stage	Features
Preliminary geological investigation	<p>Office study</p> <p>Collection and study of:</p> <ul style="list-style-type: none"> <li>Topographic, soil, and geological maps</li> <li>Aerial photographs</li> <li>Boring logs and well data</li> <li>Information on existing engineering projects</li> </ul> <p>Field survey</p> <p>Observations and geology of area, documented by written notes and photographs, including such features as:</p> <ul style="list-style-type: none"> <li>Riverbank and coastal slopes, rock outcrops, earth and rock cuts or fills</li> <li>Surface materials</li> <li>Poorly drained areas</li> <li>Evidences of instability of foundations and slopes</li> <li>Emerging seepage and/or soft spots</li> <li>Natural and man-made physiographic features</li> </ul>
Subsurface exploration and field testing and more detailed geologic study	<p>Exploratory phase</p> <ul style="list-style-type: none"> <li>Widely but not uniformly spaced disturbed sample borings (may include split-spoon penetration tests)</li> <li>Test pits excavated by backhoes, farm tractors, or dozers</li> <li>Geophysical surveys to interpolate between widely spaced borings</li> <li>Borehole geophysical tests</li> <li>Water table observations</li> </ul> <p>Final phase</p> <ul style="list-style-type: none"> <li>Additional disturbed sample borings including split-spoon penetration tests</li> <li>Undisturbed sample borings</li> <li>Field vane shear tests for soft materials</li> </ul>

Table 6-3  
Preliminary Appraisal of Foundation Strengths

Method	Remarks
Penetration resistance from standard penetration test	In clays, 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 LL and PL	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	Useful where previous experience is available Used to estimate shear strengths



Table 6-4  
Laboratory Testing of Fine-Grained Cohesive Soils

Type Test	Purpose	Scope of Testing
Visual classification	To visually classify the soil in accordance with the USCS	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	<u>Foundation soils:</u> for classification, comparison with natural water contents, or correlation with shear or consolidation parameters <u>Borrow soils:</u> 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 overconsolidated 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-undrained 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 6-5  
Laboratory Testing of Coarse-Grained Noncohesive Soils

Test	Purpose	Scope of Testing
Visual classification	To visually classify the soil in accordance with the USCS	All samples
Gradation	To 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	To 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 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

matter. High plasticity clays may present a problem because of detrimental swell-shrink behavior when subjected to cycles of wetting and drying.

(2) Either fine-grained soil materials of high water content must be dried to a water content suitable for the desired type of construction, or the embankment design must take into account the fact that the soil has a high water content and is, therefore, soft and compressible. Because the drying of soils is very expensive, time consuming, and highly weather dependent, the design should incorporate the properties of the soil at its natural water content or should require only a minimum of drying. When the dike fill is to be compacted, the borrow material must have a sufficiently low water content so that placement and machine compaction can be done effectively. Semicompacted fill can tolerate fine-grained soils with higher water contents, while uncompacted (cast) fine-grained fill can be placed at even higher water contents. Since dike construction is normally done in low, wet areas, problems with materials being too dry are rarely encountered.

b. Material Sources. A careful analysis of all available material sources, including location, material type, and available volume should be made. Possible sources include any required excavation area, the material adjacent to the dike toe, a central borrow area, and material from maintenance dredging operations.

(1) Required excavation. Soil material from required excavations should be given first consideration since it must be excavated and disposed of anyway. Included in this category is material from adjacent ditches, canals, and appurtenant structures, as well as material from inside the containment area. This usage also eliminates the problem of dealing with borrow areas left exposed permanently after project completion.

(2) Material adjacent to dike toe. This is the most common source of dike material because it involves a short-haul distance. Hauling can be eliminated by the use of a dragline-equipped crane. Dike stability can be seriously affected if the excavation is made too close to the toe. A berm is usually left in place between the toe of the dike and the excavation to ensure dike stability and to facilitate construction. The required width of the berm should be based on a stability analysis.

(3) Central borrow area. When sufficient material cannot be economically obtained from required excavations or the dike toe, a central borrow area is often used. This may be within the containment area or may be off-site. A central borrow pit within the containment area serves to increase available containment volume. Central borrow areas can be used for either hauled or hydraulic fill dikes. Dredging from a water-based central borrow pit is usually economical for hydraulic fill dikes. Usually a deeper pit with smaller surface area is preferred since this requires less movement of the dredge.

(4) Maintenance dredging. Maintenance dredging can be a very economical source of borrow material. The coarse-grained materials from maintenance dredging are desirable for dike construction. Zones around the dredge discharge usually will provide the highest quality of material. However, fine-grained soils may not be suitable because of their very high water content and

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may require considerable drying. The use of previously placed dredged material from maintenance operations has been commonly used to raise existing dikes. It is readily available and serves to increase the capacity of the containment area.

c. Materials Exploration and Testing. All discussion of field investigation procedures, including exploratory investigation of strength, and of laboratory index properties tests given in Tables 6-2, 6-3, 6-4, and 6-5 is applicable to the characterization of potential embankment materials. The objective is to develop sufficient information regarding the various sources of fill material for a comparison among feasible alternatives.

6-4. Embankment Design Considerations. The development of an investigation for the dike foundation and for proposed borrow areas, the selection of a foundation preparation method, and the design of the embankment cross section require specialized knowledge in soil mechanics. Therefore, all designs and specifications should be prepared under the direct supervision and guidance of a geotechnical engineer and should bear his approval.

a. Factors in Design. In addition to the project constraints described in 6-1.c.(1), the site-specific factors that should be considered in the design of containment dikes are foundation conditions; dike stability with respect to shear strength, settlement, seepage, and erosion; available dike materials; and available construction equipment.

b. Dike Geometry. The height and crown width of a dike are primarily dependent on project constraints generally unrelated to stability. Side slopes and materials allocation within the cross section are functions of foundation conditions, materials availability, and time available for construction.

c. Embankment and Foundation Stability. Proposed cross-section designs should be analyzed for stability as it is affected by foundation and/or embankment shear strength, settlement caused by compression of the foundation and/or the embankment, and external erosion. The analytic methods described and referenced herein contain procedures that have proven satisfactory from past use, and most are currently employed by the CE. Specific details concerning methods for analyzing dike stability are reported in TR D-77-9 (item 16) and in EM 1110-2-1902. Several computer programs are available to CE districts to assist in stability analyses, either on mainframe or on microcomputers.

d. Causes of Dike Instability.

(1) Inadequate shear strength. Overstressing of low shear strength soils in the dike and/or the foundation (often coupled with seepage effects) is the cause of most dike failures. Failures of this type can be the most catastrophic and damaging of all since they usually occur quickly and can result in the loss of an entire section of the dike along with the contained dredged material. These failures may involve the dike alone, or they may involve both the dike and the foundation. Thus, two forms of instability may occur:

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(a) Where the foundation is much stronger than the embankment, the dike slope can fail in a rotational slide tangent to the firm base as shown in Figure 6-2. However, if a much weaker horizontal plane or layer exists at or near the contact between the dike fill and the foundation, the failure may be a translation type, taking the form of a sliding wedge as shown in Figure 6-3.

(b) When the strength of the foundation is equal to or less than that of the fill, a rotational sliding failure that involves both the fill and the foundation may occur, as shown in Figure 6-4. If the foundation contains one or more weaker horizontal planes or layers, then a translation type failure, in the form of a sliding wedge, may occur as shown in Figure 6-5.

(c) Recommended minimum factors of safety and applicable shear strength tests for slope stability analyses of containment dikes are given in Table 6-6. These values are to be used where reliable subsurface data from a field exploration and laboratory testing program are available for input to a stability analysis. The factors of safety given in Table 6-6 are applicable to dikes less than 30 feet in height where the consequences of failure are not severe. For dikes greater than 30 feet in height and where the consequences of failure are severe, the criteria given in Table 1 of EM 1110-2-1902 should be used.

(d) When the foundation soils are very soft, as is often the case, various design sections are used to provide stability, as shown in Figure 6-6. A floating section may be used, with very flat slopes and often a berm. The settlement of this section may become detrimental. The soft foundation may be displaced by the firmer dike material, or the soft foundation may be removed and replaced with compacted fill.

(2) Seepage. Potentially detrimental seepage can occur through earth dikes and foundations consisting of pervious or semipervious materials unless prevented by positive means such as impervious linings, blankets, or cutoffs. Seepage effects can create instability through internal erosion (piping) of the dike or foundation materials, or they may lead to a shear failure by causing a reduction in the shear strength of the dike and/or foundation materials through increased pore water pressure or by the introduction of seepage forces. The following conditions may create or contribute to seepage problems in containment dikes:

(a) Dikes with steep slopes composed of coarse-grained pervious materials or fine-grained silt. The seepage surface through the embankment may exit on the outer slope above the dike toe, as shown in Figure 6-7, 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 near the ponding surface elevation, as shown in Figure 6-8, creating a potentially severe seepage problem.

(b) Dikes built on pervious foundation materials or where pervious materials are near the surface or exposed as a result of nearby excavation. As shown in Figure 6-9, this is a common condition where material adjacent to the dike toe is used for the embankment. This condition may lead to the development of large uplift pressures beneath and at the outer toe of the dike,

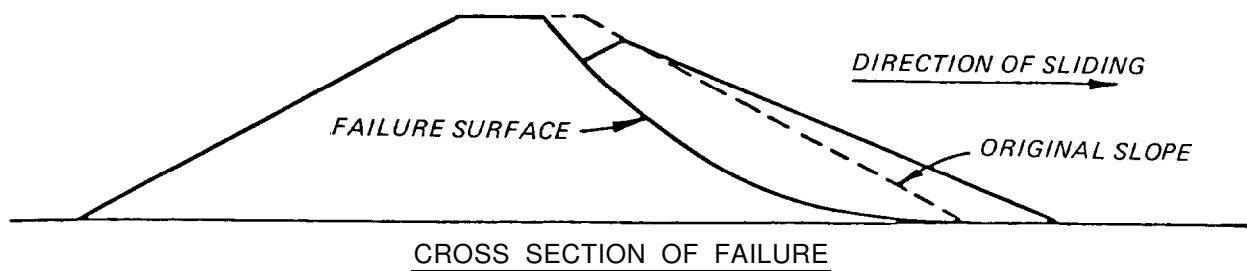


Figure 6-2. Rotational failure in dike

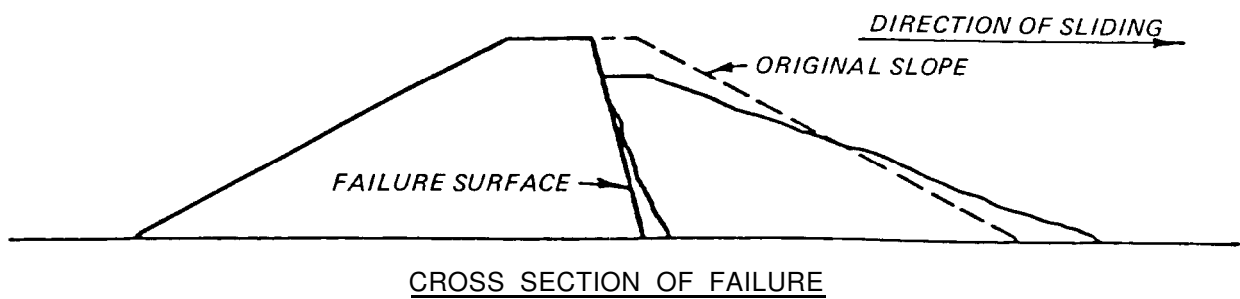


Figure 6-3. Translatory failure in dike

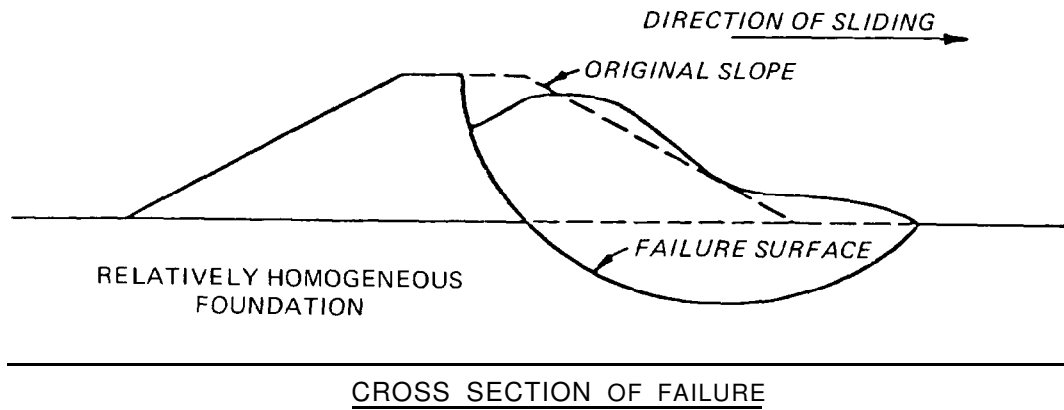


Figure 6-4. Rotational failure in both dike and foundation

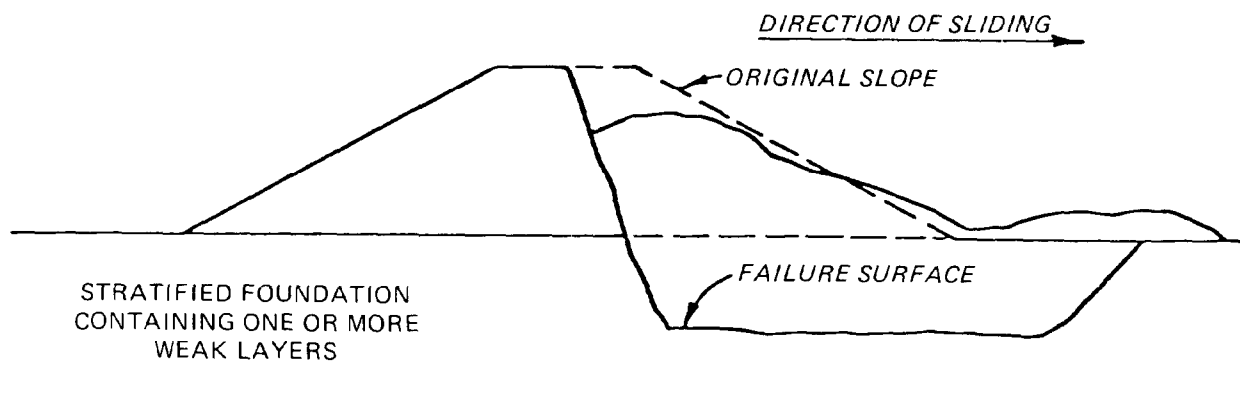


Figure 6-5. Translatory failure in both dike and foundation

Table 6-6  
Applicable Shear Strengths and Recommended  
Minimum Factors of Safety\*

Condition	Shear Strength		Slope Analyzed	Minimum Factor of Safety†	
	Impervious Soils**	Free- Draining Soils		Main Dikes	Appurtenant Dikes
End of construction	Q	S	Exterior and interior	1.3‡	1.3
Steady seepage	Q, R††	S	Exterior	1.3	1.2
Sudden drawdown	Q, R††	S	Exterior	1.0	NA

\* Criteria not applicable to dikes greater than 30 feet in height or where the consequences of failure are very severe. For such dikes use criteria given in Table 1 of EM 1110-2-1902.

\*\* For low plasticity silt where consolidation is expected to occur rather quickly, the R strength may be used in lieu of the Q strength.

† To be applied where reliable subsurface data from exploration and testing are available; where assumed values are used, recommended minimum factors of safety should be increased by a minimum of 0.1.

†† Use Q strength where it is anticipated loading condition will occur prior to any significant consolidation taking place; otherwise use R strength.

‡ Use 1.5 where considerable lateral deformation of foundation is expected to occur (usually where foundations consist of soft, high-plasticity clay).

causing overall instability from inadequate shear strength or may result in piping near the embankment base. Methods for analyzing this condition are reported in WES TM 3-424 (item 34).

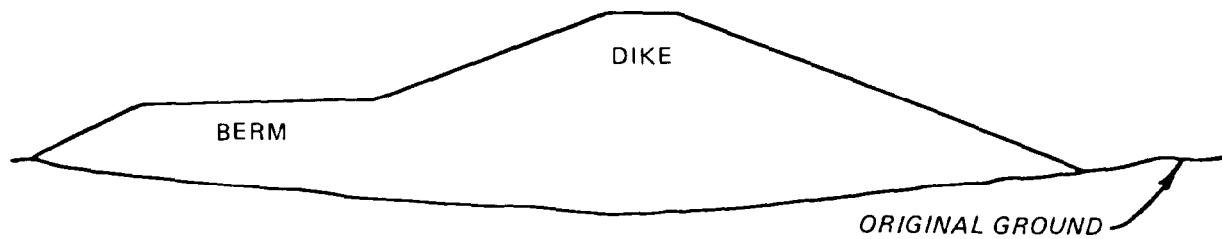
(c) Dikes constructed by casting methods with little or no compaction. When used with fine-grained soils, this method of construction may leave voids within the dike through which water can flow freely, resulting in piping of dike material.

(d) The existence of seepage paths along the contact between structures touching the dike. This condition can be caused by inadequate compaction of the dike materials, shrinkage of material adjacent to structures, or differential settlement. As in the previous case, piping of the dike material often results in and normally leads to breaching of the dike.

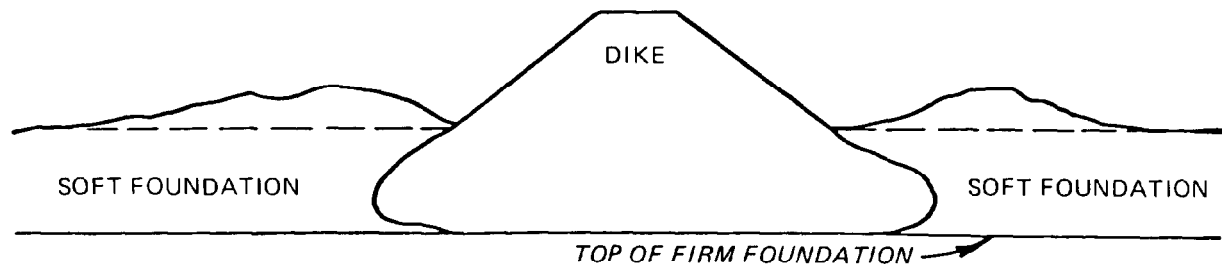
e. Dike Settlement.

(1) Settlement of dikes can result from consolidation of foundation and/or embankment materials, shrinkage of embankment materials, or lateral spreading of the foundation. Like uncontrolled seepage, settlement of a dike can result in failure of the dike, but more likely will serve to precipitate

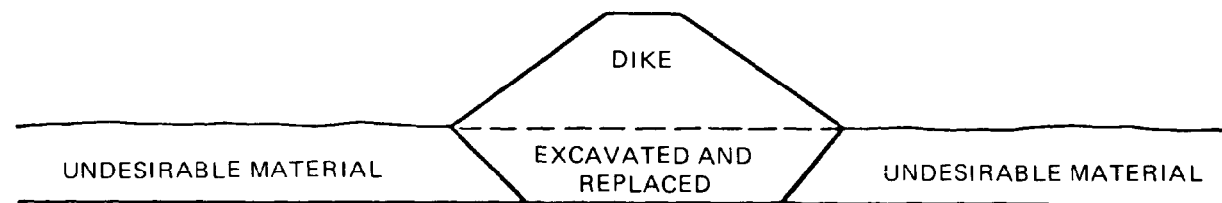




a. FLOATING SECTION



b. DISPLACED SECTION



c. SECTION FORMED BY EXCAVATION AND REPLACEMENT

Figure 6-6. Basic methods of forming dike sections for stability

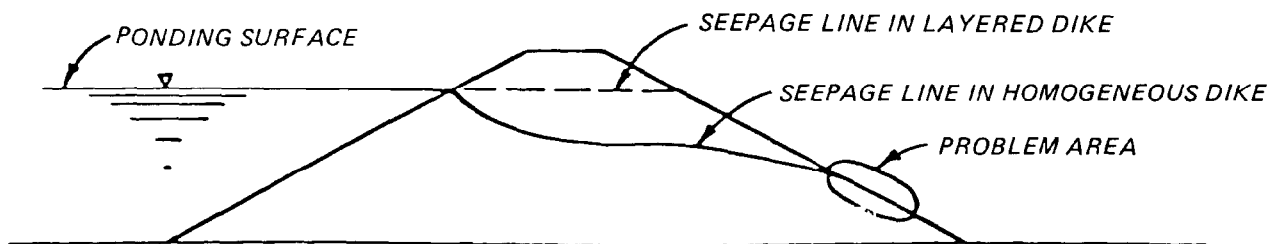


Figure 6-7. Seepage lines through dike

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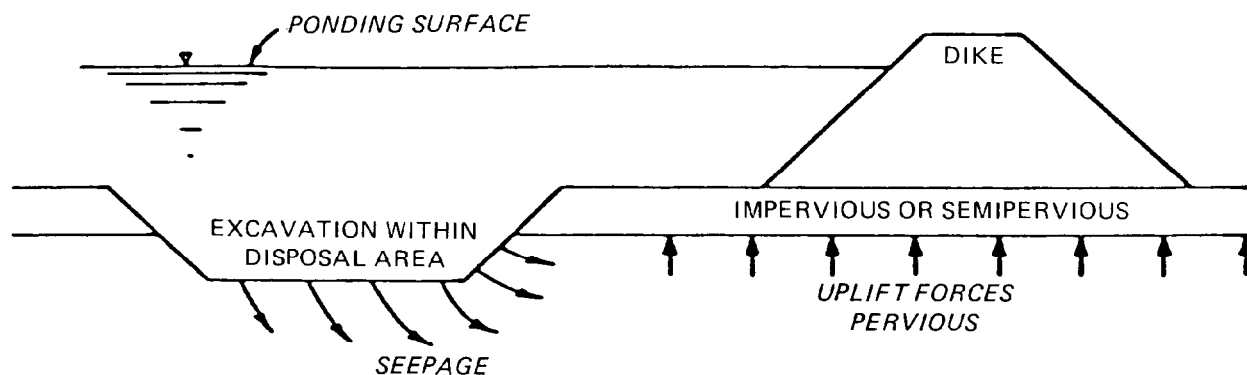


Figure 6-8. Seepage entrance through area excavated within disposal area

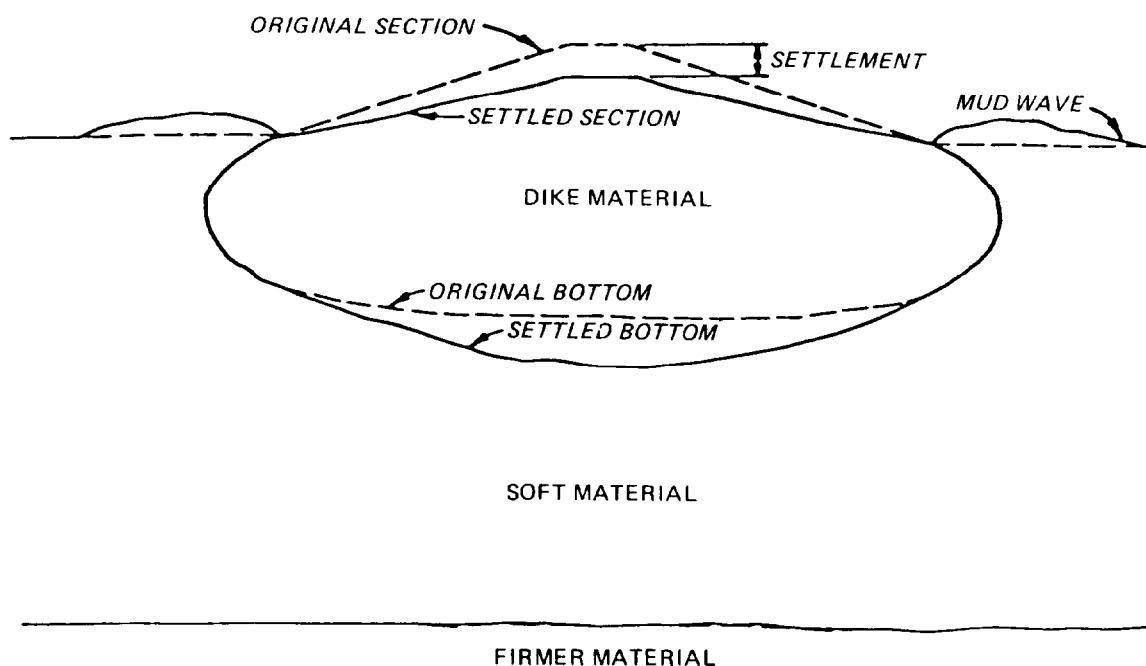


Figure 6-9. Example of excessive uniform settlement

failure by another mode such as seepage or shear failure. Consolidation, shrinkage, and some lateral deformation occur over a period of time, directly related to the soil permeability and the load intensity. Some lateral deformation can occur quickly, however, particularly during construction using the displacement method. Settlement problems are almost always related to fine-grained soils (silts or clays). Settlement and/or shrinkage of coarse-grained soils (sand and gravel) is generally much less than for fine-grained soils and occurs quickly, usually during construction.

(2) Specific forms of settlement that cause problems with dikes include: excessive uniform settlement, differential settlement, shrinkage of uncompacted embankment materials, and settlement resulting from lateral deformation, or creep, of soft foundation soils. Excessive uniform settlement can cause a loss in containment area capacity as a result of the loss of dike

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height, as shown in Figure 6-9. Differential settlement can result in cracking of the dike, which can then lead to a shear or piping failure. This is an especially acute problem at the contact between a dike and an adjacent structure. Examples of differential settlement resulting from materials of different compressibility are shown in Figure 6-10. Embankment shrinkage in dikes built with fine-grained soils and placed by means of casting or hydraulic filling can result in volume reductions of as much as 35 percent as a result of evaporation drying.

f. Erosion. Retaining dike failures can be initiated by the effects of wind, rain, waves, and currents that can cause deterioration of exterior and interior dike slopes. The exterior slopes, which are exposed to constant or intermittent wave and/or current action of tidal or flood waters, are usually subject to severe erosion. Interior slopes may also suffer this form of erosion, particularly in large containment areas. The slopes of dikes adjacent to navigable rivers and harbors may be eroded by wave action from passing vessels.

(1) Weathering. Erosion of dike slopes due to the effects of wind, rain, and/or ice is a continuing process. Although these forces are not as immediately severe as wave and current action, they can gradually cause extensive damage to the dike, particularly those dikes formed of fairly clean coarse-grained soils.

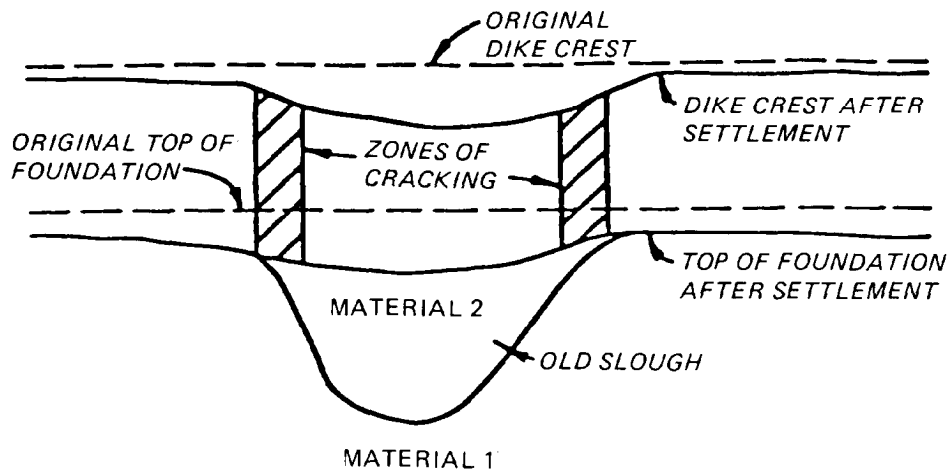
(2) Disposal operations. Normal disposal operations can cause erosion of interior dike slopes near the pipeline discharge and/or exterior slopes at the outlet structures. The pipeline discharge of dredged material is a powerful eroding agent, particularly if the flow is not dispersed.

g. Use of geotextiles.

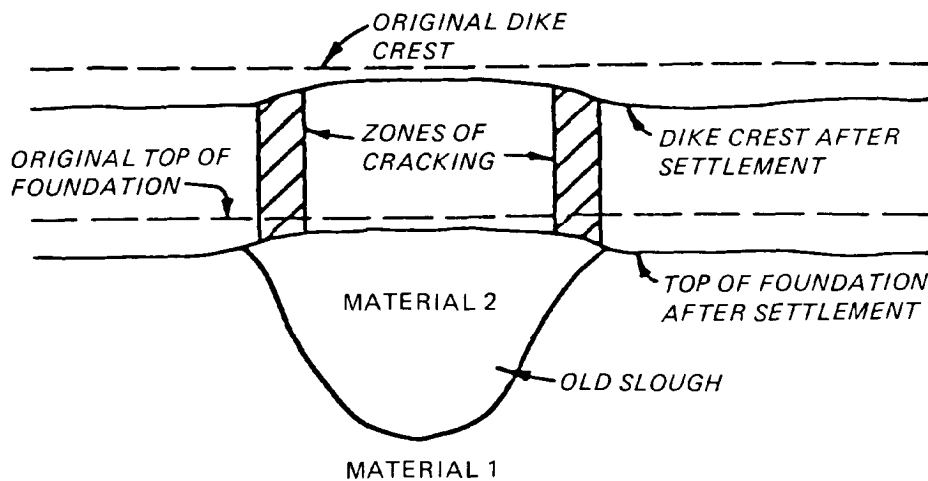
(1) Selection. Geotextiles (permeable textile materials) are being increasingly used in dike construction to provide tensile reinforcement where it will increase the overall strength of the structure. The selection of geotextiles for use in a containment dike is usually based on a substantial cost savings over feasible, practical, alternate solutions, or on the improvement in performance of a design (e.g., more effective installation, reduced maintenance, or increased life).

(2) Stability analyses with geotextile reinforcement. Although the use of a geotextile as reinforcement introduces a complex factor into stability analyses, no specific analytic technique has yet been developed. Therefore, the conventional limited equilibrium-type analyses for bearing capacity and slope stability are used for the design of geotextile reinforced dikes. The bearing capacity analysis, as given in EM 1110-2-1903, assumes the dike to be an infinitely long strip footing. Slope stability analyses, as described in EM 1110-2-1902, involve calculations for stability of a series of assumed sliding surfaces in which the reinforcement acts as a horizontal force to increase the resisting moment. Potential failure modes for fabric-reinforced dike sections are shown in Figure 6-11. Examples of stability analyses for geotextile reinforced embankments are given in item 10.

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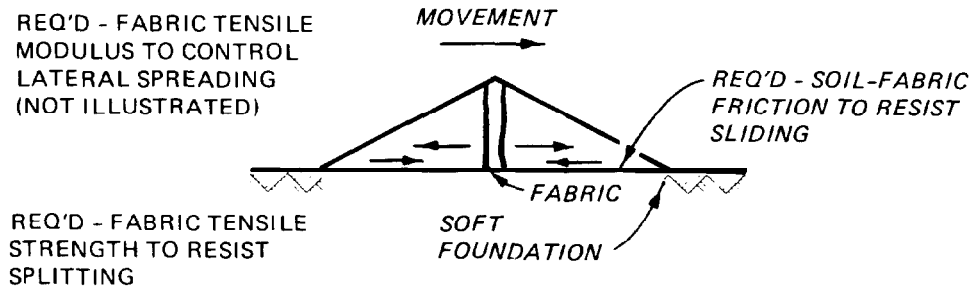


a. COMPRESSIBILITY OF MATERIAL 2  $\gg$  MATERIAL 1

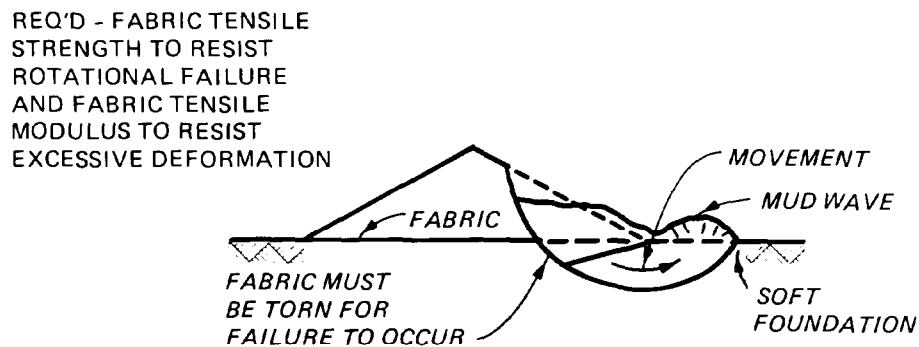


b. COMPRESSIBILITY OF MATERIAL 2  $\ll$  MATERIAL 1

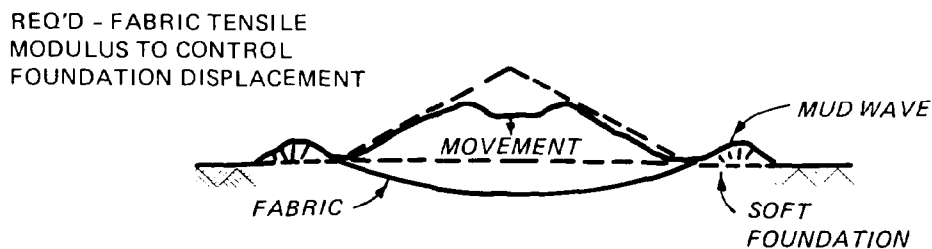
Figure 6-10. Differential settlement from foundation containing materials of different compressibility



A. POTENTIAL EMBANKMENT FAILURE FROM LATERAL EARTH PRESSURE



B. POTENTIAL EMBANKMENT ROTATIONAL SLOPE/FOUNDATION FAILURE



C. POTENTIAL EMBANKMENT FAILURE FROM EXCESSIVE DISPLACEMENT

Figure 6-11. Potential fabric-reinforced embankment failure modes

h. Raising of existing dikes. The height to which a dike can be placed in one stage is sometimes limited by the weakness of the foundation. This limits the capacity of the containment area. The loading of the foundation due to the dike and/or dredged material causes consolidation, and consequent strength gain, of the foundation materials over a period of time. Thus, it is often possible to raise the elevation of an existing dike after some time. Construction of dikes in increments is usually accomplished by incorporating the initial dike into the subsequent dike, as shown in Figure 6-12a, or by constructing them on the dredged fill, at some distance from the inside toe of the existing dike, as shown in Figure 6-12b.

6-5. Construction Equipment.

a. Equipment Types. Types of equipment commonly used in dike construction are listed in Table 6-7 according to the operation they perform. Some types of equipment are capable of performing more than one task, with varying degrees of success. Most of the equipment listed is commonly used in earthwork construction. However, because many dikes are founded on soft to very soft ground, low-ground-pressure versions of the equipment must usually be used in those areas. Specific information on general construction equipment may be found in EM 1110-2-1911. Guidance on equipment available for use on soft soils is given in item 16 and item 13 and on dredging equipment in item 21.

b. Selection Criteria. In the selection of equipment for any particular task, consideration should be given to the following:

- (1) Quantity of soil to be excavated, moved, or compacted.
- (2) Type of soil to be excavated, moved, or compacted.
- (3) Consistency of soils to be excavated, moved, or compacted.
- (4) Distance soil must be moved.
- (5) Trafficability of soils in borrow, transport, and dike placement areas.
- (6) Availability of equipment to fit project time schedule.
- (7) Purchase and operating costs.
- (8) Auxiliary tasks or uses for equipment.
- (9) Maintenance needs; availability of parts.
- (10) Standby or backup equipment needs.
- (11) Time available for construction of dike.
- (12) Money available for construction of dike.

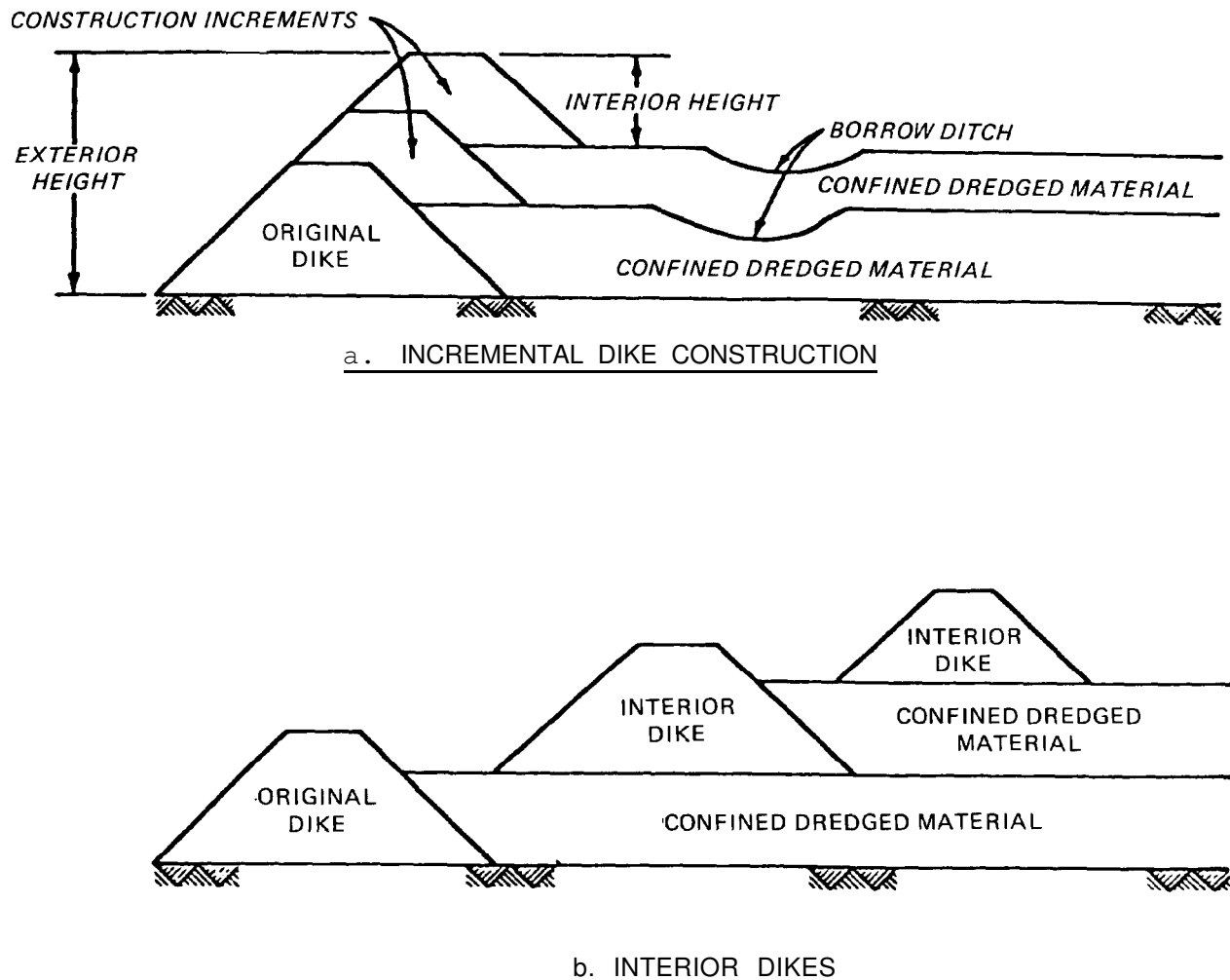


Figure 6-12. Dike raising methods

6-6. Dike Construction. The general construction sequence for a containment dike is normally foundation preparation, borrow area operations, transportation and placement of the dike materials in the embankment, and manipulation and possibly compaction of the materials to the final form and shape.

a. Factors in Method of Construction. The choice of construction method for a containment dike will be governed by available embankment materials, foundation conditions, trafficability of haul roads and the foundation, availability of construction equipment, and project economics.

b. Foundation Preparation. The preparation of a dike foundation usually involves clearing, grubbing, and stripping. Some degree of foundation preparation is desirable to help ensure the integrity of the structure. Clearing and grubbing should be a minimum treatment for all projects. However, in marshy areas where a surface mat of marsh grass and roots exists over a typical soft clay layer, experience has shown that it is often more beneficial from a stability and construction standpoint to leave the mat in place rather

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Table 6-7  
Equipment Commonly Used in Dike Construction

<u>Operation</u>	<u>Equipment</u>	<u>Application</u>
Excavation	Scraper	Firm to stiff soils; firm roadway
	Dragline	Soft soils that cannot support scrapers
	Dredge	Granular or soft soils below water
Transportation	Scraper	Hauling firm, moist soils
	Truck	Hauling firm, moist soils
	Dragline	Casting soft, wet soils
	Dredge	Pumping soils from below water
Scarification	Disc	Scarifying surface of compacted soil
Spreading	Scraper	Haul and spread from same machine
	Grader	Spread truck-hauled soils
	Crawler dozer	Used on soft terrain
Compaction	Sheepsfoot roller	Clays, silts, clayey or silty sands
	Pneumatic roller	Clays, silts, clayey or silty sands
	Vibratory roller	Clean sand; less than 10% fines
	Crawler tractor	All soils for semicompaction
	Hauling equipment	All soils for semicompaction
Shaping	Grader	Firm to stiff soils
	Crawler dozer	All soils; useful on soft soils
	Dragline	Rough shaping in very soft soils

than remove it, even though this will leave a highly pervious layer under the dike.

(1) Clearing. Clearing consists of the complete removal of all above-ground matter that may interfere with the construction and/or integrity of the dike. This includes trees, fallen timber, brush, vegetation, abandoned structures, and similar debris. Clearing should be accomplished well in advance of subsequent construction operations.

(2) Grubbing. Grubbing consists of the removal of below ground matter that may interfere with the construction and/or integrity of the dike. This includes stumps, roots, buried logs, and other objectionable matter. All holes and/or depressions caused by grubbing operations should have their sides flattened and should be backfilled to foundation grade in the same manner proposed for the embankment filling.

(3) Stripping. After clearing and grubbing, the dike area is usually stripped to remove low-growing vegetation and the organic topsoil layer. This will permit bonding of the fill soil with the foundation, eliminate a soft, weak layer that may serve as a translation failure plane, and eliminate a potential seepage plane. Stripping is normally limited to the dike location



proper and is not usually necessary under stability berms. All stripped material suitable for use as topsoil should be stockpiled for later use on dike and/or borrow area slopes. Stripping is not normally required for dikes on soft, wet foundations or for dikes built by other than full compaction.

(4) Disposal of debris. Debris from clearing, grubbing, and stripping operations can be disposed of by burning in areas where permitted. Where burning is not feasible, disposal is usually accomplished by burial in suitable areas such as old sloughs, ditches, and depressions outside the embankment limits (but never within the embankment proper). 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 placed so that no debris may escape and damage or block the outlet structure. All buried debris should be covered by a minimum of 3 feet of earth.

(5) Foundation scarification. For compacted dikes on firm foundations only, the prepared foundation should be thoroughly scarified to provide a good bond with the embankment fill.

c. Borrow Area Operations. Factors that should be considered in the planning and operation of a borrow area are site preparation, excavation, drainage, and environmental considerations.

(1) Site preparation. The preparation of the surface of a borrow area includes clearing, grubbing, and stripping. The purpose of this effort is to obtain fill material free from such objectionable matter as trees, brush, vegetation, stumps, roots, and organic soil. In marshy areas, a considerable depth of stripping may be required due to frequently occurring 3- to 4-foot root mats, peat, and underlying highly organic soil. Often, marshy areas will not support the construction 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.

(2) Excavation. Planning for excavation operations in borrow areas should give consideration to the proximity of the areas to the dike, topography, location of ground-water table, possible excavation methods and equipment, and surface drainage.

(3) Drainage. Drainage of borrow areas (including control of surface and ground water) is needed to achieve a satisfactory degree of use. Often, natural drainage is poor, and the only choice is to start at the lowest point and work toward the higher areas, thereby creating a sump. Ditches are often effective in shallow borrow areas. Ditching should be done in advance of the excavation, particularly in fine-grained soils, to allow maximum drying of the soils prior to excavation.

(4) Environmental considerations. Permanently exposed borrow areas are usually surface treated to satisfy aesthetic and environmental protection considerations. Generally, projects near heavily populated or industrial areas will require more elaborate treatment than those in sparsely populated areas. Minimum treatment should include topographic shaping to achieve adequate drainage, smoothing and blending of the surface, treatment of the surface to

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promote vegetation growth, and placement of vegetation to conform to the surrounding landscape. Item 23 should be consulted for more detailed information concerning landscaping methods.

d. Transportation and Placement of Materials. Three basic methods for transporting and placing dike materials in the embankment are hauling by means of trucks or scrapers, casting by means of a dragline, and pumping, or hydraulic filling, using a dredge. The relative advantages and disadvantages of these methods are summarized in Table 6-8.

e. Manipulation, Compaction, and Shaping. After placement, the dike materials may be compacted, semicompacted, or uncompacted. Many variations and combinations of these methods can and have been used. Classification by these methods does not necessarily refer to the end quality of the embankment; rather it refers to the amount of control of water content and compactive effort used during construction. The relative advantages and disadvantages of the methods of compaction are summarized in Table 6-9.

f. Construction Quality Control. The control of quality of construction operations is an extremely important facet of dike operations. Some of the more pertinent items to be inspected during construction of the dike are given in Table 6-10. For further guidance on control of earthwork operations, see EM 1110-2-1911.

#### 6-7. Miscellaneous Features.

a. Discharge Facilities. Both excessive uniform and differential settlement of the dike can cause distortion and/or rupture of weir discharge pipes located under or through dikes (Figure 6-13) and can cause distortion of the weir box itself (Figure 6-14). The settlement effect can be somewhat mitigated by cambering (Figure 6-15) or raising one end (Figure 6-16) of the pipe during construction.

b. Seepage Control. Antiseepage devices, either metal fins or concrete collars, have been used in the past to inhibit seepage and piping along the outside wall of the outlet pipe. These have not proven effective. To aid in the prevention of piping failures along the pipe-soil interface, an 18-inch-minimum annular thickness of drain material (clean, pervious sand, or sand/gravel) should be provided around the outlet one-third of the pipe, as shown in Figure 6-17. This may be omitted where the outlet one-third of the pipe is located in sand.

c. Additional Uses of Geotextiles. The use of geotextiles to provide soil reinforcement was presented in section 6-4.g. In addition, geotextiles have been extensively used as filter fabrics to replace the filter materials (section 6-7.b.), drain materials, a separation medium, and an armor medium to inhibit erosion item 10. A brief summary of geotextile functions in dike construction is given in Table 6-11.

Table 6-8  
Commonly Used Methods of Transporting Soils  
in Dike Construction

<u>Method</u>	<u>Advantages</u>	<u>Disadvantages</u>
Hauling	May use central borrow area Permits use of high-speed, high-capacity equipment Allows better selection of soil type	All traveled surfaces must be firm to support equipment Cannot be used in soft, wet areas or underwater May require specialized low-pressure equipment
Casting	Dragline bucket can move very soft, wet soils Can operate on soft foundation	Low speed; low capacity Requires frequent movement of dragline equipment Short casting distance
Dredging	Move large quantities of soils from below water Permits use of dredged materials in dike May be used on soft foundation and roadway	Requires dredge and pipeline Soils cannot be compacted without drying; requires large sections with very flat slopes

Table 6-9  
Commonly Used Methods of Compacting Soils  
in Dike Construction

Method	Advantages	Disadvantages
Compacted	Placed in thin layers and well compacted, strong dike, low compressibility Steep slopes, minimum space occupied Highest quality control	Requires that soils be dried to water content near plastic limit Requires competent foundation Highest cost
Semicompacted	Uses soils at natural water content, no drying needed May be used on weaker foundations Uses thick lifts May be hauled or cast	Requires flatter slopes May be limited in height Poorer quality control May require specialized low-pressure equipment
Uncompacted	Permits use of cast or dredged materials May be placed on very soft, wet foundation Fill placed at natural water content Lowest cost for dike	Requires very flat slopes May be severely limited in height or require stage construction Poorest quality control

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Table 6-10  
Operations or Items to Be Inspected During  
Construction of Dikes

<u>Type Construction</u>	<u>Items or Operation to Be Checked</u>
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

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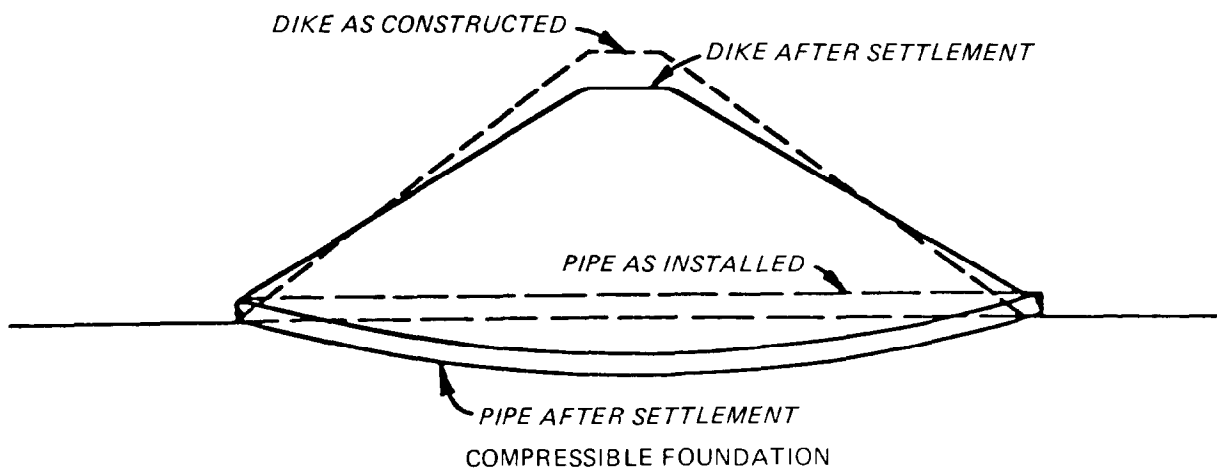


Figure 6-13. Swagging of pipe due to settlement of dike and foundation

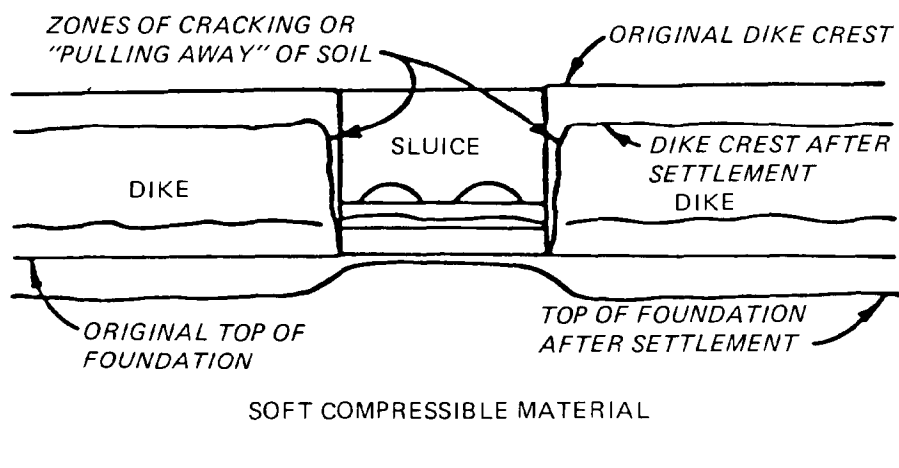


Figure 6-14. Cracking at dike-structure junction caused by differential settlement because dike load is much greater than weir load

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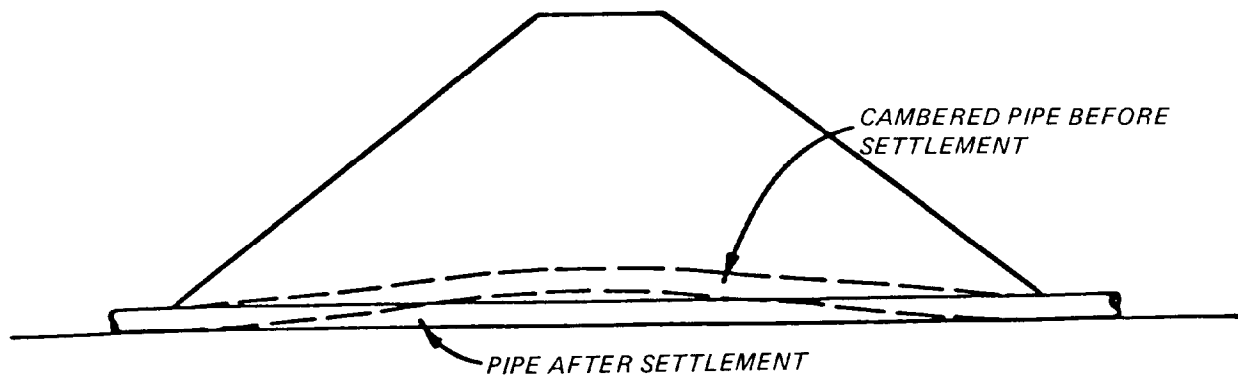


Figure 6-15. Cambered pipe beneath dike

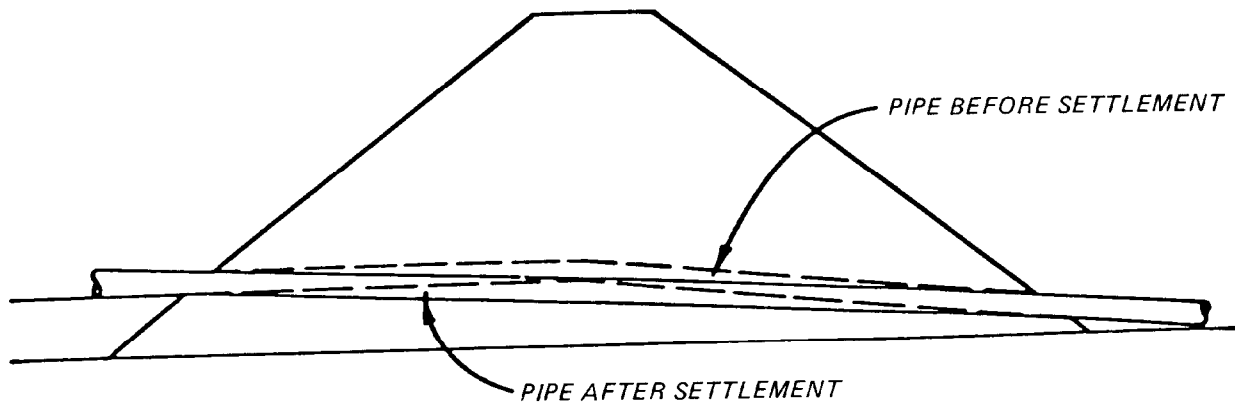
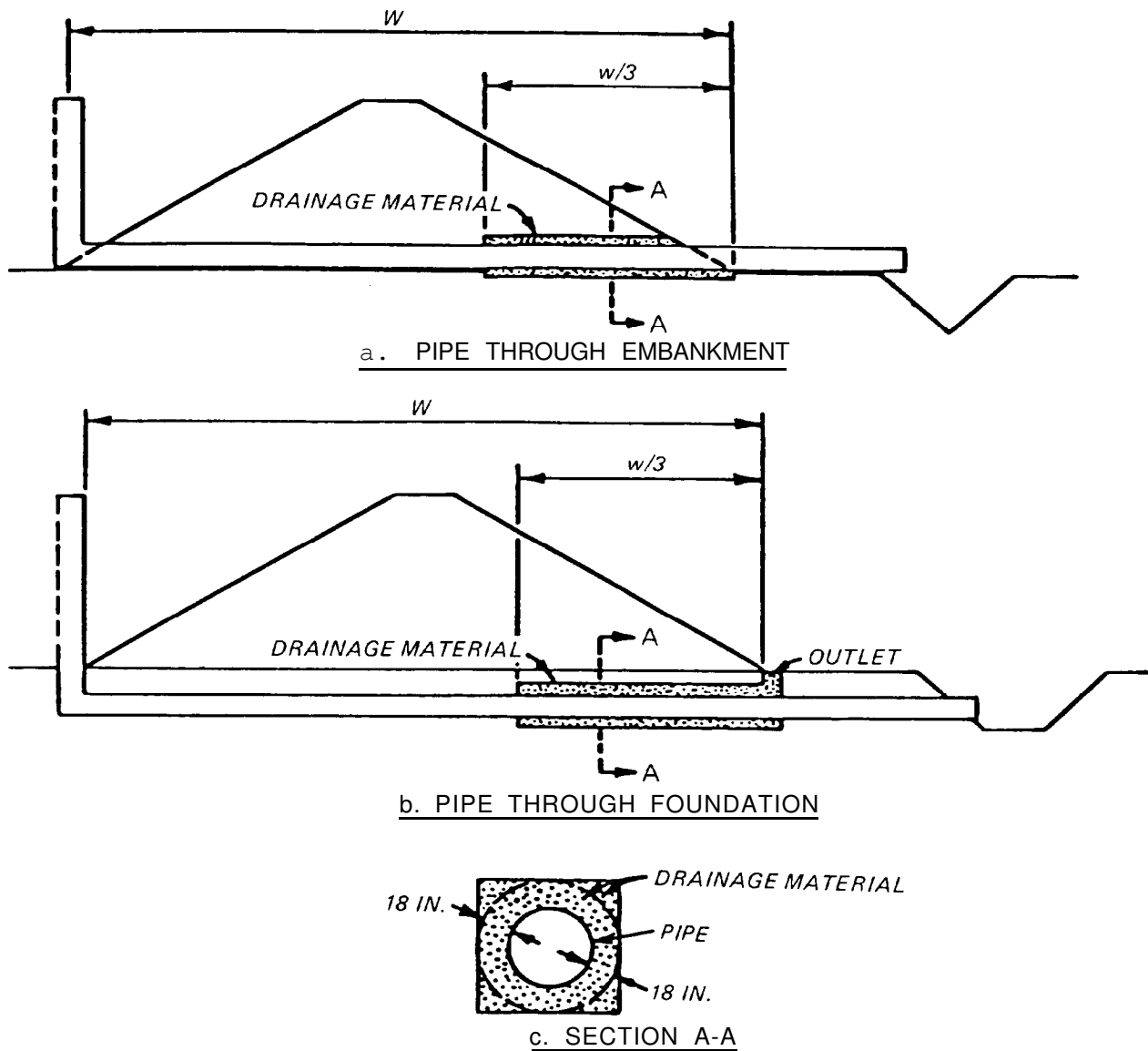


Figure 6-16. Cambered and raised pipe beneath dike

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NOTE: W = SECTION WIDTH

Figure 6-17. Annular drainage material around outlet one third of pipe



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Table 6-11  
Description of Geotextile Functions

Function	Description
Filter	The process of allowing water to escape easily from a soil unit while retaining the soil in place. The water is carried away by some other drain (e.g., rock or rock with pipe).
Drain	The situation where the fabric itself is to carry the water away from the soil to be drained.
Separation	The process of preventing two dissimilar materials from mixing. This is distinct from the filtration function, in that it is not necessary for water to pass through the fabric.
Reinforcement	The process of adding mechanical strength to the soil-fabric system.
Armor	The process of protecting the soil from surface erosion by some tractive force. Usually in these situations, the fabric serves only for a limited time.

## CHAPTER 7

## OPERATION AND MANAGEMENT OF CONTAINMENT AREAS

7-1. General Considerations. This chapter presents procedures for the effective management and operation of containment areas. Management activities are required before, during, and following the dredging operation to maximize the retention of suspended solids and the storage capacity of the areas. These activities include site preparation, removal and use of existing dredged material for construction purposes, surface water management, suspended solids monitoring, inlet and weir management, thin-lift placement, separation of coarse material, dredged material dewatering, and disposal area reuse management. Management activities described in this part are not applicable in all cases, but should be considered as possibilities for improving the efficiency and prolonging the service life of containment areas.

7-2. Predredging Management Activities.

a. Site Preparation. Immediately before a disposal operation, the desirability of vegetation within the containment area should be evaluated. Although vegetation may be beneficial because it helps dewater dredged material by transpiration and may improve the effluent quality by filtering, very dense vegetation may severely reduce the available storage capacity of the containment area and may restrict the flow of dredged slurry throughout the area, causing short-circuiting. Irregular topography within the containment area will directly affect resulting topography of the dredged material surface following the dredging operation. It may be beneficial to grade existing topography from planned inlet locations toward the weir locations to facilitate drainage of the area.

b. Use of Existing Dredged Material. If dikes must be strengthened or raised to provide adequate storage capacity for the next lift of dredged material, the use of the dried dredged material or suitable construction material from within the containment for this purpose will be beneficial. In addition to eliminating the costs associated with the acquisition of borrow, additional storage capacity is generated by removing material from within the area. Consideration should also be given to the use of any coarse-grained material present from previous dredging operations for underdrainage blankets or for other planned applications requiring more select material.

c. Placement of Weirs and Inflow Points.

(1) General placement for site operation and management control. Outflow weirs are usually placed on the site perimeter adjacent to the water or at the point of lowest elevation. The dredge pipe inlet is usually located as far away as practicable from these outflow weirs or at a location closest to the dredging areas. However, these objectives may sometimes be conflicting. If the disposal area is large or if it has irregular foundation topography, considerable difficulty may be encountered in properly distributing the material throughout the area and obtaining the surface elevation gradients necessary for implementation of a surface trenching program. One alternative is to use interior or cross dikes to subdivide the area and thus change the large

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area into several smaller areas. Effective operation may require that the dredge pipe location be moved periodically from one part of the site to another, to ensure a proper filling sequence and obtain proper surface elevation gradients. Also, shifting inflow from one point of the site to another and changing outflow weir location may facilitate obtaining a proper suspended solids concentration in disposal site effluent.

(2) Installation and operation of multiple outflow weirs. In conjunction with provisions for moving the inflow point over the disposal site, it may also be worthwhile to contemplate installation of more outflow weirs than would be strictly required by design methods. Availability of more outflow points allows greater flexibility in site operation and subsequent drainage for dewatering, as well as greater freedom in movement of dredge inflow points while still maintaining the flow distances required to obtain satisfactory suspended solids concentrations in disposal site effluent. Also, a higher degree of flexibility in both disposal site inflow and outflow control will allow operation of the area in such a manner that desired surface topography can be produced, facilitating future surface trenching operations.

d. Interior Dike Construction.

(1) Need for interior dike construction. The basic rationale behind the construction of interior disposal area dikes is to subdivide the area into more manageable segments and/or to control the flow of dredged material through the disposal area. Control of material placement is normally to facilitate future disposal site operations, such as dewatering, or to provide proper control of disposal area effluent. Interior dikes may also be used as a haul road and access for movement of material for dike construction or other beneficial uses.

(2) Economics of interior dike construction. As a general rule, the use of interior cross dikes in any disposal area will increase the initial cost of construction and may result in increased operating costs. However, facilitation of disposal site operations, particularly future dewatering, may result in a general reduction in unit disposal cost over the life of the site. The benefit derived from dikes should be evaluated against the amount of disposal volume required for their construction. If the dikes can be constructed from dredged material or material available in the disposal site foundation and subsequently raised with dewatered dredged material, the net decrease in storage capacity will be approximately zero.

(3) Disposal site operation using subareas in series.

(a) Cross dikes may be used to control and direct the inflow and are normally built to allow site subcontainment area (subarea) operation either in series or in parallel. In series, the flow is routed first into one subarea, with sedimentation producing segregation of larger particles, and the overflow from the first subarea is routed to a second subarea where finer particles fall from suspension and then perhaps into another subarea, etc., with the outflow point being located at the end of the last subarea. In some instances, cross dikes are built across the entire site width, and a long overflow weir is provided to allow outflow into the next subarea in the

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series. In other instances, spur dikes are built into the containment area to cause a twisting path for the flow.

(b) In general, the use of series-oriented subdisposal areas should be considered carefully, since the actual result of such use may be the opposite of that desired by the designer. During disposal, coarse-grained sand and gravel will settle very quickly around the disposal pipe location. Other material will remain in suspension, depending on its effective particle size, water salinity, and flow velocity. A subarea can be effective in separating coarse material in an area where later recovery for other use will be easier. As a practical matter, a subarea or containment basin to trap or separate specific silt and clay sizes is rather impractical. A rational design for a series of subareas might require an initial subarea to trap sand and gravel, with the remainder of the material, i.e., the fine-grained fraction, going to a larger subarea. Then, if desired, a final subarea could be used for retention of fine material in conjunction with use of chemical flocculants, to maintain proper water quality in the disposal area effluent. When designing the series of subdisposal areas, care must be taken to obtain adequate size. If the first subarea in the series is filled, it will no longer function and provide the required residence time, and its function must be assumed by the next unit in the series.

(4) Disposal site operation using subareas in parallel. To facilitate site dewatering, operation of interior compartments on a parallel basis may be used. In this concept, flow is initially routed into one compartment; then, when it is filled to the proper depth or when suspended solids concentration standards in the effluent are exceeded, the flow is routed to another portion of the site. This procedure allows more carefully controlled placement of material to the desired thickness throughout the site. Parallel compartments also allow more efficient drying to occur in compartments not in active use since the water ponded for sedimentation is confined to the active compartment (see Figure 7-1).

(5) Sequential dewatering operations. If the disposal site is large enough to contain material from several periodic dredgings, each compartment may be used sequentially for a separate operation. In this manner, a sequence such as the following may be developed. The first compartment is filled, and, after decant, dewatering operations are initiated. As dewatering operations proceed, the next disposal is placed in the second compartment and subsequent disposal in the third, etc. While fresh material is being deposited in part of the site, the dewatered material from the initial placement may be borrowed and used to raise perimeter dikes, facilitating reuse of the initial subarea. This sequence of operations is shown in Figure 7-2.

e. Improvement of Site Access.

(1) Adequate provisions for site access are essential when the long-term operation and management plan for a disposal site includes provision for future dewatering activities and/or removal of dewatered material for dike raising or other productive use. General considerations for site access may include:

- (a) Access roads on or adjacent to perimeter and interior dikes.

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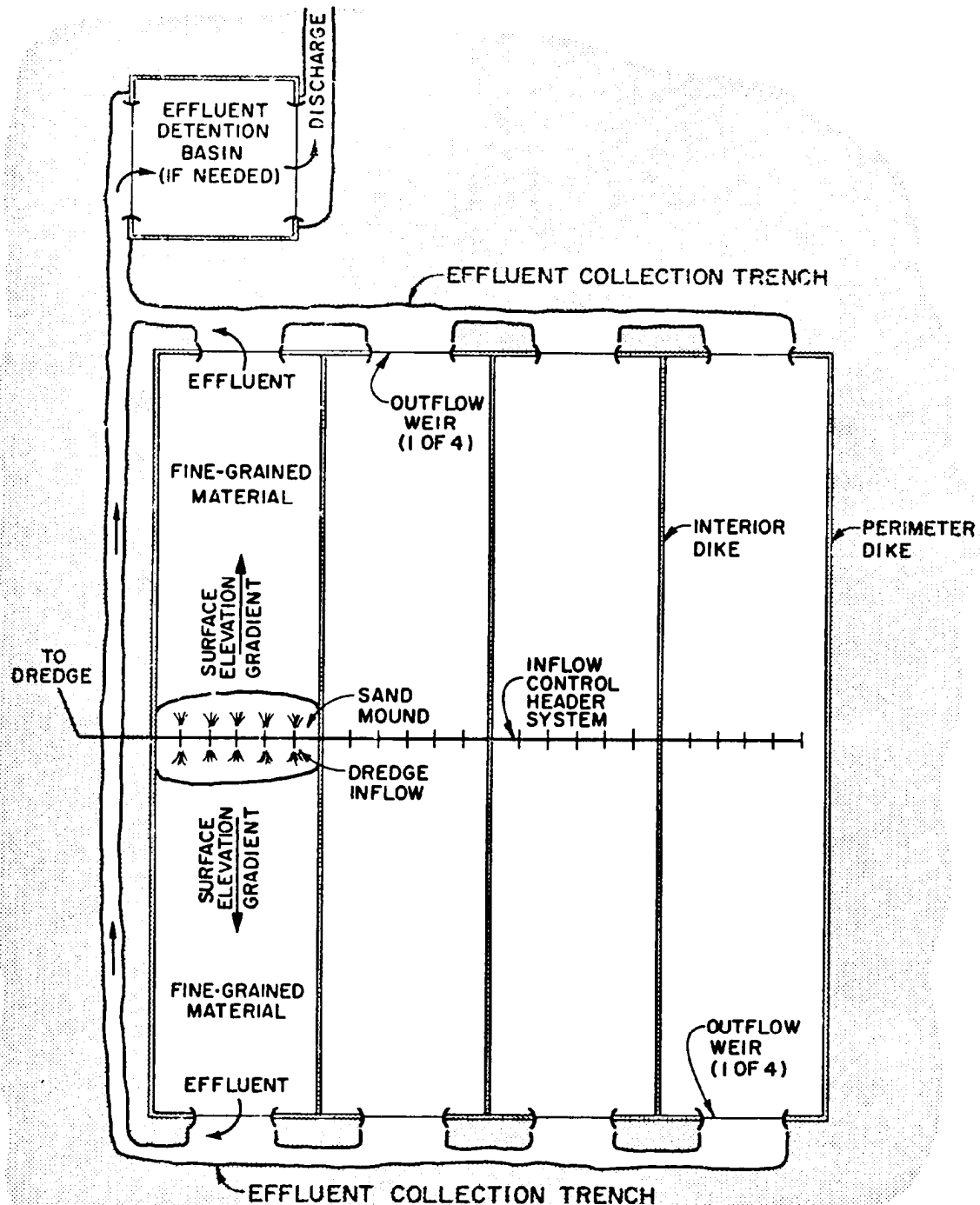


Figure 7-1. Conceptual illustration of disposal site layout to permit parallel compartment use and produce surface topography facilitating future dredged material dewatering

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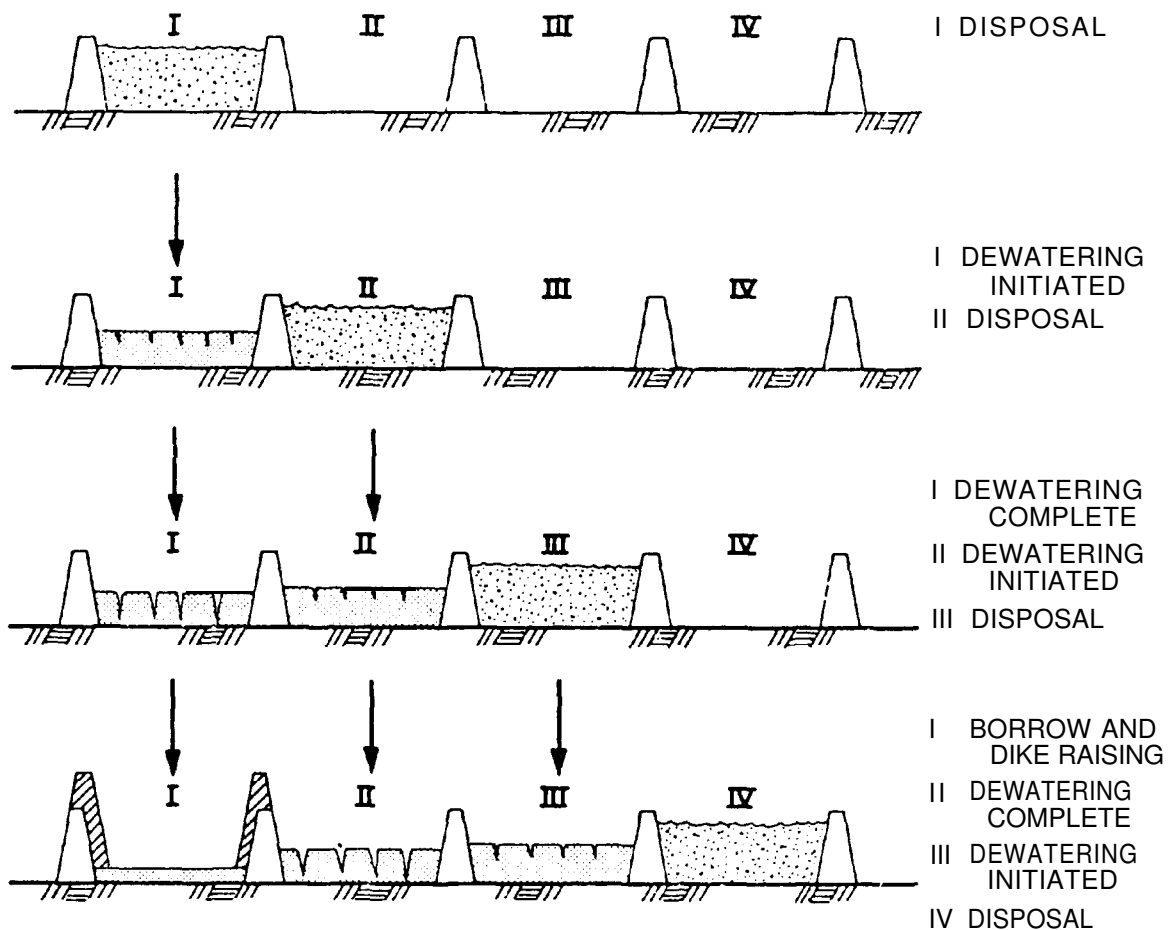


Figure 7-2. Conceptual illustration of sequential dewatering operations

- (b) Crossing points on interior ditches used for drainage or dewatering.
- (c) Access for equipment and personnel to reach weir structures for repair or maintenance.
- (d) Ramps for access onto dikes from both inside and outside dike faces.
- (e) Ramps for pipelines leading to inflow points.
- (f) Equipment turnarounds.
- (g) Stockpiles of materials for sandbagging and emergency dike repairs.
- (h) Offloading ramps for equipment transported by water.

(2) If future borrow of interior dewatered dredged material is contemplated, it may be most cost-effective to construct small access roads into the area, as a substructure for future haul roads or dragline access. Such stable platforms may be covered with some fine-grained dredged material, but

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their emplacement in the disposal area will allow subsequent equipment operation without immobilization.

f. Scheduling of Dredging Operations to Take Maximum Advantage of Climatic Conditions. Many nonengineering considerations affect the actual time during which disposal operations are conducted. They include:

- (1) Expenditure of funds with respect to fiscal year.
- (2) Relative priority of the operation with respect to other work.
- (3) Lag time necessary to obtain proper specifications preparation and contract advertisement.
- (4) Variation in time when the contractor must move on the job.
- (5) Size of dredge.
- (6) Existing weather conditions.
- (7) Environmental considerations (i.e., dredging windows).
- (8) Lag time required for preparation of the disposal site.

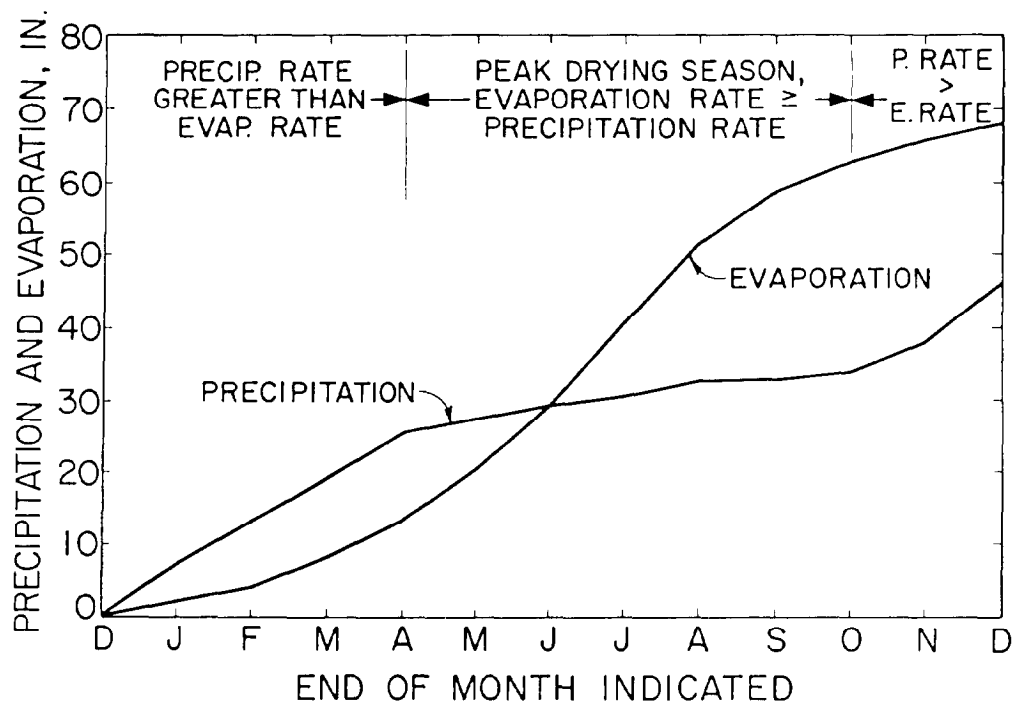
Nevertheless, considerable advantage may be gained, in an engineering sense, from scheduling disposal operations to occur at appropriate periods of the calendar year, depending upon prevailing climatic conditions. By conducting the disposal phase during a period of relatively low evaporative demands, the initial postdisposal activity (i.e., decanting and gradual reduction of ponded water depth) will occur when minimum evaporative forces are available for dewatering. If the disposal operation can be scheduled so that the material reaches the approximate decant-point water content when seasonal evaporation rates begin to be maximized, evaporative dewatering will be facilitated. Dramatic results can occur over short time periods when conditions are prime for drying. Estimation of the calendar period for optimum evaporation, based on projected climatic conditions, is illustrated in Figure 7-3. Examples are from the San Francisco, California, and Mobile, Alabama, areas. If possible, disposal operations should be terminated, ponded water removed, and the material sedimented/consolidated to the decant point by the time (calendar month) when the evaporation rate begins to increase.

### 7-3. Management During Disposal.

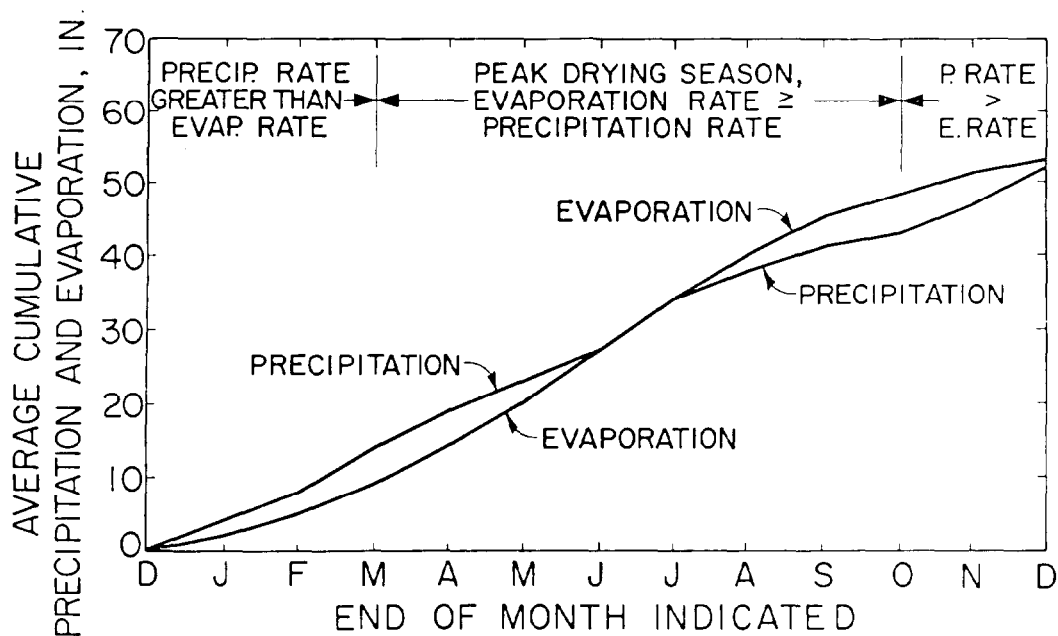
#### a. Surface Water Management.

(1) The management of surface water during the disposal operation can be accomplished by controlling the elevation of the outlet weir(s) throughout the disposal operation to regulate the depth of water ponded within the containment area. Proper management of surface water is required to ensure containment area efficiency and can provide a means for access by boat or barge to the containment area interior.

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a. San Francisco, California, area



b. Mobile, Alabama, area

Figure 7-3. Illustrations of method for estimating calendar periods when evaporation rates are maximized



(2) At the beginning of the disposal operation, the outlet weir is set at a predetermined elevation to ensure that the ponded water will be deep enough for settling as the containment area is being filled. As the disposal operation begins, slurry is pumped into the area; no effluent is released until the water level reaches the weir crest elevation. Effluent is then released from the area at about the same rate as slurry is pumped into the area. Thereafter, the ponding depth decreases as the thickness of the dredged material deposit increases. After completion of the disposal operation and the activities requiring ponded water, the water is removed as quickly as effluent water quality standards will allow. Figure 7-4 illustrates the concept.

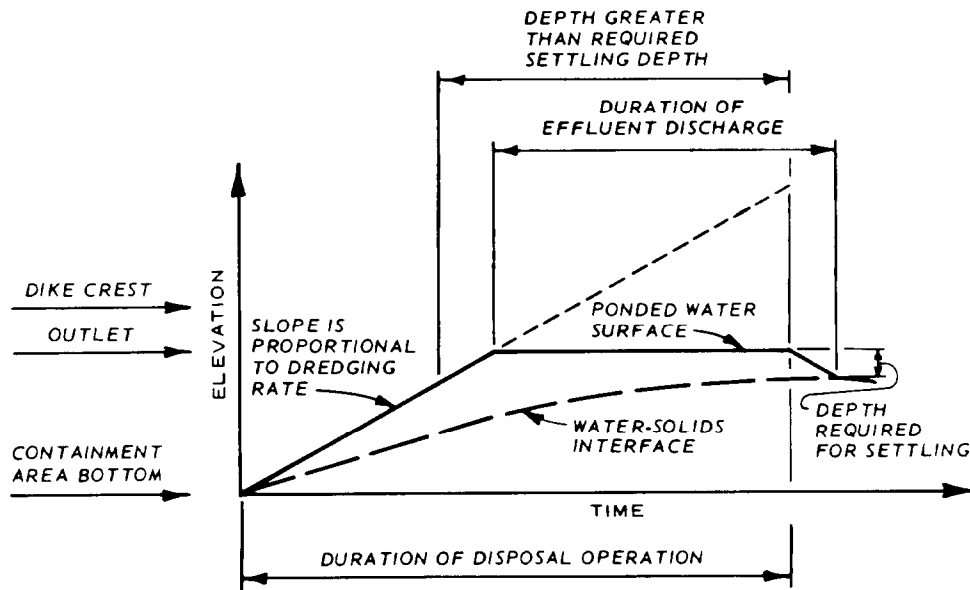


Figure 7-4. Surface water management

b. Suspended Solids Monitoring. A well-planned monitoring program during the entire dredging and decanting operation is desirable to ensure that effluent suspended solids remain within acceptable limits or to verify conditions for future design or site evaluations. Since suspended solids concentrations are determined on a grams per litre basis requiring laboratory tests, it is desirable to complete a series of laboratory tests during the initial stages of operation. Indirect indicators of suspended solids concentration, such as visual comparison of effluent samples with samples of known concentration or utilization of a properly calibrated instrument, may then be used during the remainder of the operation, supplemented with laboratory determination of effluent solids concentrations as needed for record purposes.

(1) Samples of both inflow and outflow can be taken for laboratory tests. The solids determination should be made on the samples using the procedure described in Chapter 3.

(2) When the dredging operation commences, samples should be taken from the inlet pipe at approximately 12-hour intervals to verify design assumptions. Effluent quality samples should be taken periodically at approximately

6-hour intervals during the dredging operation for laboratory solids determinations to supplement visual estimates of effluent suspended solids concentrations. The sampling interval may be changed based on the observed efficiency of the containment area and the variability of the effluent suspended solids concentrations. More frequent sampling will be necessary as the containment area is filled and effluent concentrations increase.

c. Inlet and Weir Management.

(1) If multiple weirs are used, discharging the weirs alternately is sometimes useful for preventing short-circuiting. As the area between the inlet and one outlet fills or as the inlet location is moved, the flow may channelize in a more or less direct route from inlet to weir. If this occurs, the flow should be diverted to another weir. Simultaneous discharge of slurry from several inlets located on the perimeter can also be advantageous, because the lower velocity of the slurry flow results in more pronounced mounding around the edge of the containment area. This mounding in turn increases the slope from inlet to outlet, and drainage will be improved.

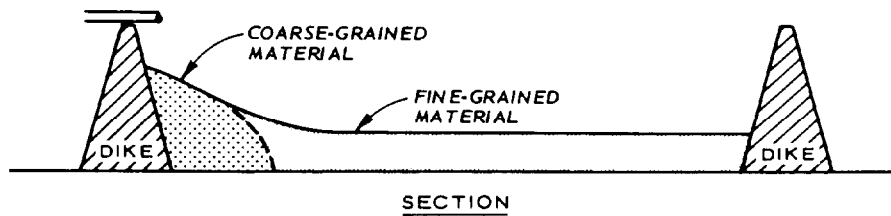
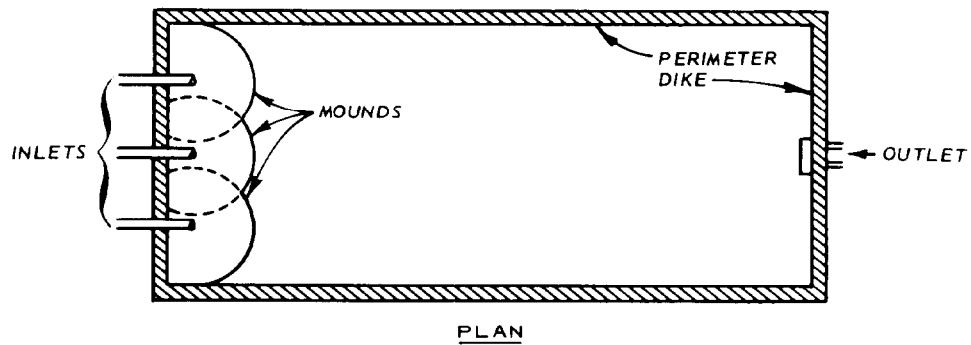
(2) The removal of water following the dredging operation can be somewhat expedited by managing inlets and weirs during the disposal operation to place a dredged material deposit that slopes continually and as deeply as practical toward the outlets. Figure 7-5 shows a containment area with a weir in one end and an inlet zone in the opposite end. Inlets are located at various points in the inlet zone, discharging either simultaneously (multiple inlets) or alternately (single movable inlet or multiple inlets discharging singly). A common practice is to use a single inlet, changing its location between disposal operations. The result of this practice is the buildup of several mounds, one near each inlet location. By careful management of the inlet locations, a continuous line of mounds can be constructed, as shown in Figure 7-5. When the line of mounds is complete, the dredged material will slope downward toward the weir. If the mound area is graded between disposal operations, the process can then be repeated by extending the pipe over the previous mound area and constructing a new line of mounds, as shown in Figure 7-5.

d. Thin-Lift Placement of Dredged Material. Gains in long-term storage capacity of containment areas through natural drying processes can be increased by placing the dredged material in thin lifts. Thin-lift placement also greatly enhances potential gains in capacity through active dewatering and disposal area reuse management programs.

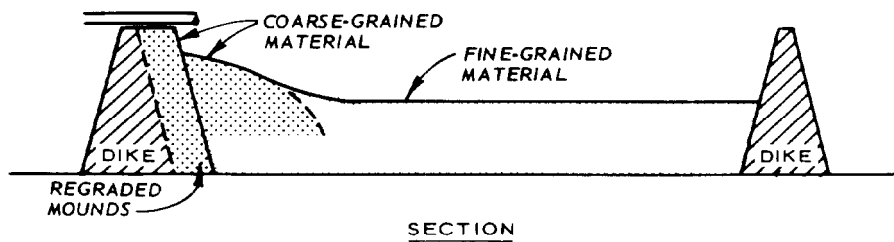
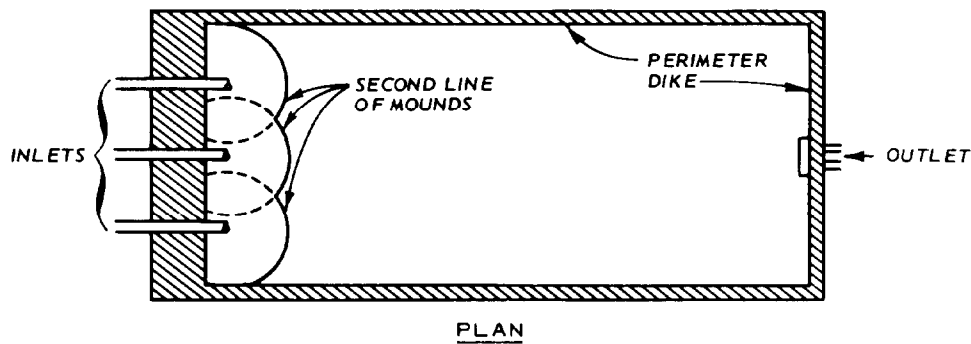
(1) One approach to placing dredged material in thin lifts is to obtain sufficient land area to ensure adequate storage capacity without the need for thick lifts. Implementation of this approach requires careful long-range planning to ensure that the large land area is used effectively for dredged material dewatering, rather than simply being a containment area whose service life is longer than that of a smaller area.

(2) Large containment areas, especially those used nearly continuously, are difficult to manage for effective natural drying of dredged material. The practice of continuous disposal does not allow sufficient time for natural drying. However, dividing a large containment area into several compartments

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a. FIRST LINE OF MOUNDS



b. SECOND LINE OF MOUNDS

Figure 7-5. Inlet-weir management to provide smooth slope for inlet to weir

can facilitate operation because each compartment can be managed separately so that some compartments are being filled while the dredged material in others is being dewatered.

(3) One possible management scheme for large compartmentalized containments is shown conceptually in Figure 7-2. For this operation, thin lifts of dredged material are sequentially placed into each compartment. The functional sequence for each compartment consists of filling and settling, and surface drainage and dewatering, and dike raising (using dewatered dredged material). The operation must be designed to include enough compartments to ensure that each thin lift is dried before the next lift is placed.

#### 7-4. Postdredging Management Activities.

a. Periodic site inspections and continuous site management following the dredging operation are desirable. Once the dredging operation has been completed and the ponded water has been decanted, site management efforts should be concentrated on maximizing the containment storage capacity gained from continued drying and consolidation of dredged material and foundation soils. To ensure that precipitation does not pond water, the weir crest elevation must be kept at levels allowing efficient release of runoff water. This will require periodic lowering of the weir crest elevation as the dredged material surface settles.

b. Removal of ponded water will expose the dredged material surface to evaporation and promote the formation of a dried surface crust. Some erosion of the newly exposed dredged material may be inevitable during storm events; however, erosion will be minimized once the dried crust begins to form within the containment area.

c. Natural processes often need man-made assistance to effectively dewater dredged material since dewatering is greatly influenced by climate and is relatively slow. When natural dewatering is not acceptable for one reason or another, then additional dewatering techniques should be considered.

d. Removal of coarse-grained material and dewatered fine-grained material for productive uses through Disposal Area Reuse Management (DARM) techniques will further add to capacity and may be implemented in conjunction with dike maintenance or raising. In the case of fine-grained dredged material, DARM is a logical follow-up to successful dewatering management activities. This concept has been successfully used by CE Districts and demonstrated in field studies. Guidelines for determining potential benefits through DARM are found in WES Technical Report DS-78-12 (item 24). Additional information on productive uses of dredged material is found in EM 1110-2-5025.

#### 7-5. Long-Term Management Plans for Containment Areas.

a. Adequate dredged material disposal areas are becoming increasingly difficult to secure in many areas of the country. For this reason, it is necessary that the remaining resources of confined disposal sites be properly utilized and managed. A management plan is a vehicle that can be used to assure the most effective use of containment in future years.

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b. The following objectives would normally be set in the plan development:

- (1) Maximize volumetric disposal capacity.
- (2) Dewater and densify fine,-grained material to the greatest extent feasible.
- (3) Reclaim and remove useable material for productive use.
- (4) Maintain acceptable water quality of effluent.
- (5) Abide by all legal and policy and easement constraints.

c. Development of a management plan should include an extensive evaluation of management alternatives based on data accumulated through field investigations and laboratory testing. Integration of the disposal plan with overall navigation system needs is essential. The plan should be developed using the latest available technical approaches for evaluation of the benefits of management practices. A management plan developed for the Craney Island disposal area in the Norfolk District (item 27) is a well-documented example that illustrates how the procedures described in this manual can be used in developing management approaches.

d. A working group or management plan committee is an effective means to ensure that the plan benefits from the input of all District elements. The committee would logically be composed of representatives from Planning, Engineering, and Operation elements. Once a management approach is selected, a monitoring program should be initiated for use in evaluating the effectiveness of management techniques, especially dewatering activities. A monitoring program serves to verify benefits attained and to form a basis for updating or modifying the management approaches.

## CHAPTER 8

## AUTOMATED DESIGN AND MANAGEMENT PROCEDURES

8-1. Need for Automated Procedures.

a. In many of the analyses described in this manual, tedious repetitive calculations for alternative designs and analysis of the design sensitivity to various parameters are required to answer the many "what if" questions which arise. These repetitive calculations are naturally conducive to computerization to allow the evaluation of more alternatives and more detailed sensitivity analyses.

b. The blending of the engineering techniques for dredging design and management with the computerized approach resulted in a computer program called the Automated Dredging and Disposal Activities Management System (ADDAMS). This is a centralized program containing different computerized modules and an associated data management system. In creating ADDAMS, the developers agreed that the program must be easy-to-use, easy-to-modify, internally consistent, and well documented.

c. ADDAMS is set up so that users do not need to be computer experts to run the program. Logging into the computer is the most sophisticated step in using the program. Once inside ADDAMS, the user is led through the program with the aid of keywords and menus. ADDAMS has a data-base management system that can save and update a user's data from one run to the next, but in ADDAMS the system is essentially transparent to the user. All the user needs to do is assign a file name to the data file.

8-2. Current Status.

a. The ADDAMS program now performs a large number of different functions. The program, however, is modular in that the user need learn only that portion of the program needed to accomplish a given task. Current modules now available in ADDAMS include those related to short-term sizing (Chapters 3 and 4), long-term sizing (Chapter 5), a disposal area sequencing model, and other modules related to disposal area design and cost-estimating. Figure 8-1 is a schematic showing how the modules are related through an executive program that controls the overall program and manages the data. Another benefit of the modular nature of the program is that it is fairly easy to add new features or upgrade old modules. It is even possible to maintain old and new versions of a given module data-base update. Since ADDAMS will continually be improved and upgraded, as any often-used computer program, it is highly desirable to upgrade the program in one aspect without affecting other program features.

b. The ADDAMS program is currently running and available for CE users on the CDC Cybernet system. The user's guide and documentation are available in draft form (item 19). When these documents have been published, the program will be made available to the public through the Engineer Computer Program Library at WES. The program is being updated regularly. As it is applied to various studies, those using the program are identifying areas that can be

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upgraded, and the developers are incorporating these suggestions into the program. This should make the program more flexible as well as more relevant to real world problems.

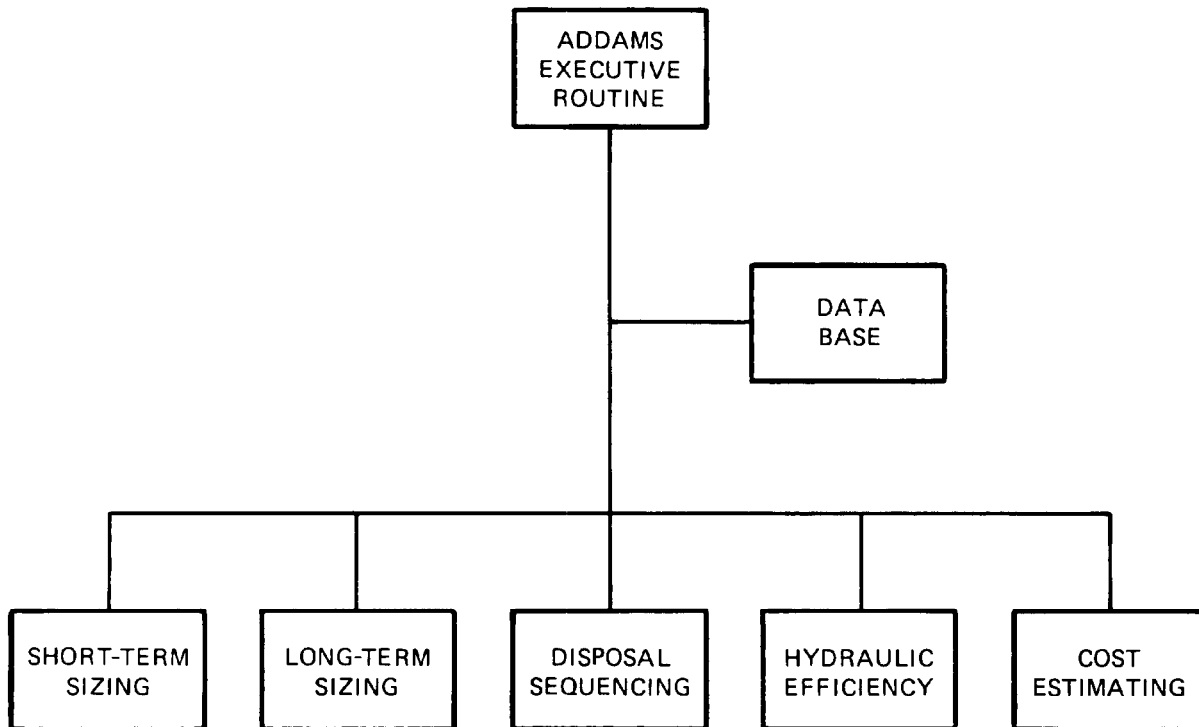


Figure 8-1. Schematic of current ADDAMS program