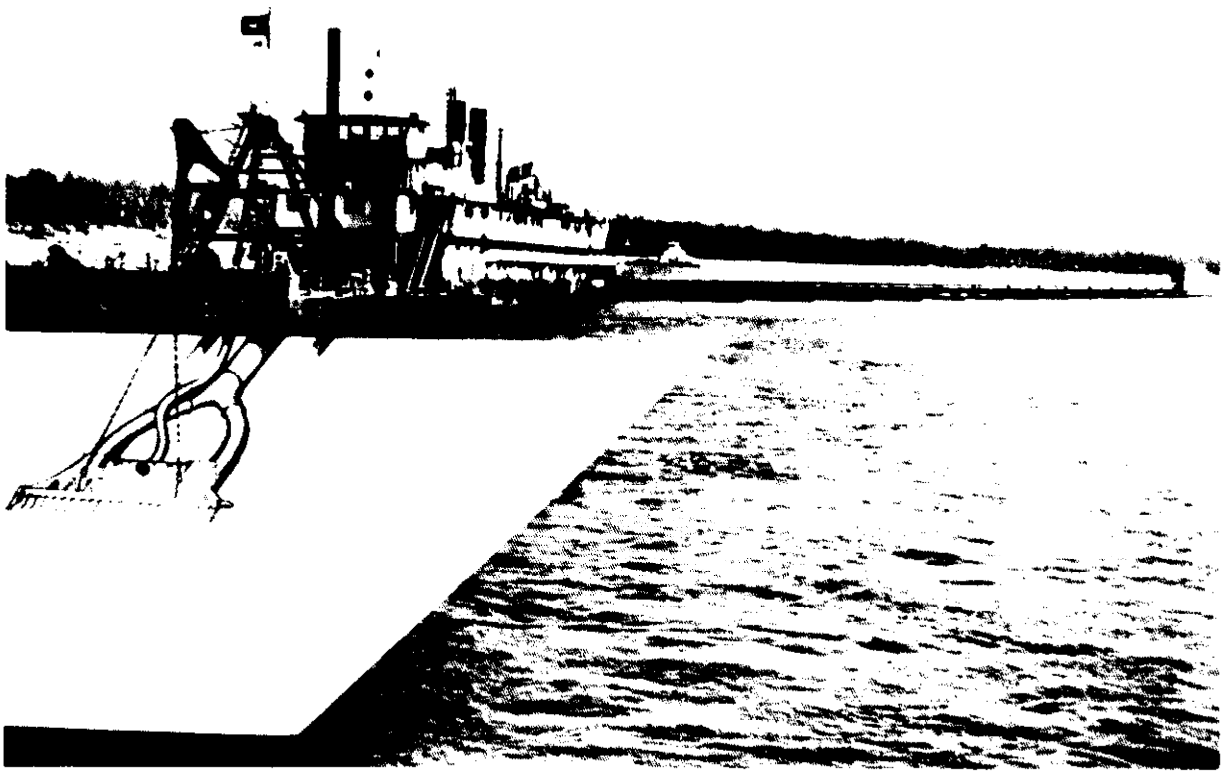

Photo credit: U.S. Army Chips of Engineers

Chapter 10
Managing Dredged Material

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Managing Dredged Material

OVERVIEW

Dredging involves the removal of bottom sediment from rivers and harbors and its transportation to another location for disposal. ' 'New work' dredged material is generated during the initial development of a port, harbor, or navigation channel, or the widening and deepening of existing navigational channels. In addition, "maintenance' dredging is required for most channels because fine-grained, river-borne sediment settles out of suspension and gradually accumulates in the channels (44), and because coarse-grained sediment is eroded from along shorelines and also begins to fill the channels. The U.S. Army Corps of Engineers (COE) considers a small fraction of this maintenance material, general] y dredged from areas near highly industrialized ports and harbors, to contain high enough levels of pollutants to require special management during disposal.[1]

COE is responsible for maintaining over 25,000 miles of navigable waterways that service over 155 commercial ports and more than 400 small boat harbors; these ports and harbors are valuable for commercial, defense, and recreational purposes. Projects run by COE, other Federal and State agencies, and private efforts result in the dredging of about 550 million wet metric tons of sediment each year, at a cost of about $725 million (442).[2] Most dredged material originates from COE projects that have been authorized by Congress. Box X briefly describes the major Federal statutes that control the disposal of dredged material.

Dredged material accounts for about 80 to 90 percent by volume of the waste material that is dumped into marine environments each year. About one-third of all dredged material (180 million wet metric tons) is disposed of in marine environments: two-thirds of this material is disposed of in estuaries and the remainder is dumped in coastal waters or the open ocean. Two dozen sites receive about 95 percent of all dredged material dumped in coastal waters and the open ocean (442); an unknown but large number of sites are used for disposal in estuaries. Pressure to use marine environments for dredged material disposal will continue and possibly increase.

Disposal of *uncontaminated* dredged material does not appear to have had major negative impacts on organisms in most large estuaries or open ocean waters, although some temporary impacts have occurred. In some cases, uncontaminated dredged material can be used for beneficial purposes such as beach replenishment. In some smaller estuaries and some coastal waters, however, disposal of uncontaminated material can contribute to observable degradation. During disposal operations, most bottom dwelling (or "benthic' organisms that are covered by disposed material will die because of physical burial or suffocation. These physical impacts generally are short-term and restricted to the disposal sites; recolonization can take from several months to a few years after cessation of disposal activities. However, marine resources can be permanently damaged at disposal sites that are used regularly and/or that are used for large volumes of dredged material. For example, a quahog fishery off of Narragansett was totally lost after the disposal of several million cubic yards of dredged material.

The disposal of *contaminated* dredged material is generally of greater concern. According to COE, about 3 percent of the material dredged from estuaries and coastal areas is heavily contaminated with pollutants (metals and organic chemicals) derived from point and nonpoint sources. When this material is disposed of and settles on the bottom,

ICOF, uses a series of screening tests, discussed below, to determine when dredged material requires special handling. Quantitative national criteria that could be used to decide whether dredged material is contaminated, however, are currently lacking.

[2]Dredged material is usually measured by volume in cubic yards. To facilitate comparisons, where possible, with the amounts of other waste types, volumes of dredged material have been multiplied by the density of such material, which is approximately 1.18 metric tons per cubic yard, to give wet metric tons. The density of material from any given site may vary somewhat from this figure, however, so the resultant calculations should be considered estimates only,

Box K—Statutory Framework

Several Federal statutes control dredging and disposal operations. The General Survey Act (1824) directed the Corps of Engineers (COE) to develop and improve harbors and navigation, and Section 10 of the River and Harbor Act (1899) required COE to issue permits for any work in navigable waters. Dredging and disposal operations have since been addressed more fully in the major environmental statutes passed during the 1970s, particularly the Marine Protection, Research, and Sanctuaries Act (MPRSA) and Clean Water Act (CWA).

Marine Protection, Research, and Sanctuaries Act

Under Section 103, COE must evaluate proposed projects that involve the transportation and dumping of dredged material in most coastal waters and in the open ocean. The evaluation of these activities is based on environmental impact criteria developed by the Environmental Protection Agency (EPA) in conjunction with COE; these criteria generally contain all the constraints set forth in the London Dumping Convention. Non-Federal projects that are approved receive an ocean dumping permit from COE. Federal projects performed by COE are evaluated in the same manner, but they do not receive permits.

EPA has the primary responsibility for designating ocean disposal sites, although COE may also initiate the site-selection process. EPA can prohibit the use of any disposal site, but has not done so. The National Marine Fisheries Service (NMFS), with assistance from the U.S. Fish and Wildlife Service (FWS), provides environmental input to COE during the review of Section 103 activities.

Clean Water Act

Under Section 404 of CWA, COE regulates discharges of dredged or fill material in "waters of the United States"—most freshwater areas and wetlands, estuaries, and coastal waters inside the territorial sea boundary. The permit applicant or project sponsor is responsible for finding appropriate disposal sites. Permit applications are evaluated by COE, using guidelines developed jointly by COE and EPA. Other agencies—EPA, FWS, and NMFS—provide comments and recommendations, and EPA may veto the use of a proposed disposal site. Where COE's jurisdictions under Section 103 and Section 404 of CWA overlap in the territorial sea, COE usually issues only an ocean dumping permit.

The States also review permit applications for disposal operations in estuaries and in the territorial sea. Under Section 401, these disposal operations must be certified by the affected State as complying with applicable water quality criteria.

Other Federal Statutes

The Comprehensive Environmental Response, Compensation, and Liability Act established the Superfund program to ensure the cleanup of sites that have been highly contaminated by improper disposal practices of the past (583). There are about 30 known freshwater and marine sites that may require dredging and disposal under the Superfund program (N. Francingues, pers. comm., 1986).

The Coastal Zone Management Act requires that States with federally approved coastal zone management programs review permit applications for dredging and disposal activities in estuaries and the territorial sea. Under Section 307, these activities must be certified by the applicant as complying to the maximum extent practicable with the State program. States must either concur with or object to the certification determination.

benthic organisms that recolonize the deposits may take up and bioaccumulate some of these pollutants. Although few potentially harmful pollutants appear to be released directly into the water column, the pollutants can be transferred from benthic organisms to predator organisms. To date, no known human health impacts have been documented from the transfer of pollutants from dredged material up the food chain, although such impacts would be difficult to detect and generally have not been investigated.

Disposal of contaminated material generally involves expensive techniques designed to isolate the material from the environment. In some marine environments, it can be covered or "capped" with a layer of uncontaminated sediment or special containment islands can be built. On land, it can be disposed of in specially managed upland containment areas. It is unlikely, however, that currently available disposal techniques will permanently isolate all pollutants.

No disposal option is categorically better than another, because operational, economic, environmental, and social factors vary greatly among dredging projects (496). As a result, the choice of disposal options usually requires site-specific and often subjective evaluations (169).

Finding suitable disposal sites is the overriding problem now facing COE and other sponsors of dredging projects. Although COE policy stresses the balanced consideration of all disposal options, Federal regulatory requirements are generally stricter for disposal in the open ocean than for disposal in freshwater and estuarine environments. Federal and State requirements tend to be least restrictive for upland disposal, and policies that ha~e attempted to curb pollution in freshwater and marine environments have indirectly encouraged dredged material disposal in upland containment areas. However, disposal in upland areas is generally costly, and finding upland sites is becoming more difficult. Thus, future decisions regarding disposal of dredged material in the Nation's estuaries and coastal waters will be greatly affected by policies regarding disposal on land and in open ocean waters.

DREDGED MATERIAL DISPOSAL: AMOUNTS AND SITES

Inventory of Dredged Material Amounts

Almost 60 percent—about 310 million wet metric tons—of all dredged material in the United States comes from estuarine and coastal areas. Of this material, an average of about 180 million wet metric tons is disposed of in marine environments: about two-thirds in estuaries, one-sixth in coastal waters, and one-sixth in the open ocean.[3] Of the remaining material dredged from estuarine and coastal areas, most is disposed of in upland containment areas (above the water table, but near the dredging site), but some is disposed of in intertidal areas, open freshwater areas, or containment islands.

The amount of material disposed of in coastal and open ocean waters has fluctuated greatly during the last 25 years, between 35 and 120 million wet metric tons per year, with much of the fluctuation resulting from varying dredging demands on the lower Mississippi River (figure 35; the figure and the discussion in this paragraph do not include disposal activities in estuaries). If the volumes of dredged material from the lower Mississippi River are ignored, dredging volumes decreased from 1974 to 1981 and then began to increase in 1982.

Dredged material can be used in a variety of beneficial ways. About 15 to 20 percent of all dredged material is used for: beach nourishment; subaqueous mounds for shoreline protection; construction aggregate; fill material for commercial development or parks; cover material for sanitary landfills; construction material for dikes, levees, and roads; development of marshes and upland habitat; soil supplementation on agricultural land; and reclamation of strip mines (565).

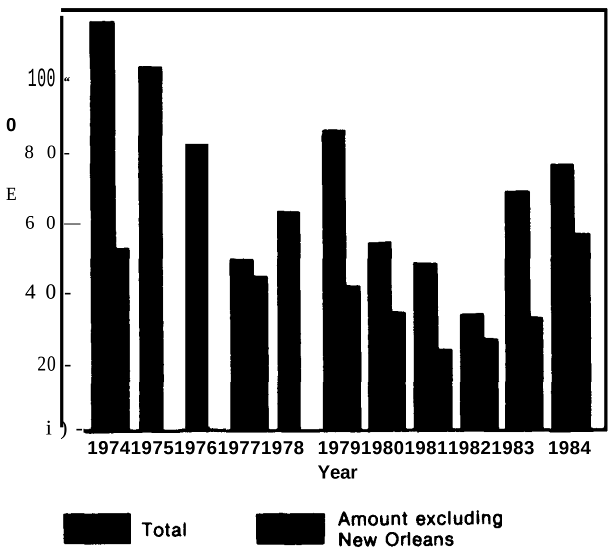
Disposal Sites

Sites in Coastal and Open Ocean Waters

As of January 1987, about 126 disposal sites were located in coastal waters and the open ocean (D. Mathis, COE, pers. comm., January 1987). Most of these sites are distributed relatively evenly along the Atlantic, Gulf, and Pacific coasts, although a few are located in the Caribbean and the South Pacific (442). Although half of the sites receive some use each year, 95 percent of all coastal and open water disposal occurs at about two dozen sites. Some disposal sites are rarely used. Half of the sites have areas of 0.5 square miles or less; the remainder have areas of up to 4 square miles. About three-fourths are located in water less than 60 feet deep; only 18 are in water over 300 feet deep.

[3]These figures are based on an OTA survey of the 18 COE coastal districts with primary responsibility for maintaining ports and harbors. The amount of dredging and disposal fluctuates greatly from year to year and in different areas Of the material that is disposed of in coastal and open ocean water-s, almost half is disposed of in the Gulf of Mexico, and the remainder is split between the Atlantic and Pacific Oceans

Figure 35.—Amounts of Dredged Material" Disposed of in Coastal Waters and the Open Ocean, 1974-84



"From U.S. Amy Corps of Engineers' Projects.

NOTE: Missing second bar for 1975, 1976, and 1978 reflects lack of data

SOURCES: U.S. Army Corps of Engineers, *1980 Report to Congress on Administration of Ocean Dumping Activities,* Pamphlet 82-PI (Fort Belvoir, VA: Water Resources Support Center, May 1982); U.S. Army Corps of Engineers, *Ocean Dumping Report for Calendar Year 1981*, Summary Report 82-S02 (Forf Belvoir, VA: Water Resources SupPort Center, June 1982); U.S. Army Corps of Engineers, *Ocean Dumping Report for Calendar Year 1982,* Summary Report 83-SR1 (Fort Belvoir, VA: Water Resources Support Center, October 1983); J. Wilson, U.S Army Corps of Engineers, personal communication, 1986.

Section 103 of the Marine Protection, Research, and Sanctuaries Act (MPRSA) established a formal process for 'designating coastal and open ocean disposal sites. In 1977, the Environmental Protection Agency (EPA) published comprehensive criteria for the designation process and granted 3-year "interim' designations for previously used disposal sites (630). Preparation of an environmental impact statement (EIS) for each site and "final" designation were to be completed by January 1981, but this process encountered many delays (579).

As of November 1986, EPA had granted final designation to 19 sites (Office of Marine and Estuarine Protection, EPA, pers. comm., November 1986). Although COE does not formally designate sites, as of January 1986 it had "selected' about 15 additional sites that it considered suitable for final designation (D. Mathis, COE, pers. comm., January 1987). Most of these sites were selected for one-time use, for example, for the disposal of material from channel deepening projects in Mobile and Norfolk, with disposal of any subsequent maintenance material occurring at other, EPA-designated sites. Most of the remaining 90 or so coastal and open ocean sites are being used under extensions of EPA's original interim designations.

No major dredging project has been canceled because a coastal or open ocean disposal site lacks final designation. However, a portion of the Tampa Harbor deepening was delayed, and the State of New York has prohibited the use of several undesignated disposal sites in coastal waters. COE, port authorities, and the dredging industry are concerned that future projects could be canceled or delayed if interim disposal sites cannot be used, for example, because of litigation over delays in the designation process (442).

Sites in Estuarine Waters

Defining the number of disposal sites in estuaries is difficult because material often is discharged along much of a navigation channel, although at some distance from the channel itself. Thus, it is difficult to judge whether this constitutes one or multiple disposal sites. Section 404 of the Clean Water Act (CWA) controls this kind of disposal through a permitting process, but it does not include provisions for formally designating sites. Generally, a permit for disposal in an estuary specifies that a site will be used for a given length of time; in many cases, the permit is only for one disposal operation, although the site could be used again under another permit.

In addition, about 30 sites have received multiple-use permits under Section 404 (D. Mathis, COE, pers. comm., January 1987). These sites—for example, Alcatraz Island in California and Puget Sound in Washington-tend to be controversial, and the permitting process often involves preparing an EIS, even if the site is not to be used on a continuing basis. Most dredged material disposal that occurs in estuaries, however, does not occur at these multiple-use sites.

Future Need for Marine Disposal

Dredged material disposal in marine waters could increase for several reasons. First, some projects

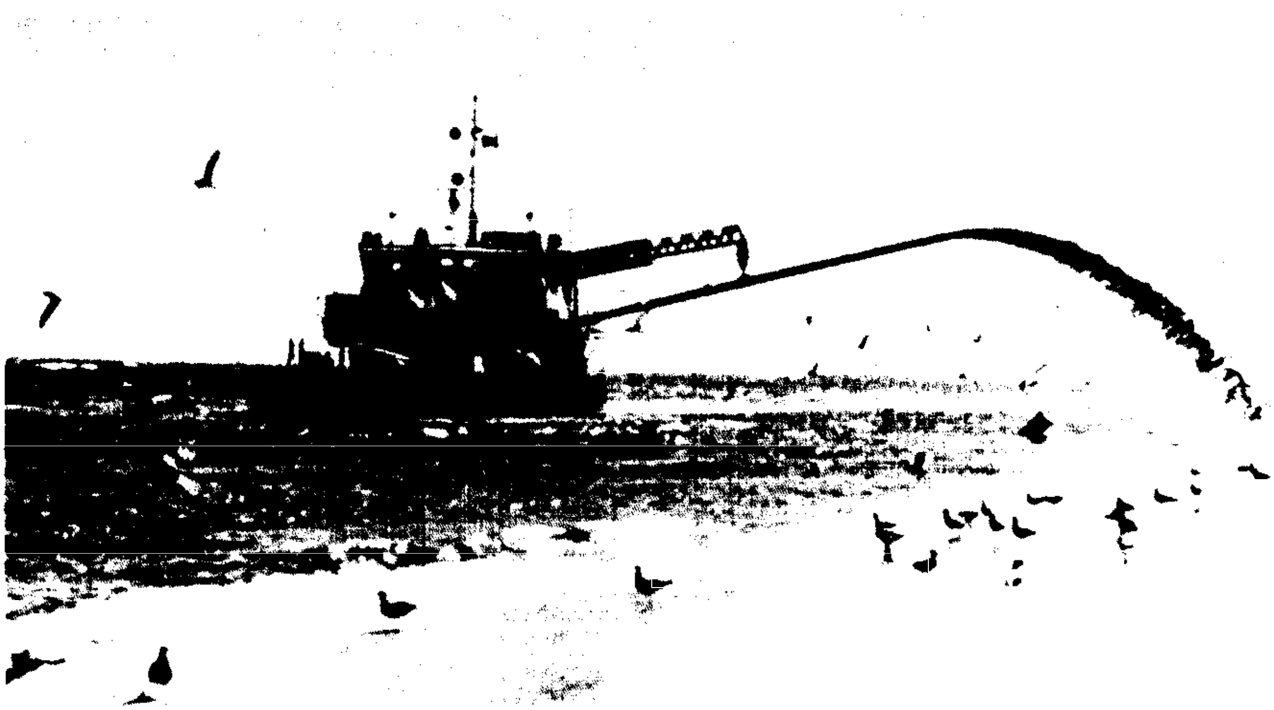


Photo credit: U.S. Army Corps of Engineers

After being excavated from a navigation channel, dredged material can be "sidecast" from the dredge and used to replenish beaches.

proposed for increasing commercial traffic would involve the development of harbors and deepening of channels. These projects would generate large amounts of material, and deeper channels, once created, generally would require increased maintenance dredging. Since most coastal ports have used marine waters heavily for disposal from similar projects in the past, such disposal is likely to continue; for example, about 90 percent of dredged material from COE's New York District is disposed of at the Mud Dump site in the New York Bight. Second, some observers argue that the United States must develop additional capacity to handle large, deep-draft vessels if it is to maintain or increase its present role in the international economy. Because of the high costs of port construction and uncertainties about the total required capacity for deep-draft ships, however, only a limited number of such ports are likely to be built (388). Third, some ports may need to be deepened to accommodate an increasing number of naval vessels.

Although all major U.S. ports have made some plans for expansion and channel deepening, new federally authorized port projects have faced many delays over the last 10 to 15 years. The Water Resources Development Act passed by Congress in 1986, however, authorized many of these projects, including 6 deep-draft projects and 35 general cargo and shallow water improvements. It also established cost-sharing between the Federal Government and local sponsors or port authorities. If all the authorized projects are completed, the Federal share would be $3 billion and the local or port share would be $2 billion. New dredging projects will now proceed, and marine disposal of some material is likely. The cost-sharing arrangement, however, could inspire local sponsors to reduce the amount of requested dredging, with a subsequent decrease in the amount of material requiring disposal (P. Johnson, Office of Technology Assessment, pers. comm., November 1986).

DREDGED MATERIAL CHARACTERISTICS

Sediment Composition

Sediment is composed of varying amounts of several natural substances: sand, gravel, silt, and/or clay; organic matter and humus (i. e., decomposed organic matter); and chemical compounds such as sulfides and hydrous iron oxide. Sediments also can be contaminated with various metals and organic chemicals, from both point and nonpoint pollution sources.

Pollutants commonly found in dredged material include metals (e. g., cadmium, chromium, copper, iron, lead, mercury, nickel, silver), chlorinated hydrocarbons (e. g., PCBs, DDT), polycyclic aromatic hydrocarbons, and other petroleum products. Most pollutants are adsorbed or tightly bound to the organic material and the clay particles in dredged material, thereby reducing their potential availability to marine organisms that inhabit the water column, but not necessarily to benthic organisms that dwell on or in the sediment (46,549).

No quantitative criteria exist for defining the degree to which dredged material is contaminated,[4] so it is difficult to estimate exactly how much dredged material is clean, somewhat contaminated, or highly contaminated. COE considers a large portion of dredged material to be relatively clean. For example, as much as 20 percent of all sediment dredged by COE is ' 'new work' material, which generally is not contaminated because it was deposited long before the settlement and industrialization of North America. Sand, which does not readily adsorb pollutants, and sediments located some distance from present or past pollution sources usually are relatively clean.

To determine when dredged material is contaminated enough to require special management, either in upland or island containment areas or by capping, COE generally relies on a series of screening tests. Based on these tests, COE considers about 3 percent (approximately 7 million wet metric tons) of all material dredged in its coastal districts to be highly contaminated and to require special management.[5] In addition, participants at an OTA workshop estimated that about 30 percent of all maintenance material might be contaminated to some degree, even though it is not managed specially (584). These participants and other observers consider highly contaminated dredged material to be less contaminated than material disposed of in sanitary landfills (103) and than some hazardous material (299).[6]

Most contaminated sediment is found in the immediate vicinity of ports and harbors, or in areas where direct municipal and industrial discharges into estuaries and coastal waters have contributed considerable amounts of pollutants. Riverborne clays that are "trapped" in estuaries and navigation channels also may have been contaminated when they were transported through upstream regions. Dredging and disposal operations do not introduce new pollutants into aquatic environments; they simply redistribute sediments that are already contaminated.

Effects of Dredging Equipment on Composition

The physical characteristics of dredged material are significantly influenced by the type of dredging equipment used to excavate and transport the sediment. Two major types of dredges are used: hydraulic and mechanical.

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[4]EPA is studying the feasibility of developing sediment quality criteria for certain metals and organic chemicals (C. Zarba, EPA, pers. comm., November 1986). These criteria could be used, for example, to determine whether dredged material is sufficiently contaminated so as to pose undue risks to bottom -dwelling marine organisms.

[5]This figure is based on the survey of COE coastal districts; since quantitative nationwide criteria are lacking, responses about the degree of contamination were based on the best judgment of COE personnel and their experience with dredged material requiring special management.

[6]It is unclear whether the Resource Conservation and Recovery Acts toxic characteristic leachate procedure (TCLP) toxicity test, developed by EPA to evaluate the potential for leaching from land-based disposal sites, is legally applicable to dredged material. The previous test (the extraction procedure, or EP, toxicity test) specified that material should be tested in its field-collected form, which for dredged material would always be wet. According to COE, wet dredged material, even if highly contaminated, will generally pass the EP test (103,269,299). On the basis of the EP test, highly contaminated dredged material could be considered acceptable for upland disposal; subsequent oxidization of the material, however, could make it susceptible to leaching. In contrast, dried dredged material, even if not considered highly contaminated, might not pass the test.

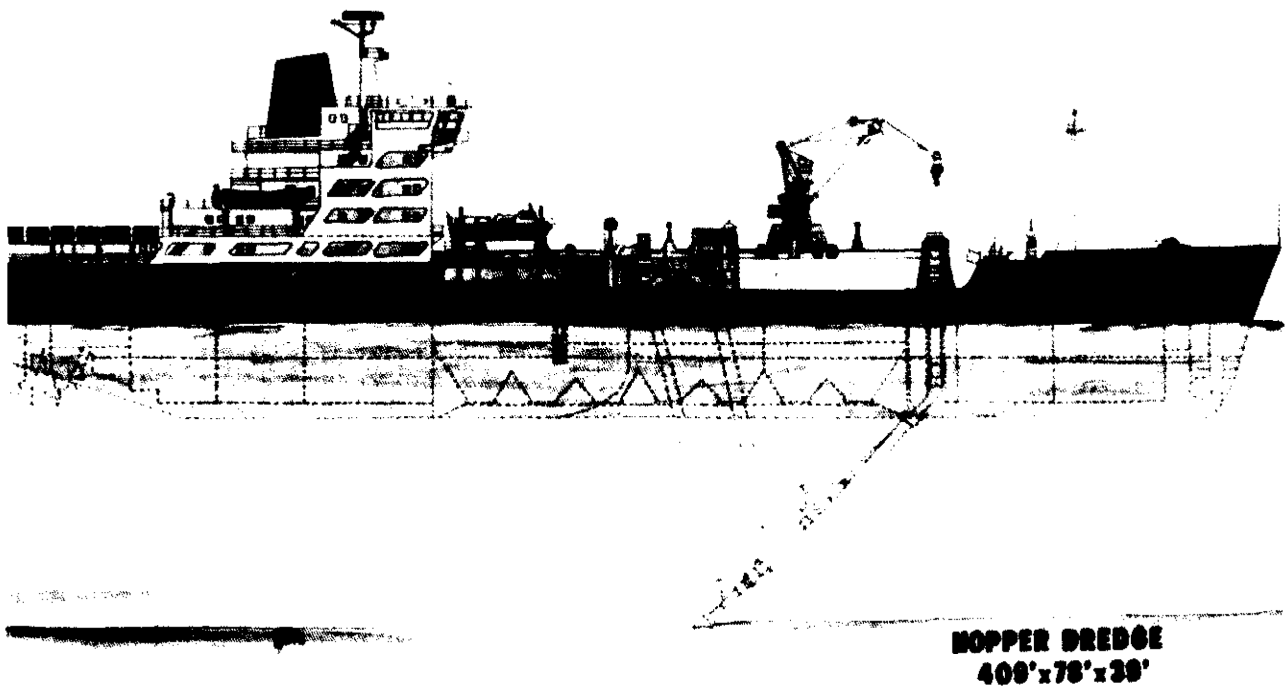

Photo credit U S Army Corps of Engineers

Much of the dredging in the United States is conducted by ships known as hopper dredges, which hydraulically excavate material from a channel bottom and place it in '(hoppers" within the hull. After the ship moves to a designated disposal site, the material is either dumped into the water or discharged through a pipeline to a beach or a diked containment area. This diagram of a hopper dredge shows some of the equipment used to excavate material from the bottom.

Most of the dredging in the United States is done with *hydraulic dredges,* Hydraulic dredges add significant amounts of water to the material, which enables the resulting slurry—about 80 to 90 percent water—to be pumped through a pipeline to a disposal site. Hydraulic dredges include both pipeline dredges and hopper dredges. Pipeline dredges discharge the material through a pipeline leading away from the dredge; they are rarely used in the open ocean because the pipeline can be broken by sizable waves. Hopper dredges are ships that hydraulically fill their hulls with dredged material slurry, cruise to the disposal site, and dump the dredged material through doors in the hull; they operate most effectively in the open ocean or in vessel traffic.

Mechanical dredges are used on small jobs (e. g., around piers). They have clamshells or buckets that remove sediment at its original, or "in situ, density without adding significant amounts of water. Mechanically dredged sediment is typically transported to a disposal site in barges **(240).**

PHYSICAL FATE OF DREDGED MATERIAL AFTER DISPOSAL

Disposal in Marine Environments

When a load of dredged material is dumped from a stationary hopper dredge in water depths of less than 200 feet, most of the material descends rapidly (a few feet per second) through the water column as a high-density mass. The remainder—about 1 to 5 percent of the released sediment—remains suspended in the water column as a plume of slowly settling particles. When the rapidly descending mass reaches the bottom, the largest blocks of material remain in the impact area. Fine-grained material (as opposed to coarser, sandy material) spreads several hundred feet radially along the bottom and away from the impact point, in the form of a layer of "fluid mud" that can measure several feet in thickness (234).

In estuaries and coastal waters, the accumulation of dredged material on the bottom can be significant if dumping occurs over long periods or involves large volumes. Ever since the late 1800s, for example, dredged material has been dumped in the New York Bight within a few miles of the present Mud Dump site (located 6 miles east of New Jersey and 11 miles south of Long Island). More than 85 percent of the dredged material has remained at the disposal site, forming three well-defined hills that rise 30 to 50 feet above the bottom (125,171). Other material has accumulated northwest of these mounds, evidence of shoreward transport and/or dumping of dredged material short of the disposal site.

In the deep ocean, where water may be thousands of feet deep, the rapidly descending mass of material will entrain water as it descends and lose its integrity. After this occurs the material continues to settle slowly through the water column as a widely dispersed plume of suspended sediment. This material eventually is distributed widely over the bottom, usually without any significant buildup (93,234,439). If the total volume of material dumped at an open ocean site exceeds a few hundred thousand metric tons, however, the deposition may be sufficient to bury benthic organisms.

When slurry made of dredged material is disposed of in rivers, estuaries, and enclosed coastal areas via pipeline dredges, an estimated 97 to 99 percent of the slurry descends rapidly to the bottom of the disposal area. Once on the bottom, the slurry typically accumulates in the form of a low gradient mound of fluid mud. About 1 to 3 percent of the slurry remains suspended in the water column in the form of a turbidity plume. Turbidity plumes usually spread a few thousand feet from the discharge point and dissipate within several hours after the dredging is completed (500).

Once deposited, the long-term fate of dredged material depends on many factors, including bottom topography, the nature of the sediment, and erosion and transport by currents (234). Several models can be used to predict long-term transport of dredged material (235).

Disposal in Intertidal and Upland Containment Areas

To dispose of dredged material in intertidal or upland areas, it is usually pumped by a pipeline dredge into a diked containment area. The sediment will settle inside the area, and the ponded surface water is generally drained off as "effluent." If the ponded water and any rainfall on top of the settled material is drained completely, a dried crust will form over the surface of the area (217). However, the dredged material under the crust will remain almost indefinitely at a grease-like consistency with a solids content of about 30 to 40 percent (431).

IMPACTS OF DREDGED MATERIAL DISPOSAL

Disposal in Marine Environments

In marine environments, a number of adverse impacts can occur as dredged material descends through the water column or when it settles on the bottom. Impacts can occur in two areas: 1) on the water column and pelagic organisms, and 2) on bottom-dwelling organisms. No impacts on human health are known to have occurred from the transfer of pollutants in dredged material through the food chain; even if they were detected, however, it would be difficult to attribute them solely to dredged material disposal because other sources of pollutants are present in most areas.

Impacts on the Water Column and Pelagic Organisms

Levels of suspended solids in the water column during dredging and disposal operations are usually low enough to cause few, if any, detectable physical impacts on pelagic organisms (i. e., those in the water column) (232). If surrounding waters become too turbid, several control techniques can be used (14). Another approach is to schedule projects to avoid seasons, such as during spawning, when potential impacts to marine organisms are great (320).

As dredged material descends through the water column, some pollutants (e. g., hydrogen sulfide, manganese, iron, ammonia, and phosphorus) may be released and their concentration in the water column may increase. In dispersive waters these increases are usually diluted rapidly (62,232,708). In small estuaries and sheltered coastal waters, however, such releases may adversely affect organisms in the water column. It appears to be rare, however, for pelagic organisms to bioaccumulate metals and organic chemicals released from contaminated dredged material, although detecting such impacts and attributing them to a particular waste type is difficult.

Impacts on Bottom-Dwelling Organisms

Physical Impacts.—Most benthic organisms that are covered by more than a foot or so of dredged material will die from suffocation within minutes or hours after disposal (232, 708). Some burrowing organisms may be able to move vertically through the deposited material, especially if the dredged material is similar to the original bottom sediment. Bottom-dwelling fish typically leave a dumpsite during disposal operations, but they may return later if the habitat is not severely altered.

Physical impacts to bottom-dwelling organisms are generally restricted to the dumpsites. In large estuaries and coastal waters such as Chesapeake Bay or Puget Sound, disposal of uncontaminated material probably has an insignificant overall impact on the ecosystem. Physical impacts also are likely to be less significant (although possibly more widespread) at deeper sites because the material is more dispersed over the ocean bottom (440). In smaller estuaries or embayments, however, ecosystem impacts can be more significant. In general, disposal sites that are used once a year or more frequently will not fully recover as long as disposal continues. In addition, particularly sensitive benthic communities such as undersea grasses, coral reefs, and oyster beds may never recover.

In most areas that have been covered by uncontaminated dredged material, recolonization by benthic organisms begins within a period of weeks; extensive recolonization can take from several months to a few years after cessation of dumping activities (232,708). If the dredged material is similar to the original sediment, recolonization will occur more rapidly and the new community will more closely resemble the original community, Otherwise, the new community may show changes in the types and distribution of species, or changes in the total biomass of organisms present.

Some disposal of uncontaminated dredged material has harmed fisheries and other marine resources. For example, a quahog fishery was totally lost when several million wet metric tons of dredged material were disposed of at the Brenton Reef disposal site near Narragansett in 1969 and 1970 (442). In another instance, a coral reef off southern Florida was smothered by a disposal operation (J. Wilson, COE, pers. comm., 1986). On the other hand, some sites adversely affected by dredged material disposal may later be colonized by other organisms and become important commercial and sport fishing sites. The Brenton Reef site, for instance, was colonized by lobsters and is now a favorite location for lobster fishermen (442).

Chemical Impacts.—In addition to physical impacts, some pollutants in dredged material maybe released to the lower water column over a period of months or years because of: the expulsion of interstitial (or pore) water as the material consolidates on the bottom (125), the burrowing of organisms in the upper layers of sediment (124), or the resuspension of material during storms (709). Benthic organisms that recolonize the deposit area may take up and sometimes bioaccumulate some pollutants from the lower water column or the sediment itself (46,232,260). Pollutants of particular importance include methyl mercury, cadmium, and many chlorinated and polynuclear aromatic hydrocarbons (442).

Potential and actual adverse effects from pollutant uptake are discussed in chapters 5 and 6. In many situations, it is difficult to discern how bioaccumulation affects benthic organisms or the ecosystem in general (437), or where the pollutants came from. In the New York Bight, for example, dumped sewage sludge and dredged material are major contributors of many metals, suspended solids, phosphorus, and PCBs, but it is difficult to ascertain how much is contributed by the dumping of dredged material alone (125). In addition, metals often tend to be tightly bound to the clays and organic matter in dredged material; in such cases, they are less likely to be released to the water column.

Disposal in Intertidal Areas and Upland Containment Areas

In *intertidal areas,* impacts depend largely on the characteristics of the disposal site. If a 3- to 6-inch layer of clean dredged material is placed over a marsh, most plants will regrow within several years. Once vegetated, these marshes are quickly colonized by various invertebrates (e. g., mussels, snails, and crabs) and birds. Thicker layers of dredged material will probably destroy the marsh grass and significantly change the elevation of the area so that marsh grass may not regrow (3 19). Some metals and organic chemicals can be taken up by plants, especially if the dredged material is exposed to oxidizing conditions during low tide (179,265,479). Once taken up by plants, pollutants can be transferred to wildlife or to estuarine organisms that feed on the plants or plant detritus (301).

Upland disposal in diked containment areas has been favored by many Federal and State regulatory agencies during the last decade because of concerns about potential impacts associated with marine and freshwater disposal (259). Several problems, however, can occur in upland situations. For instance, if ponded water on top of the settled material is drained, pollutants can escape in the drained effluent (15 ,289,43 1,449). In addition, the material remaining in the containment area often oxidizes, increasing the acidity of the material. Under these conditions, metals that were formerly bound to the dredged material (e. g., cadmium, lead, mercury, nickel) can be released in runoff from the containment area (1 79,300). Most organic chemicals tend to remain with the fine- grained dredged material in the containment area or volatilize into the atmosphere (R. Peddicord, COE, pers. comm., 1986). Upland containment areas have also been identified as sources of saltwater intrusion and other groundwater contamination (1 79,442; R.M. Engler, COE, pers. comm., 1986).

PREDICTING ENVIRONMENTAL IMPACTS

Predictions about project-specific impacts can only be made if there is adequate information about the proposed operation, the material that will be disposed of, and the disposal site environment. In some cases, predictions can be generalized for situations in which the sediments, dredging equipment, and disposal environments are similar.

Predicting Physical Fate in Marine Environments

The short-term physical fate of disposed dredged material is generally quite predictable and computer and empirical models are available for making more detailed assessments. Predicting long-term sediment transport, however, is usually more difficult (234), For example, the accuracy of long-term predictions is directly related to the availability of data on currents and other hydrographic conditions in a particular area (235). If this information is not available, detailed and costly predictions of long-term physical fate for single disposal operations may not be worthwhile, unless a large volume of material is involved. Using information from past disposal operations at similar sites is often a more effective way of predicting long-term transport.

Predicting Chemical Impacts on Marine Organisms

The COE uses a number of laboratory tests to evaluate the potential short-term toxicity of pollutants in dredged material to marine organisms:

- Bulk sediment composition analyses indicate the concentrations of pollutants that are present in the dredged material.
- Elutriate tests indicate the degree to which different pollutants might be released to the water column during disposal.
- Laboratory bioassays indicate the potential ‘ ‘acute’ toxicity (or lethality) of pollutants to organisms, over a period of 2 to 60 days (436).

- Bioaccumulation tests indicate which pollutants might be taken up by marine organisms over the short-term (436).

These standard tests generally require several months to a year to complete; costs can range from $1,000 to $30,000 per sample (table 25). The number of samples required to evaluate a particular disposal operation depends on several factors, including size of the dredging project, sensitivity of the disposal environment, and similarity of the project to past projects that have been monitored for impacts.

Federal and State regulators have tried to use bulk sediment composition analyses as the primary (and sometimes only) method for determining whether a particular sediment is contaminated enough to require special management, in part because these analyses do not require expensive and time-consuming tests. In addition, the potential toxicity to marine organisms of a given sample of dredged material is usually lower than indicated by the tests, because metals and some organic chemicals tend to be tightly bound to clay particles and humus in the material and to be less available to the organisms (259). Because of this factor, COE has assumed that sediment passing these tests can be disposed of safely in any environment without concern about potential chemical effects; if the sediment f-ails these tests, it is considered contaminated enough to be unsafe for unrestricted disposal in marine environments.

The use of these types of tests to determine whether dredged material is contaminated enough to require special management has been criticized. For instance, bulk sediment composition analyses do not necessarily indicate the likelihood that pollutants will be released from the sediment to the water column or whether they will be taken up by marine organisms. Laboratory bioassays do not indicate which pollutants are responsible for any observed effects nor can they detect long-term, chronic effects, and bioaccumulation tests do not necessarily indicate whether further effects will occur (436,437).

Table 25.—Approximate Costs of Laboratory Tests for Predicting Chemical Impacts of Marine Disposal, Per Sample

Bulk sediment analyses.	.$ 5,000
Elutriate test ... , ...	.$ 1,000 to $ 5,000
Bioassay	.$ 1,000 to $ 5,000
Bioaccumulation tests	.$15,000 to $30,000

SOURCE Office of Technology Assessment, 1987; based on W.E Pequegnat, *An Overview of the Scientific and Technical Aspects of Dredged Materi-a/ Disposal in the Marine Environment*, contract prepared for U S. Congress, Of fice of Technology Assessment (College Station, TX January 1986)

In addition, the lack of standardized, quantitative "sediment quality criteria' is a major problem, especially for sediments that are neither extremely contaminated nor extremely clean (C. Zarba, U.S. EPA, pers. comm., November 1986; K. Kamlet, A.T. Kearney, Inc., pers. comm., November 1986). Regulatory agencies could use sediment quality criteria— designed to indicate when pollutant levels in dredged material are likely to cause impacts on marine organisms—to assess the degree of contamination of dredged materia). EPA is considering developing quantitative sediment quality criteria for some metals and organic chemicals (C. Zarba, U.S. EPA, pers. comm. , November 1986). Without such criteria, the results of any qualitative tests are subject to varying interpretation. Thus, tests such as the bulk sediment composition analyses are probably most useful as screening tools to identify clean sediments, but not to assess the degree of contamination of sediments.

Predicting Impacts From Other Disposal Options

In upland containment areas, the consolidation of dredged material slurry can be predicted with reasonable accuracy, based on empirical observations and measurements (555). Chemical impacts, however, are more difficult to predict,

COE has developed several tests to predict the chemical impacts that might be associated with upland disposal. These tests show the quality of ponded water that might be discharged during the disposal operation, the quality of surface runoff from the disposal area, the potential for long-term leaching of pollutants into adjacent aquifers or surface waters, and the potential uptake of pollutants by plants and animals that might eventually inhabit the area, These tests also require several months to complete, but they are generally more expensive than tests for marine disposal (table 26). EPA has developed other tests under the Resource Con-

Table 26.—Approximate Costs of Laboratory Tests for Predicting Chemical impacts of Upland Disposal, Per Sample

Bulk sediment analyses.	$ 5,000
Quality of ponded water tests	$ 7,500
Runoff quality tests	$20,000
Leachate quality tests[a]	$75,000 to $100,000
plant/animal uptake tests	$30,000 to $ 40,000

[a]Leachate quality tests address the potential for Contaminating groundwater. Standard tests are being developed and costs for routine testing may be lower than values cited.

SOURCE: Office of Technology Assessment, 1987; baaad on W.E. Pequegnat, *An Overview of the Scientific and Technical Aspects of Dredged Material Disposal in the Marine Environment,* contract prepared for U.S. Congress, Office of Technology Assessment (College Station, TX: January 1986).

servation and Recovery Act (RCRA) to assess the potential for hazardous wastes to leach from land disposal sites. Whether these tests are legally applicable to the disposal of dredged material is unclear.

DISPOSAL TECHNIQUES FOR CONTAMINATED DREDGED MATERIAL

If dredged material is determined, by whatever method, to be highly contaminated, it generally requires special management during disposal to isolate it from the environment. These special techniques include disposal in:

1. water, under a layer or "cap" of uncontaminated sediment,
2. an upland containment area, or
3. a containment island.

These disposal options all require long-term maintenance to maximize the degree of sediment isolation. Even then, it is unlikely that all pollutants will be permanently isolated.

Capping in Marine Environments

In relatively quiescent marine (and freshwater) environments, contaminated dredged material can sometimes be isolated from aquatic organisms by covering it with a layer of uncontaminated material (47 ,261,363,5 11). About 3 feet of cover material is usually required to minimize the possibility of organisms burrowing into the contaminated material. Capping does not change the nature of the material under the cap: it still remains contaminated.

Capping has several advantages, especially in relatively quiescent marine environments. First, caps appear to be stable and subject to little erosion in these environments; it is conceivable that additional capping material might not be needed for several decades. Second, as long as the cap is not disturbed the contaminated material remains in a relatively unoxidized state, thereby minimizing the upward migration of pollutants from the dredged material (47). Finally, costs for capping can be much lower than costs for disposal in upland containment areas or containment islands. The London Dumping Convention considers capping in quiescent marine environments to be an acceptable method, if subject to careful monitoring (136).

Capping also has several disadvantages, however. First, the water column may be exposed to some pollutants as the dredged material descends to the bottom, although releases to the water column tend to be small. Second, if water depth at the site increases beyond 100 feet, it becomes difficult to restrict lateral spreading when dredged material is placed on the bottom. [7] Third, capping requires a large volume of clean cover material, leading to increased costs. This can be minimized if contaminated material from one project is covered with uncontaminated material from another

[7]When contaminated sediment is removed with a pipeline dredge, the slurry can be pumped through a ' 'diffuser' mounted at the end of the pipeline (390). By reducing the velocity of the slurry as it leaves the pipeline, a diffuser system minimizes the exposure of the water column to the contaminated dredged material, allows more precise placement of the material, and minimizes the lateral movement of the material along the bottom. First designed in the United States in the late 1970s, diffusers have been used to cap contaminated sediment in Rotterdam Harbor and recently were tested on contaminated dredged material from Calumet Harbor, Chicago, IL (R. Montgomery, pers. comm., 1986).

project. Fourth, once the dredged material is on the bottom, contaminated water may be released as the sediment consolidates prior to capping or after capping if the cap "sinks' into the contaminated sediment. Finally, storms or currents can erode the cap, thus requiring the expense of additional clean material.

Capping of contaminated material has been used over the last decade in the United States, Japan, Canada, and the Netherlands (442). In this country it has been used in water depths of 100 feet or less in Long Island Sound, the New York Bight, off the coast of Maine, the Duwamish Waterway near Seattle, and Alaska.

In some cases, natural or artificial subaqueous pits can be filled with contaminated dredged material and capped (37). Pits restrict the lateral spreading of the dredged material, and a cap that is level with the bottom is less susceptible to erosion than a mounded surface. Approximately 125 natural and artificial pits have been identified in rivers, estuaries, and coastal areas of the United States, many near ports and harbors (39).

Upland Containment Areas

Upland containment areas are used to physically, and presumably chemically, contain contaminated dredged material. As with capping, material disposed of in upland containment areas still remains contaminated.

The primary advantage of upland disposal is that it allows greater management and control than is possible in marine environments (259,317,431). For instance, the area could be lined with clay or synthetic materials to reduce the potential for groundwater contamination, water discharged from the site could be controlled and treated, lime could be applied to increase pH and minimize the leaching of metals, or the area could be covered with clean sediment to isolate the contaminated sediment from runoff, Such management techniques, however, can greatly increase the overall costs of disposal.

The major disadvantage of upland disposal is the potential for release of metals (e. g., cadmium, lead, mercury, nickel). Drying the dredged material to enhance its consolidation and increase the area's capacity significantly increases the potential for mobilization and subsequent release of most metals to the environment. Oxidizing conditions, which are more common in upland than aquatic environments, increase the likelihood that metals will be taken up by plants and transferred to animals, released in runoff from the site, or leach into groundwater.

Containment Islands

Another option to dispose of contaminated sediment is to build containment "islands' in relatively protected areas close to a port. These islands consist of an outer perimeter that is gradually filled with contaminated dredged material over a period of a few decades. The primary advantage of containment islands over upland containment areas is that the contaminated material is maintained in a saturated and unoxidized chemical environment, thereby minimizing the potential for migration and release of pollutants. These islands can cause undesirable changes in water circulation or benthic communities or become navigational hazards, however, unless they are located away from navigation channels or biologically important resources.

Several containment islands have either been built or proposed. For example, Hart-Miller Island in the Chesapeake Bay was designed to accept contaminated dredged material from Baltimore Harbor for the next two decades. It has a capacity of 53 million cubic yards (about 63 million wet metric tons), covers approximately 1,100 acres of shallow bottom, and cost $59 million to build (442). The New Jersey Department of Environmental Protection has proposed that the New York and New Jersey Port Authority build a containment island in Raritan Bay. After a containment island has been filled and capped, the island can be developed commercially or used for recreation or wildlife habitat if continued isolation of the contaminated material can be ensured.

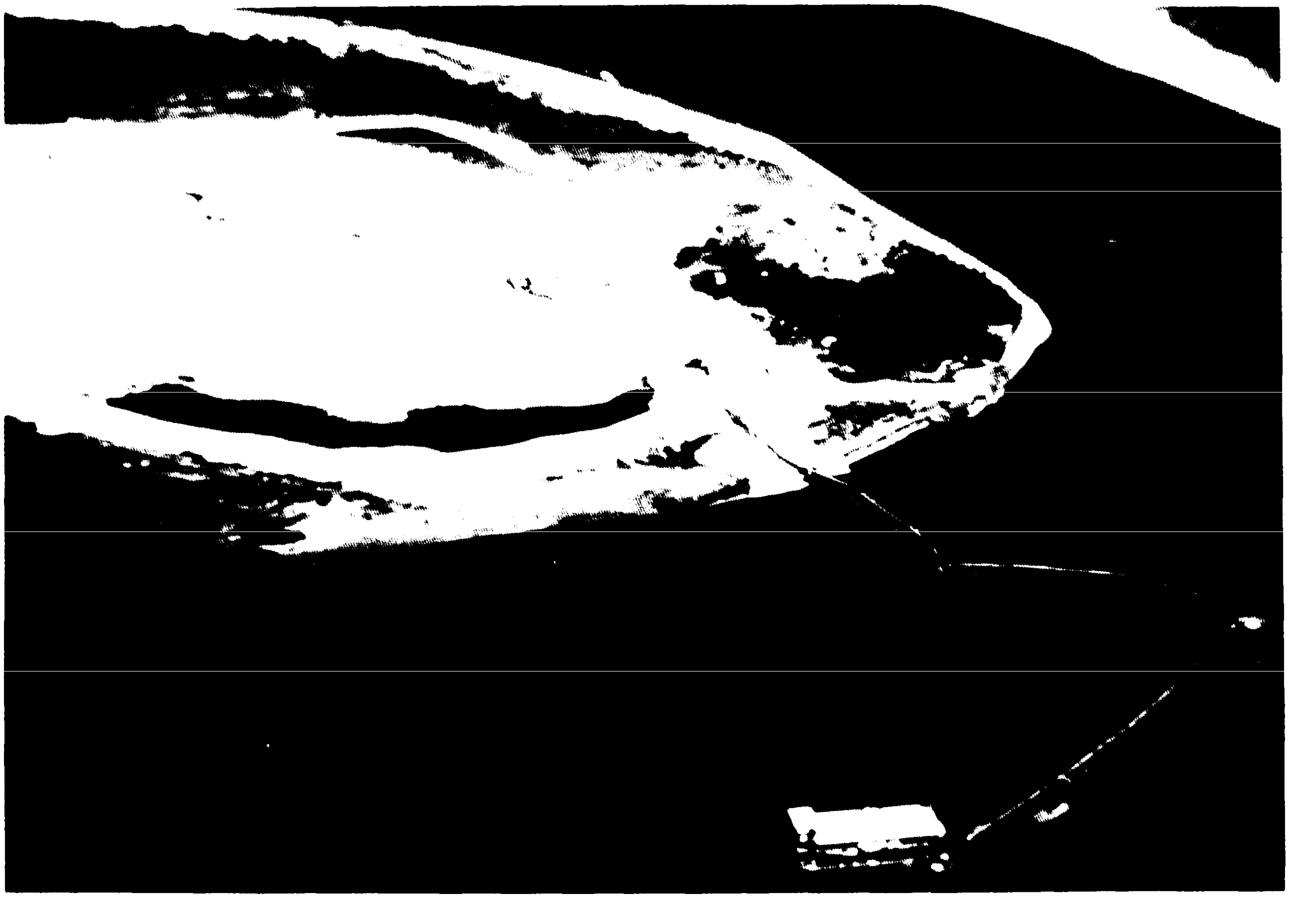

Photo credit: U.S. *Army Corps of Engineers*

In some cases, dredged material is disposed of in diked containment islands that are built in relatively protected areas. The containment island shown here, located in North Carolina, is being filled with dredged material pumped through a pipeline from the dredge in the foreground.

COSTS OF DISPOSAL OPERATIONS

Dredging and disposal costs vary significantly from one project to another. In 1986, uncontaminated material averaged about $1.50 per cubic yard for disposal. For marine disposal, the costs of operations using pipeline dredges ranged from about $0.50 to $2.00 per cubic yard (table 27). Costs for ocean disposal using a hopper dredge or dumping barge are usually somewhat greater, reflecting the transport distance to the disposal sites. The use of upland containment areas is considerably more expensive than disposal in marine environments. Costs for disposing highly contaminated dredged material may be 2 to 10 times higher than ordinary disposal costs.

Table 27.—Approximate Costs Per Cubic Yard for Dredged Material Disposal

	Uncontaminated	Contaminated
Marine environments[a]	$0.50 to $2	$3 to $5
Upland containment	$5 to $20	$30 to $60

[a]Using pipeline dredge with disposal in adjacent waters

SOURCE: Office of Technology Assessment, 1987, based on W.E. Pequegnat, *An Overview of the Scientific and Technical Aspects of Dredged Material Disposal in the Marine Environment,* contract prepared for U S Congress, Office of Technology Assessment (College Station, TX January 19s6)

POLICY ISSUES

Dealing With the Shortage of Disposal Areas

Estuaries and coastal waters are among the most important aquatic environments, but many are severely stressed by pollutants from a variety of waste disposal activities and from runoff. Because of concerns about the immediate physical impacts and potential long-term chemical impacts of dredged material disposal in these waters, coastal States (e. g., California, Delaware, Maryland, North Carolina, Florida, and others) have increasingly restricted waste disposal during the last decade. For example, Maryland does not allow dredged material from Baltimore Harbor to be disposed of in its marine waters without special management, even though some of the material (that generated by any new work, as opposed to maintenance work) would not be contaminated (442).

Despite this trend, two-thirds of all marine dredged material disposal still takes place in estuaries. One reason for this is that most of the material is dredged from these waters. Another is that disposal in estuaries generally is less costly than disposal in upland areas or in waters more distant from shore. Third, according to COE, Federal regulatory policies have made it easier to obtain permits for disposal in estuaries than in coastal and open ocean waters. COE considers the testing requirements under CWA for disposal in estuaries and rivers (or for pipeline discharge of dredged material within the territorial sea) to be less stringent than MPRSA requirements for dumping in coastal and open ocean waters.[8]

Policies about disposal of wastes in estuaries and coastal waters are influenced by policies about disposal in open ocean waters and on land. If a policy to provide greater protection to estuaries and coastal waters is pursued, it may become difficult to decide where else to put dredged material. As discussed, disposal in the open ocean already appears to be regulated more stringently than in other marine environments. In addition, open ocean disposal usually increases transportation costs significantly and it may not be practical in most situations.

Although the regulatory requirements for upland disposal are less comprehensive (and probably less stringent) than requirements for disposal in aquatic environments, finding new upland containment areas can be difficult and costly. Disposal in upland containment areas is controlled indirectly through Section 404 of CWA and State coastal zone management programs, and some States have imposed standards on the effluent discharged from upland containment areas. Upland disposal may also be subject to State or local land-use requirements. Finally, a shortage of upland containment areas is developing as available areas reach their designed capacity and as concerns about the effects of upland disposal increase.

At the same time, it is not clear that dredged material disposal should be prohibited totally in estuaries and coastal waters. Disposal in some instances causes only short-term and reversible impacts, especially when the volume of material is small, dumping does not occur frequently or continuously, and the dredged material is not a significant source of pollutants. In addition, COE contends that dredged material should receive less stringent regulatory treatment than other wastes because comparable concentrations of pollutants in dredged material may be less available to organisms than the same pollutants in other wastes. COE also notes that dredged material that is disposed of in estuaries usually is not "added' to estuaries, but simply moved from one location to another.

In general, finding a disposal site for dredged material in any environment is becoming increasingly difficult, partly because of public attitudes. Sometimes public attitudes reflect real uncertainties about the impacts of dredged material disposal. For example, it is true that the long-term impacts of disposal in marine waters and on land are not well understood. Similary, the relative importance of different sources of pollutants are also uncertain and in some cases may never be resolved. (For instance,

[8]It is unclear whether the decrease in material disposed of in coastal and open ocean waters that occurred prior to 1982 (other than in the Mississippi River area) reflects differences in regulatory requirements or simply normal fluctuations in dredging operations. Similarly, it is unclear whether the increase beginning in 1982 reflects an easing of the requirements for ocean disposal permits, perhaps in response to the Federal District Court decision that overturned a ban on the disposal of sewage sludge in the ocean (ch. 7).

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despite millions of dollars of research, the importance of dredged material relative to other pollutant sources in the New York Bight is still unclear.) Public attitudes, however, also can reflect a lack of awareness of the facts. For example, many people think that dredged material from the Mud Dump site in the New York Bight adversely affected New Jersey beaches (441); sediment transport studies, however, show that less than O. 1 percent of the sediment near these beaches is derived from dredged material disposed of at the site (709).

Siting decisions can also be affected by questions about the credibility of COE statements regarding the impacts of dredged material disposal. These questions arise in part because COE both regulates dredging activities and conducts many of them, and because it traditionally has been managed as a development agency. In addition, it does not need Section 404 or Section 103 permits to conduct its own federally authorized dredging projects, although it must comply with all applicable Federal laws and regulations and obtain appropriate State permits. COE also has sponsored most of the technical research on the impacts of marine and land-based disposal, having spent over $100 million since the early 1970s. To avoid bias, however, much of the research has been conducted and/or reviewed by non-COE groups. Recent State-supported research has tended to support the findings of Cos-ponsored research.

Since disposal sites are becoming increasingly difficult to develop and use, one management approach is to minimize the amount of required dredging, and thus the impacts generated, by developing long-term management plans for dredged material disposal. Revised regulations proposed by COE (for 33 CFR Part 337.9) recognize the value of such plans and suggest their use (51 FR 104: 19693-19706, May 30, 1986). In addition, since most marine disposal consists of material dredged from ports and harbors, it makes sense to link dredging plans with broader management plans for surrounding estuaries and coastal waters. Several examples of such planning efforts exist. The Grays Harbor (Washington) Estuary Management Plan provides a blueprint for the port future dredging and development (441). In the Chesapeake Bay, EPA is conducting a $27 million study of water quality and resources, including all different causes of degradation, and as a part of this effort COE's Baltimore District is studying the effects of dredging on the Bay (441). Finally, the Puget Sound Water Quality Authority was formed by the State of Washington to provide a broad framework for cleaning up Puget Sound, and as part of this initiative COE'S Seattle District is developing a management plan for dredged material disposal (441).

Long-term management plans for dredged material disposal have several advantages. First, they can be used to guide future decisions about port development while protecting the long-term productivity of an estuary. Such plans can consider the physical, biological, aesthetic, social, and economic resources associated with each proposed project, as well as interrelationships among proposed projects (61,273,496). Second, management plans can provide consistency and predictability for regulators, developers, environmentalists, and all State and Federal agencies. To ensure broad consensus, the planning process can involve all relevant State and Federal agencies, as well as local special interest groups with broad public representation. Finally, long-term plans could help streamline the regulatory review process, thereby reducing the time required to approve future projects and allowing more efficient scheduling of dredging and disposal operations.

Long-term planning efforts, however, are not without potential drawbacks. First, they are initially time-consuming and expensive. Second, unless these plans are incorporated into long-term compliance documents or permits, they may be subject to shifting agency policies. Finally, planning can be difficult because the long-term need for disposal sites is often hard to predict, given uncertainties about future port development.

In addition to developing long-term management plans where feasible, it will be important to conduct more peer-reviewed research about long-term impacts. Both laboratory and long-term field studies need to continue addressing several areas, including: how to assess sediment contamination; the long-term effects of bioaccumulation on individual organisms and community structure; the quality of effluent water discharged from upland containment areas; and procedures to minimize adverse impacts from the dredging and disposal of contaminated sediment in different environments (296). To increase the usefulness of research results to Federal and State decisionmakers, COE and EPA could jointly summarize and periodically update the state-of-knowledge on dredging and disposal operations. Short, readable publications would also help to explain to the public the necessity for, and the impacts associated with, dredging and disposal operations (e. g., see ref. 563).

Providing Balanced Consideration of All Disposal Options

As discussed in chapter 1, specific decisions or general policies about the disposal of any material should be based on a comprehensive evaluation of all available options. Evaluations are becoming more important, especially for large dredging projects or ones that involve contaminated material, as disposal sites become scarcer. One example of this type of evaluation is the Dredged Material Disposal Management Plan, prepared by the Port of New York and New Jersey. The plan compares eight disposal alternatives that might be used when the Mud Dump site in the New York Bight is filled to capacity in 15 to 20 years (562).

Regulations proposed by COE in May 1986 would provide general guidelines to ensure that all dredging and disposal alternatives are compared comprehensively by all COE districts. Such comparisons might indicate, for example, that dredged material disposal in the open ocean is more favorable in a specific situation than disposal in estuaries, coastal waters, or on land, even though regulatory requirements appear to be more stringent for the open ocean.

COE has developed a technical framework, with laboratory testing procedures, for evaluating the potential impacts of different disposal options (169). This framework is being tested on contaminated sediment from Commencement Bay, Washington (438). A comprehensive implementation manual describing the different laboratory procedures, however, does not yet exist. This kind of manual, which would need periodic updating to incorporate newly developed techniques, could provide guidance so planners could routinely evaluate the potential impacts of waste disposal. However, it also could impose detailed and costly analyses all disposal operations, regardless of their size or characteristics. The development of national sediment quality criteria also would aid the evaluation of potential impacts.