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Biological Services Program

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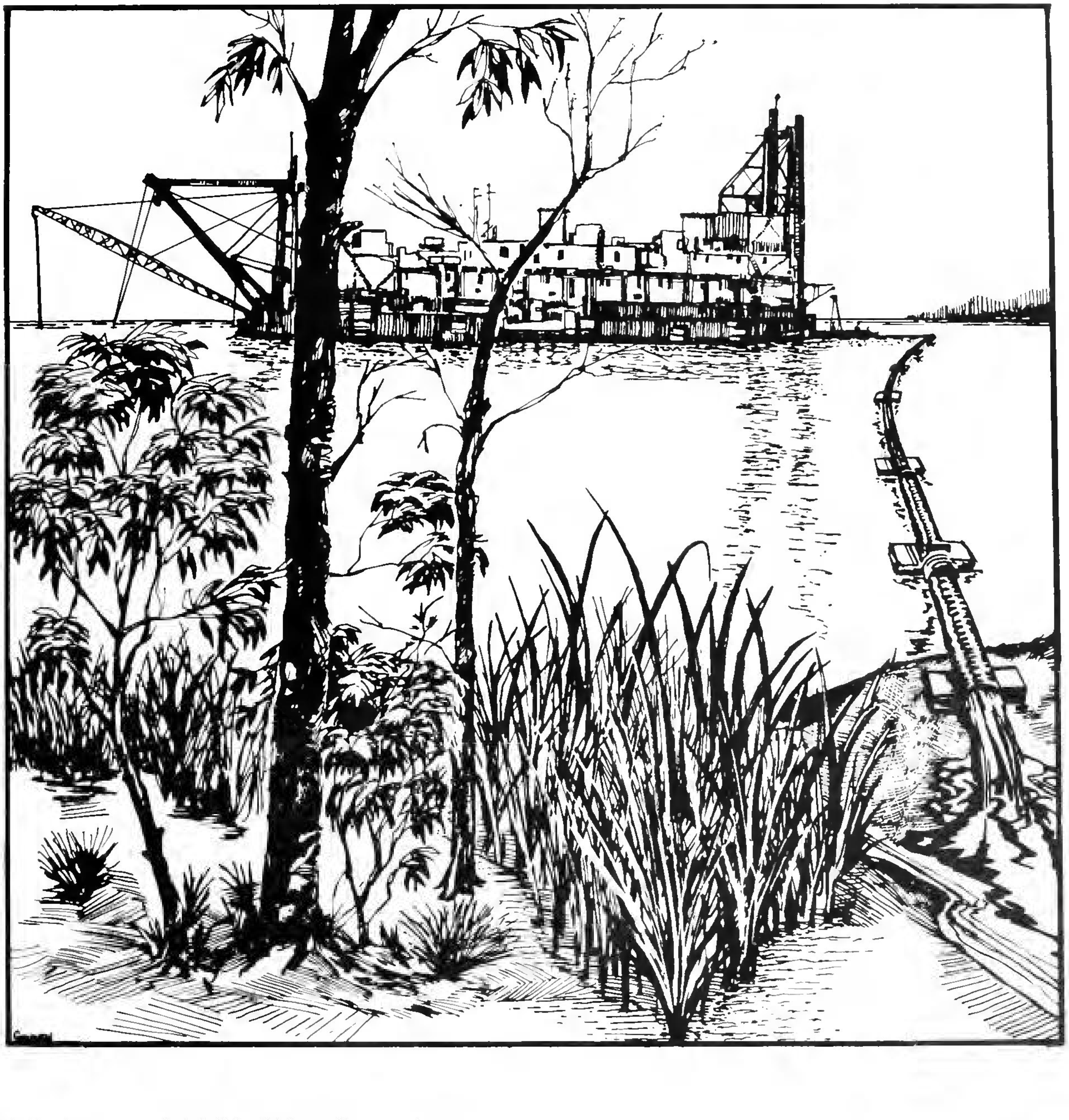
September 1980

Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review



Fish and Wildlife Service

U.S. Department of the Interior

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- To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use.
- To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

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IMPACTS OF NAVIGATIONAL DREDGING ON FISH AND WILDLIFE: A LITERATURE REVIEW

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PREFACE

"Impacts of Navigational Dredging on Fish and Wildlife: A Literature Review" was written primarily for fish and wildlife biologists who review applications for dredging permits. The state of the art of impacts of navigational dredging is discussed and the reader is directed to appropriate sources for further study. Any questions, or requests for this publication should be addressed to:

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ABSTRACT

Literature about the impacts of navigational dredging on fish, other aquatic biota, and wildlife is reviewed. Also included are types of dredging equipment, characteristics of dredged material, evaluation of dredged material pollution potential, and habitat development and enhancement opportunities arising from dredged material disposal. The review contains a brief discussion of the state of knowledge and refers the reader to pertinent literature for additional information. The discussions about impacts and habitat development are divided into "Coastal Waters" (including disposal in estuarine, continental shelf, and deep ocean waters) and "Rivers." A limited discussion of the "Great Lakes" is included as an Appendix.

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Technical and editorial reviewers of the manuscripts were so numerous that we will not attempt to name them. However, their contributions were vital for successful completion of the review.

INTRODUCTION

BACKGROUND

Assessing the impacts of navigational dredging and the disposal of dredged material is a controversial exercise; the viewpoints and approaches are endless. Without question, dredging can devastate fish and wildlife resources; however, in the absence of definitive information, impacts are sometimes more imagined than real. The attempt of this review is to bring some order to the situation by summarizing the pre-1973 literature and the results of new research since 1973. The chief source of the new information is the Dredged Material Research Program (DMRP), a 5-yr Army Corps of Engineers program that began in 1973. This program was administered by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. In addition to the DMRP, other recent significant studies have been included in this review. A partial list includes:

a. Report. International Working Group on the Abatement and Control of Pollution from Dredging Activities. 1975.
b. Impacts of Construction Activies in Wetlands of the U.S. United States Environmental Protection Agency. 1976.
c. Dredging and Its Environmental Impacts. American Society of Civl Engineers. 1976.
d. Dredging in Estuaries, a Guide for Review of Environmental Impact Statements. Oregon State University. 1977.
e. San Francisco Bay and Estuary Dredging Disposal Study, Corps of Engineers, San Francisco District. 1974 through 1979.

Boyd et al. (1972) summarized the state of knowledge and unanswered questions just before the beginning of the DMRP in 1973. In addition, one of the better compilations of the older literature was a thesis by James W. Morton which was later published (Morton 1977) by the United States Fish and Wildlife Service (FWS). This report includes most of the literature through 1974 and a portion of the 1975 literature, providing good coverage of dredging impacts in marine waters, but containing little information on impacts to freshwaters.

In our review we compared the recent (1973 to 1979) literature with the older literature and, if sufficient information was available, we attempted to form a consensus about dredging and disposal impacts on the basis of the available information from both periods. Unless the authors listed in the Literature Cited sections are cited or are directly quoted in the text of this document, the opinions expressed are our own. This literature review is not meant to reflect FWS policy.

CONTENTS

A brief sketch is provided about dredging equipment currently used in the United States or potentially available for use (Part I). The type of equipment used determines, to a great extent, the viable disposal alternatives, the type and magnitude of potential impacts, and the potential for habitat development. A brief discussion of characteristics of dredged material is provided in Part II. Characteristics of the material to be dredged strongly influences the available disposal alternatives and pollution potential.

The main body of this document is a discussion of dredging impacts and habitat enhancement opportunities. A brief assessment of each potential impact or each habitat enhancement opportunity is made and the reader is referred to the pertinent literature for further study. The discussion is divided into two major categories of U.S. Waters: "coastal waters" (Part III) includes all marine waters of the United States and its territories; "rivers" (Part IV) includes the navigable streams of the United States above saltwater influence. Our original intent was to include a third major section about the Great Lakes. However, due to a dearth of information and a lack of opportunity to review the available Great Lakes literature, we believe that such a section would convey a false impression of completeness. Thus, the small amount of information assembled about the Great Lakes was included as an appendix. In our opinion more work will have to be done before a comprehensive synopsis can be written about the impacts of dredging in the Great Lakes.

This review covers impacts to fish, other aquatic organisms, and wildlife (as well as habitat enhancement opportunities) resulting from construction of new navigational channels and maintenance dredging of existing channels. Both dredging and disposal stages are discussed. This review does not cover other types of dredging such as canal construction for oil and gas exploration and extraction, dredging for residential or commerical development, sand and gravel dredging, shell dredging, or channelization of streams for flood control.

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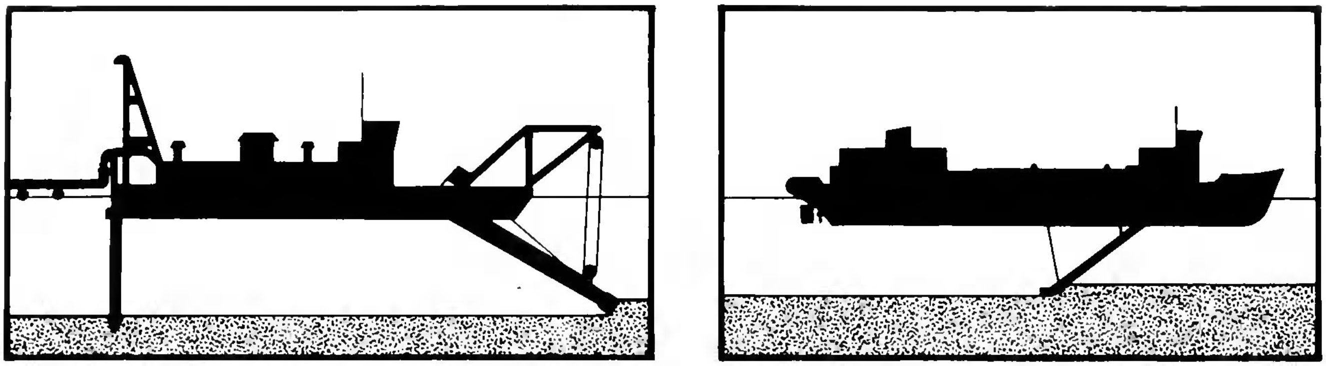
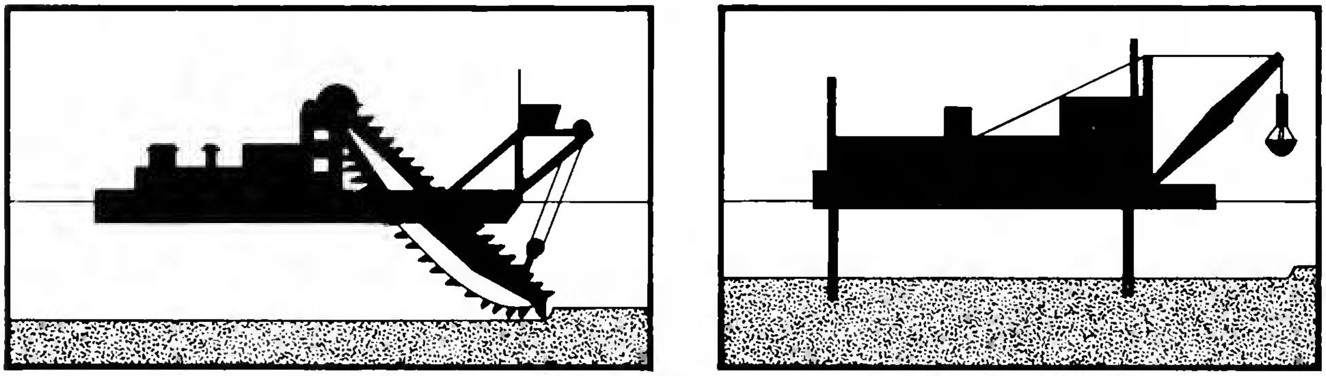
Morton, J.W. 1977. Ecological effects of dredging and dredge spoil disposal: a literature review. U.S. Fish and Wildl. Serv., Washington, D.C. Tech. Pap. 94.

HYDRAULIC

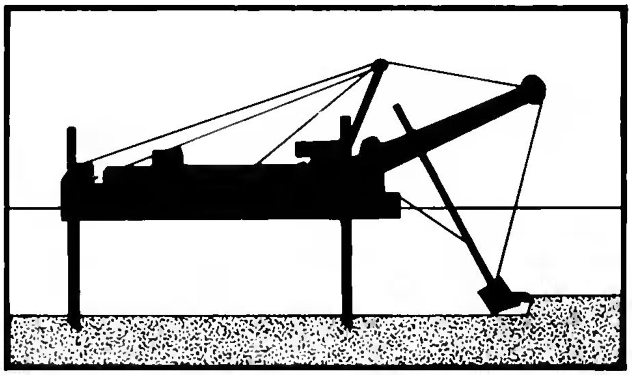


PIPELINE DREDGE HOPPER DREDGE

MECHANICAL



LADDER DREDGE BUCKET DREDGE



DIPPER DREDGE

Figure 1. Common types of dredges.

PART I

DREDGING EQUIPMENT

About 99% of the dredging volume in the United States is accomplished by hydraulic dredges (Pequegnat et al. 1978). Hydraulic dredges mix sediments with water to form a slurry which is pumped to the discharge point. Mechanical dredges such as the bucket or dipper dredge (Figure 1) are seldom used in projects involving large volumes of material but are valuable for working in small areas such as near docks or boat slips and for the cleanup of spills and contaminants. Mechanical dredges are usually mounted on barges and move material mechanically with some type of bucket. The dredged material is usually transported by barges. Less water is incorporated into the material than occurs with hydraulic dredging. Most of the information in this section is derived from Pequegnat et al. (1978). Other general discussions are found in Boyd et al. (1972) and Gren (1975, 1976). Common types of dredges are illustrated in Figure 1. Certain new types, such as pneumatic dredges, are not discussed in our review because of the lack of documentation at the time of writing.

HYDRAULIC DREDGES

Pipeline Dredges

Pipeline dredges are usually cutterhead-equipped and work by hydraulic suction. They remove both consolidated and unconsolidated material and pump it through a pontoon-supported pipeline for discharge at a disposal site. Discharge is a continuous operation as long as the dredging unit is operating. Disposal is usually nearby, but the distance can be increased up to several kilometers by the use of booster pumps. Disposal can be on land or in open water. The use of a pipeline dredge is limited to relatively protected waters because of problems with unstable pipeline units.

Pipeline dredges make up the bulk of the equipment of the private dredging industry and are the type of dredge most commonly used in the United States. Variations of pipeline dredges include suction dredges (without a cutterhead) for use in soft material and the dustpan dredge which is used extensively on the Mississippi River. The dust pan dredge has a wide (up to 14m or 45 ft) suction inlet and is especially efficient in removing sandbars. Discharge is into the water adjacent to the dredge (Gren 1976).

Hopper Dredges

The hopper dredge is a self-propelled vessel, equipped with a hydraulic suction dredge system and with hopper bins to contain and carry the dredged material to a place of disposal. Most of the hopper dredges are owned and operated by the Corps of Engineers and work in coastal waters and in the Great Lakes; however, private industry is rapidly developing such a capability. Hopper dredges are used chiefly for maintenance dredging and usually transport sediments to open water where they are dumped through bottom doors on the hoppers. The hopper dredge has the advantage of being highly mobile, less disruptive to vessel traffic, and can operate in waters too rough for a pipeline dredge.

Sidecaster Dredges

Sidecaster dredges employ a hydraulic system similar to hopper dredges. However, instead of temporarily storing the dredged material in bins, it is shunted to one side of the vessel by use of a side arm or short pipeline. In some instances, it may be pumped ashore for beach nourishment or confined disposal (Gren 1976).

MECHANICAL DREDGES

Bucket Dredges

There are several kinds of bucket dredges including clamshell, dragline, and orange peel. In their simplest form, they consist of a drop bucket attached by cables to a winch-equipped boom and lifting system generally mounted on a barge (Pequegnat et al. 1978). They are used in both maintenance dredging and new channel construction.

Ladder Dredges

A special type of bucket dredge is the bucket ladder dredge or simply the ladder dredge. A continuous chain of buckets removes sediments from the bottom and places the sediments aboard a barge for transport to the disposal area.

The ladder dredge is used in the United States only for mining operations, however, it is a common component of European dredging fleets and is being advocated for use in the United States (Mohr 1976). Mohr states that the ladder dredge has the advantages over hydraulic dredges of using less energy and creating less turbidity.

Dipper Dredges

The dipper dredge consists of a power shovel mounted on a barge and is particularly useful for excavating hard bottom material in water depths less than 10 m (33 ft).

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PART II

CHARACTERISTICS OF DREDGED MATERIAL

The composition of dredged material from a particular site affects its pollution potential as well as the potential for habitat development or other beneficial uses. Dredged material can be classified by grain size and may range from clay to sand (or even rocks). The finer grain sizes have a greater ability to adsorb and retain contaminants. The grain size also partially determines the suitability of dredge material for construction or fill material and for habitat development. According to Boyd et al. (1972), most dredged material is classified as mixed sand and silt. Some basic differences between the material derived from the construction of new channels and material derived from maintenance dredging are discussed in the following paragraphs.

MATERIAL FROM NEW CHANNEL DREDGING

Physical Characteristics

Sediments dredged from new channels consist of material that was deposited by natural processes, often before the appearance of modern man. The sediments may be clay, silt, sand, or rock and often layers of more than one type may be encountered. The presence or absence of organic matter is determined by the mode of sediment deposition.

Dredged material from new channels or "new work" projects often has chemical and engineering properties which create fewer environmental problems than material from maintenance projects (Boyd et al. 1972).

Contaminants

Except for the top layer of sediments, contaminants are normally not present in material removed from new channels. However, natural levels of heavy metals will be present and, in some instances, the effluent from these materials could exceed water quality criteria (Gustafson 1975).

Nutrients

Nutrient levels in material from new channels vary widely depending on the origin and nature of sediments.

Potential for Productive Uses

The value of dredged material for productive uses varies because of variations in composition, particularly grain size, of the material. A lack of organics is an asset in construction and fill uses, but is disadvantageous (but not critical) in marsh or other types of habitat development. The absence or low level of contaminants in material from new channels is also a definite advantage; presence of contaminants can rule out many beneficial uses.

MATERIAL FROM MAINTENANCE DREDGING

Material removed during maintenance dredging of navigation channels is an accumulation of detached soil particles which have been transported by wind and water. It is a soil resource with potential beneficial use. However, material from maintenance dredging may contain a variety of contaminants contributed by man's activities (SCS Engineers 1977).

Physical Characteristics

Maintenance material can vary widely in content but organics are usually under 5% (Table 1). Most material contains a mixture of sand, silt, and clay (Table 2). Potential beneficial uses of sediments from maintenance dredging will thus be site dependent--depending on the use in question and the properties of the candidate material. For thorough discussions of the engineering properties of dredged material, the reader is referred to Murdock and Zeman (1975), Bartos (1977), and Brown and Thompson (1977).

Contaminants

The amount of contaminants, such as petroleum hydrocarbons, pesticides, PCBs, and heavy metals, vary widely in material from maintenance dredging (Table 1). In general, industrial harbors are highly polluted, whereas, interconnecting waterways may be relatively unpolluted.

Nutrients

Fine-grained maintenance material usually contains the essential elements needed by plant life. In contrast, material containing a high sand content may be low in nutrients because of low sorbtion affinity.

Evaluation of Dredged Material Pollution Potential

Man's ability to evaluate the pollution potential of dredged material has improved in recent years, but is still an inexact science. The availability of contaminants to the biota, the actual uptake, and the impact if uptake occurs are difficult to predict. It is particularly difficult to develop tests that will predict subtle long-term impacts.

Two predictive techniques -- bulk sediment analysis and standard acute toxicity bioassays -- were widely used in the past, but have now been largely discredited as sole factors for determining pollution potential. Bulk sediment analysis measures the gross levels of various contaminants in dredged material; however, the presence of contaminants may bear little relationship to the subsequent chemical reaction, release, and availability to aquatic organisms after disposal. Bulk sediment analysis, however, may be useful in determining potential pollutants that could have long-term significance because of their presence in the bottom sediments. Likewise, standard bioassays that measure acute toxicity and utilize mortality as the end point give little insight into long-term effects of pollutants on growth, reproduction, molting, mutations, and other biological functions. The standard acute toxicity bioassay is limited to predicting short-term impacts.

An evaluation of pollution potential of dredged material has been summarized by Brannon (1978). He recommends the use of the Elutriate Test to predict the short- and long-term chemical impacts on the water column. These results should then be interpreted in light of the dispersion and dilution that will

Table 1. Ranges in concentrations of chemical constituents of dredged materials (Chen et al. 1976).

Constituent	Range expected in concentration mg/kg
Chemical Oxygen Demand, COD	1.0 - 13%
Total Organic Carbon, TOC	0.5 - 5%
pH	6 - 9
Total sulfides (acid soluble)	100 - 3,000
Oil and grease	100 - 5,000
Organic nitrogen	100 - 2,000
Ammonia	100 - 2,000
Total nitrogen	200 - 4,000
Total phosphorus	500 - 2,000
Calcium	600 - 17,000
Chloride	40 - 20,000
Magnesium	4,000 - 13,000
Potassium	17,000 - 24,000
Sodium	12,000 - 40,000
Cadmium	0.05 - 70
Chromium	1 - 200
Copper	0.05 - 600
Iron	1,000 - 50,000
Lead	1 - 400
Manganese	24 - 550
Mercury	0.2 - 2.0
Nickel	15 - 150
Zinc	30 - 500
Chlorinated pesticides	Nil - 10
Polychlorinated Biphenyls, PCB	Nil - 10

Table 2. Textural compositions of sediment samples (Wang and Chen 1977).

Sediment number	Location	% sand	% silt	% clay	Class of sediment
1	Clinton Disposal Area Houston, TX	77	16	7	Silty sand
2	Houston Ship Channel Houston, TX	78	15	7	Silty sand
3	Rouge River at Detroit Detroit, MI	83	12	5	Sand
4	Anchorage Basin in Cape Fear River Mouth Wilmington, NC	16	46	38	Silty sand
5	James River Richmond, VA	97	2	1	Sand
6	Calcasieu River Louisiana	21	43	36	Silty clay
7	Mobile Bay Alabama	55	33	12	Silty sand

occur during dumping (Jones and Lee 1978). Brannon further recommends the use of bioassessment techniques (including bioaccumulation assays, to determine both short- and long-term lethal and sublethal impacts to the biota. Gambrell et al. (1978) discuss the relative environmental risks of different disposal alternatives and the problems with different contaminants and disposal methods.

To the above recommendations we suggest adding the use of bulk sediment analysis where the addition of contaminants to a water body could have long-term significance. An example is San Francisco Bay. Pollutants enter the Bay from various sources, including dredging. They are resuspended and transported within the aquatic system and eventually there is a loss of pollutants from the Bay via the narrow mouth. If the input of pollutants is greater than the outflow, long-term buildup of sediment pollutants may be harmful to the biota (letter dated 28 April 1977 from Richard Kroger, FWS, Sacramento, California).

Potential for Productive Uses

Contaminants and organic debris found in the material from many maintenance dredging sites limit the potential uses of the material. Often contaminant levels are not environmentally acceptable. There is also often too much organic matter for certain engineering uses. There are many situations, however, where maintenance material can be put to beneficial uses.

Material from maintenance dredging, if not high in contaminants is often excellent as a substrate for recreation areas, marsh establishment, or as a soil additive. Sand and gravel may be useful for construction material, but they are usually mixed with other materials in quantities that make separation necessary. The cost of separation is often greater than the market value of the final product (Mallory and Nawrocki 1974).

Polluted material can sometimes be used as land fill for industrial sites, depending on the contaminants present and the use of the land. A frequent constraint on the use of maintenance material for construction sites is that such land fills must be developed over short periods. Unfortunately, fill from maintenance dredging usually becomes available over relatively long periods. Another constraint is the poor engineering properties of fine-grained materials (Boyd et al. 1972) which often characterize fill from maintenance dredging.

There is some potential for filling mines and pits with dredged material. Transport distance is the most critical variable. Long distance transport is now feasible, although expensive (SCS Engineers 1977). The greatest potential for disposal in mines and pits appears to be in the Great Lakes area and along some of the Midwestern rivers. Extreme caution should be exercised in the use of mines and pits for disposal of contaminated material, as ground water contaminantion could occur in some instances (Gambrell et al. 1978).

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PART III

COASTAL WATERS

The coastal zone is one of the most productive and critical areas for fish and wildlife. In Part III, impacts are divided into dredging site impacts (effects of the removal operation) and disposal operation impacts (effects of dredged material disposal). We believe some of the most severe long-term impacts from dredging are caused by the physical changes in estuaries due to "new-work" dredging. Maintenance dredging and dredged material disposal pose less severe threats, except when the sediments contain high levels of contaminants.

ASSESSMENT OF IMPACTS AT THE DREDGING SITE

Water Column Impacts

Potential water column impacts at the dredging site include increased turbidity, increased oxygen demand, and releases of contaminants and nutrients - especially free sulfides, hydrogen sulfide, and ammonia. The release of these constituents varies widely with different types of equipment, and even within the same equipment type, depending on effectiveness of operation, state of maintenance, and deployment. Turbidity associated with the dredging operation is not usually as great as turbidity associated with the disposal operation. Employment of known good dredging procedures by dredge operators will greatly reduce dredge-induced turbidity (Huston and Huston 1976). The greatest concern about the dredging operation is turbidity caused by hopper dredge overflow and clam shell dredging.

A more chronic type of turbidity is associated with the sediments from the excavated channel. These sediments become available for resuspension by wave action or currents, until they are finally transported by natural forces from the area or become biologically fixed (Taylor and Saloman 1967). The new channel becomes a trap which retains sediments that are frequently resuspended by boat traffic or maintenance dredging. Thus, the net result of new channel construction may be a general increase in turbidity (Taylor and Saloman 1967). In contrast, maintenance dredging, although it may produce a temporary increase in turbidity, may decrease long-term turbidity by deepening the channel and thus decreasing the resuspension of sediments by boat traffic.

Bottom Impacts

The use of a section of water bottom for a navigational channel often precludes its utilization for normal aquatic production. During the initial channel construction and at each maintenance dredging, 75% or more of the benthic organisms are removed from the site (U.S. Army Engineer District, San Francisco 1975). Recolonization of a new channel is often rapid and original biomass is sometimes reached in 2 weeks to 4 months (Chesapeake Biological Laboratory 1970, Slotta et al. 1973, Taylor undated, and U.S. Army Engineer District, San Francisco 1974). However, recolonization is usually by opportunistic species which are less valuable in the food chain. Original species diversity is seldom achieved (U.S. Army Engineer District, San Francisco 1975; Taylor undated). Although original biomass may often occur, Taylor and Saloman

(1967) found in Boco Ciega Bay, Florida, that the recolonization of new channels by invertebrates was negligible after 10 yr and that none of the 49 species of fish caught in the channels (as compared to 80 species caught in undredged areas) were demersal. The decrease in numbers of invertebrates in the channels was attributed to the soft silt-clay dredged sediments compared to the sand-shell undredged sediments. Decreased oxygen supply in and above the dredged channel substrate was also considered a prime factor.

More serious impacts of new channel construction may be changes in circulation patterns, salinities, sediment input and deposition, sediment supply to the coast, and nearshore wave refraction and diffraction patterns (Rees 1977). These impacts are usually detrimental but on occasion could be beneficial. An increase in water exchange rate between a bay and the ocean could be beneficial in instances when there is insufficient dilution to disperse contaminants or nutrients.

Changes in the bottom topography due to construction of the Mobile (Alabama) ship channel have contributed to the problem of annual oxygen depletion in Mobile Bay. Water in sinks in the bay bottom becomes depleted of oxygen; occasionally the oyxgen depleted water is moved shoreward by wind and wave action resulting in stress to the biota (May 1973a).

Kaplan et al. (1974) noted a drastic decrease in productivity following the dredging of a navigational channel through a small, shallow bay in Long Island, New York. Biota were reduced in the bay and in the dredged channel. The authors blamed changes in current velocity and concomitant modifications in substrate type as well as land use changes brought on by the new channel.

Dredging can be extremely destructive to coral reefs. Bak (1978) noted decreases in light penetration from turbidity caused by dredging, a loss of the zooxanthellae, and eventual death of certain coral species. Calcification rates were suppressed in two species of corals during and following the disturbance from dredging. A thorough discussion of impacts of dredging and suspended material on coral reefs is found in Stern and Stickle (1978).

After a ship channel is constructed, it becomes a sink for sediments that often contain large amounts of potential contaminants. Resuspension or reactivation of these potential contaminants is great when maintenance dredging is conducted or when ships move through the area (Lee 1976, Smith 1976).

Other Impacts

The greatest impacts from new channel construction often are related to increased industrial development which may alter drainage patterns and reduce water quality.

A potential adverse impact of dredging is the entrainment of slow-moving nekton. Large scale mortality of dungeness crabs has been blamed on hydraulic dredges in Grey's Harbor, Washington (memorandum dated 11 February 1977 from R.H. Latta, Corps of Engineers, Seattle, Washington).

ASSESSMENT OF IMPACTS OF DISPOSAL ALTERNATIVES

Dredged material is disposed: on terrestrial sites; on islands, fastlands, and beaches; on wetlands; in estuaries; on the continental shelf; and in the deep ocean. The terms "deep ocean" and "continental shelf" are used similar to that of Pequegnat et al. (1978). The continental shelf includes the area seaward of land and estuaries out to the "shelf break." The shelf break varies considerably around the coast of the U.S. but generally occurs at depths of 60 to 200 m (200 to 650 ft). Deep ocean disposal includes the area seaward from the shelf break and thus includes the continental slope and the deep ocean basin or abyss.

Terrestrial Disposal

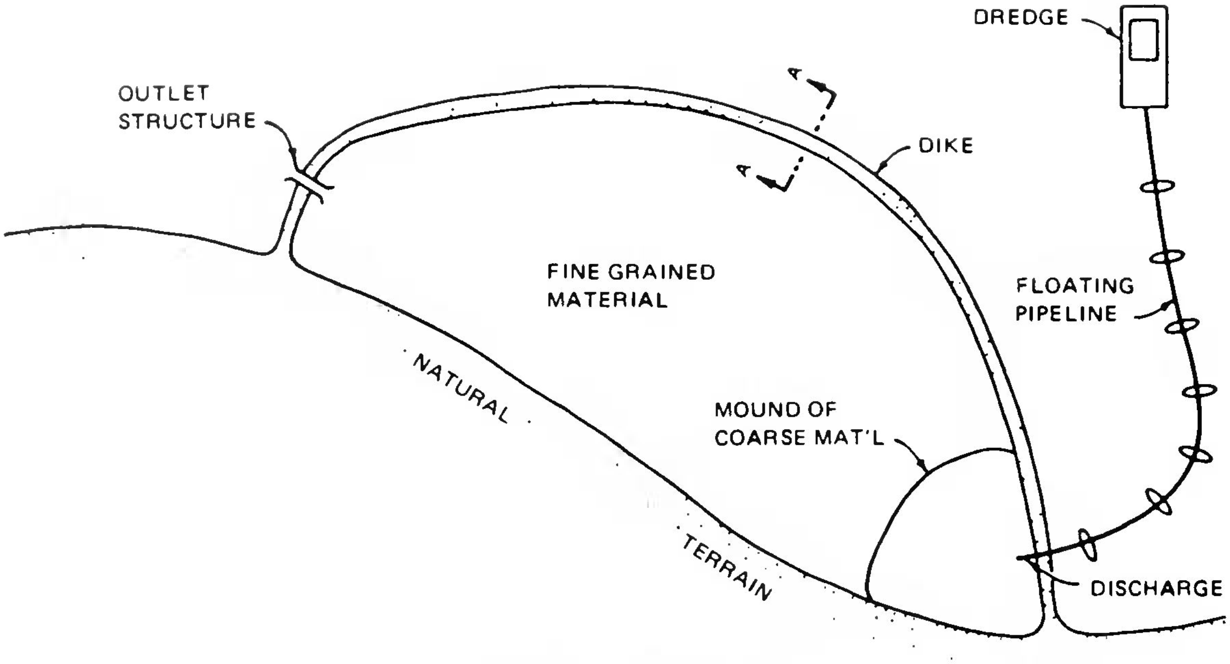
For this discussion, "terrestrial" refers to land masses above mean high tide or nonwetlands. Also included are confined disposal areas situated in shallow waters that become emergent as they are filled.

During the 1970's, confined disposal in shallow waters became a popular alternative to disposal in deeper waters and was extensively used for polluted material. However, available land for disposal of dredged material is becoming increasingly difficult to find, particularly in the northeast (Boyd et al. 1972). Wetlands, once considered suitable for disposal of dredged material, are now considered more valuable for fish and wildlife. In addition, owners of well drained useable land, or land already suited for development, generally are opposed to the placing of dredged material that may present problems from the engineering or aesthetic point of view and lower the economic value of the land (Boyd et al. 1972).

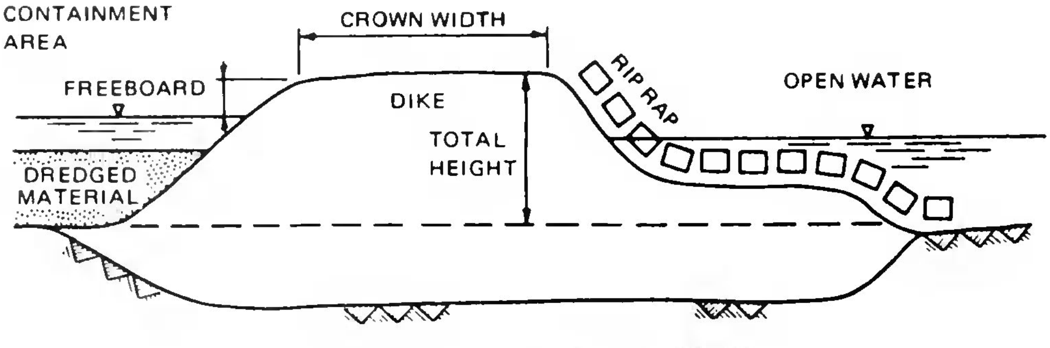
Most containment areas are surrounded by earthern dikes. Only large or more permanent containment areas are protected by riprap or stone facing. Nearly every containment area is equipped with a spillway or overflow weir and some also have settling basins (Figure 2). To accommodate varying filling rates and varying ponding time requirements, most weirs are of the stoplog or otherwise height-adjustable variety (Boyd et al. 1972).

Diked containment areas have often been considered a panacea for the disposal of contaminated dredge material. However, impacts to fish and wildlife associated with these sites may be positive or negative. Habitats resulting from disposal may or may not be more valuable or productive than the habitat that existed before. Often confined disposal areas become industrial sites and have no value to wildlife.

Confinement area levees may provide valuable habitat to wildlife. The raised land increases habitat diversity, provides habitat for birds, raccoons (Procyon lotor), mink (Mustela vison), deer (Odocoileus sp.), and other species. During periods of high water and especially during hurricanes, levees offer refuge for large numbers of animals (Glasgow and Enswinger 1957). The interiors of disposal areas may provide wetland habitat. On the negative side, local conditions may cause undesirable animal and plant species to proliferate in confinement areas. If not well located, confinement areas can seriously alter runoff patterns, thus adversely affecting the biological populations (Schroeder et al. 1977).



PLAN OF CONTAINMENT AREA



CROSS SECTION OF CONTAINMENT AREA

Figure 2. Pertinent features of a dredged material containment area (Bartos 1977).

Additional concerns are:

(a) turbidity and sedimentation from dike construction and from the the containment area discharge;
(b) the exit of contaminants from the disposal area through the effluent; and
(c) possible uptake of contaminants by waterfowl or other animals using the disposal area.

The DMRP has produced a large amount of information on the first two items but information on contaminant uptake and long-term impacts is limited.

The subject of confinement area effluent quality is quite complex. However, at the risk of oversimplification, it can be stated that the quality of the discharge is greatly influenced by confinement area design and retention time. According to the majority of the literature, most of the potential pollutants, e.g., heavy metals, oil and grease, and PCBs are sorbed to fine-grained clays and silts and are not in a soluble form. Thus, the movement of these potential pollutants is related to the fate of settable solids. Retention of solids through proper design of containment areas and proven engineering practices will result in lower levels of pollutants being discharged. Actively growing vegetation in confinement areas also increases the removal of solids from elutriate (Chen et al. 1978). Windom (1977) found overland flow in salt marshes removed nutrients and metals from disposal area effluent.

Chen et al. (1978) concluded from laboratory and field studies that effluent from containment areas generally did not meet water quality criteria for beneficial use of receiving waters (ammonia, total phosphorus, chlorinated hydrocarbons, and most trace metals exceeded levels recommended for aquatic life, drinking water, and irrigation water). There were indications in the studies that efficient retention of solids in disposal areas would result in meeting most standards. With low-density solids, organic detritus, fine iron oxides, and clay-sized minerals, long-term retention time or flocculants may be required to meet water quality standards.

The significance of the impact of disposal area effluent on receiving waters is largely unknown. Dilution occurring in the receiving waters will, in many instances, reduce many of the constituents to harmless levels. However, the fate and biological impact of persistent substances, such as organohalogens and trace metals, have not been well defined and these substances may constitute a chronic threat to the biota. Hoss et al. (1974) conducted a laboratory study of the effluent from polluted dredged material collected from the Charleston Harbor. They concluded that the effluent may be harmful to larval fishes. Heavy metals and ammonia were implicated as the possible agents causing larval mortality.

Chen et al. (1978) also noted that heavy metals are generally associated with solids and are removed from the effluent provided that retention time in the containment area is adequate. Those trace metals associated with larger particles exhibit the best retention. An analysis of data from Table 3 dramatically demonstrates the efficiency of removal of metals when they are

Table 3. Trace metal concentrations and removal efficiencies of diked containment areas at brackishwater and freshwater sites (Chen et al. 1978).

	Total Trace Metals, mg/l												
	Fe	Mn	Zn	Cd	Cu	Ni	Pb	Hg	Cr	Ti	V	As	Se
							Brackishwater Sites*						
Influent	3640	59.4	23.0	0.78	4.99	4.4	14.2	0.035	--	4.29	3.98	0.73	3.10
Effluent	423	13.2	2.63	0.032	0.48	0.416	1.82	0.0083	0.032	1.55	1.15	0.079	1.89
Background water	12.0	0.10	0.561	0.0054	0.11	0.308	0.083	0.0031	0.020	0.011	0.32	0.008	--
Percent** removal	88	78	89	96	90	91	87	76	--	64	71	89	39
Effluent / Background water	35	132	4.7	6.0	4.4	1.4	22	3	1.6	141	3.6	10	--
							Freshwater Sites						
Influent	4080	82.5	24.4	1.63	28.1	9.83	10.2	0.073	63.8	8.3	3.97	4.55	4.95
Effluent	54.3	1.30	1.28	0.088	0.57	0.272	0.291	0.019	0.26	0.26	0.22	0.32	0.16
Background water	2.75	0.23	0.365	0.0016	0.13	0.016	0.018	0.00043	0.013	--	0.029	0.004	0.008
Percent removal	99	98	95	95	98	97	97	74	100	97	95	93	97
Effluent / Background water	20	5.6	3.5	55	4.4	17	16	44	20	--	7.6	80	20

(Continued)

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* Averages are calculated from average site values.

** Disposal area removal efficiency:

$$\frac{\text{Influent-Effluent}}{\text{Influent}} \times 100 .$$

Table 3. (Continued)

	Soluble Trace Metals (<0.45 μ), mg/l												
	Fe	Mn	Zn	Cd	Cu	Ni	Pb	Hg	Cr	Ti	V	As	Se
							Brackishwater Sites*						
Influent	3.72	2.86	0.065	0.0047	0.020	0.016	0.0032	0.0017	--	0.017	0.018	0.032	0.0033
Effluent	1.21	1.95	0.061	0.0046	0.021	0.015	0.0026	0.0012	0.025	0.016	0.013	0.0046	0.0026
Background water	0.46	0.079	0.040	0.0042	0.011	0.015	0.0021	0.0010	--	0.0001	0.0040	0.0008	0.0006
Percent** removal	67	32	6	2	+5†	6	19	29	--	6	28	83	21
Effluent / Background water	2.6	25	1.5	1.1	1.9	1.0	1.2	1.2	--	160	3	5.8	4.6
							Freshwater Sites						
Influent	3.00	1.00	0.022	0.0018	0.0053	0.0069	0.0017	0.0002	0.004	1.83	0.0041	0.0004	0.0017
Effluent	0.10	0.29	0.008	0.0007	0.0049	0.0037	0.0008	0.0002	0.005	1.45	0.0039	0.0003	0.0005
Background water	0.10	0.030	0.007	0.001	0.0046	0.0043	0.0007	0.0002	0.003	--	0.004	0.0003	--
Percent removal	97	71	64	58	8	46	53	0	+25†	21	5	25	69
Effluent / Background water	1.0	10	1.1	0.75	1.1	0.85	1.1	1.0	1.7	--	1.0	1.0	--

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* Averages are calculated from average site values.

** Disposal area removal efficiency:

$$\frac{\text{Influent-Effluent}}{\text{Influent}} \times 100 \ .$$

† Percent increase.

combined with solids, in contrast to the inefficient removal of metals in solution. Brannon et al. (1978), Chen et al. (1978), and Hoeppel et al. (1978) provide more detailed discussions on this subject.

Within a confinement area, the uptake of contaminants through the food chain, as by feeding waterfowl, is a distinct possibility, but definitive studies are not available. Possible routes of uptake are through ingestion of either above- or below-ground portions of plants, or through ingestion of soil or aquatic invertebrates. Chemicals with higher partition coefficients will concentrate in the organic fractions and ultimately become associated with food chain organisms. Those chemicals of major concern include PCBs and polynuclear aromatic hydrocarbons that have been found at biologically significant levels in fish and wildlife (Koeman et al. 1973).

Potential pollution from confinement areas is not limited to the period of active dredging. Placing anaerobic sediments in a nonwetland containment area will enhance release of heavy metals through the process of metal sulfide oxidation and an increase in acidity. During a subsequent storm, heavy metals may be released over the weir in significant quantities. Heavy metals may become more available to the environment when placed in a terrestrial disposal area than when deposited in an aquatic environment where they may remain in an anerobic state (Khalid et al. 1977). According to Gambrell et al. (1978), certain types of dredged material may become moderately to strongly acidic upon drainage and, under non wetland conditions, the subsequent oxidation presents a high potential for contaminant mobilization.

Island, Fastland, or Beach Disposal

Dredged material is often used to construct fastlands (high and dry lands that are formed over a relatively short period of time, including islands) in existing shallow waters or wetlands as sites for industry or recreation (Gushue and Kreutziger 1977). Impacts associated with these disposal areas include: (a) the permanent loss of wetlands or water bottoms; (b) changes in water circulation patterns and flushing rates; and (c) secondary impacts from industrialization such as increased surface runoff, and point and nonpoint source pollution.

Beach nourishment projects are becoming more common and often are an alternative for the disposal of sandy material. The greatest adverse impacts associated with beach nourishment appear to be turbidity at the time of disposal and for several months thereafter as the fine-grained material is worked from the sand and transported down current. Smothering of benthic organisms appears to be a minor short-term impact.

Wetland Disposal

Disposal of dredged material in wetlands is now less frequent due to recent recognition of the value of wetlands. Often, however, the only economically viable choices are: (1) depositing dredged material in a confined disposal area that is constructed within the confines of the wetlands or (2) spreading the material thinly over a large section of the wetland. Is it better to "write off" a small parcel of wetland habitat for wildlife use, to protect the rest of the wetland, or can all of the wetlands be retained by spreading the material over a large area? This question will not be answered here, however, Reimold et al.(1978) provide some insight into the ability of marsh to recover from various depths of dredged material cover. In a Georgia salt marsh, *Spartina alterniflora* made substantial recovery from burial by up to 23 cm (9 inches) of several types of dredged material. Reimold et al. (1978), however, urged caution in spreading dredged material on marshes and noted that deposition should not result in a higher elevation than the surrounding marsh.

Estuarine Disposal

Estuaries are highly productive, complex systems and the potential for damage by dredging is great. The potential for damage from aquatic disposal appears to decrease as the disposal site is moved seaward from estuaries to the continental shelf or into the deep ocean because biological productivity and usefulness decrease while dilution and mixing increase (Pequegnat et al. 1978). Routine disposal of maintenance material (unless it is grossly polluted) is similar to other man-made and natural disturbances in impact to bottom fauna. Benthic fauna living in or near navigational channels are well adapted to such disturbance (McCauley et al. 1977).

Water column impacts.[1] Real or suspected impacts are associated with suspended solids, release of contaminants, nutrient and biostimulant release, destruction of plankton or nekton through physical contact with dredged material, interference with animal migrations, dissolved oxygen depletion, and toxic organics.

Direct destruction of plankton and nekton is of little consequence because of the great reproductive capacity of plankton and because nekton can usually avoid dredged material being deposited.

The severity of water column impacts is strongly related to the degree of dilution and mixing experienced. It appears that the potential impacts listed above are not likely to adversely impact the water column in well-mixed waters. No adverse impacts were noted at four disposal sites in well-mixed waters intensively monitored by the DMRP (Wright 1978).

With the exception of fluid mud, suspended solids or turbidity from dredged material disposal are not usually a serious problem (Hirsch et al. 1978). Fluid mud has been arbitrarily defined as sediment with a bulk density of less than 1.3, a high water content, and suspended concentrations higher than 10 g/l (Nichols et al. 1978). Fluid mud and other adverse impacts of suspended particles are discussed in the section about bottom impacts. Turbidity generated by maintenance dredging has a visual or aesthetic impact but appears to be short-lived and of less magnitude than turbidity from natural occurrences such as storms or floods (May 1973b, Markey and Putnam 1976, Schroeder et al. 1977).

Peddicord (1976: 606) made the following comment: "Under most conditions suspended particles themselves are lethal only at concentrations higher than normally created by dredging operations, with important possible exceptions.

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[1] In this section we mainly discuss acute impacts of toxicants. For a discussion of chronic impacts see "bottom impacts."

The effects of suspensions of uncontaminated natural sediments do not seem to differ significantly from those of inert clay minerals. Experiments with contaminated natural sediments indicate a much greater potential for adverse impact than would be associated with uncontaminated sediment. Sensitive species are killed more easily at warmer temperatures or if dissolved oxygen is reduced."

Turbidity has the greatest potential for damage in soft freshwater where it is extremely persistent. Hard water (200 mg/l or greater of total dissolved solids) and saltwater induce flocculation and consequent rapid settling (Wechsler and Cogley 1977). Later resuspension of dredged material can occur and cause slight to moderate turbidity problems (Vitter 1972, National Marine Fisheries Service 1976).

Synergistic and antagonistic effects of suspended particles, toxicants, dissolved oxygen, and other constituents of dredged material and the receiving waters complicate the evaluation of impacts.

The following discussion of techniques of controlling dispersion of dredged material at open-water disposal operations is summarized from the report of Barnard (1978). Normally about 1% to 3% of the material discharged is suspended in the water column. The rest of the slurry descends rapidly to the bottom where it may remain in a mound or it may become fluid mud and move in a lateral direction or downslope. According to Barnard (1978: 3), laboratory studies (but not actual field observations) indicate water-column turbidity can be controlled to a great extent by using different discharge configurations. "The simple open-ended pipeline, discharging above and parallel to the surface, will maximize the dispersion of the slurry throughout the water column and produce a thin, but widespread fluid mud layer. In water depths in excess of 2 m, (6.5 ft) the dispersion of the material in the water column can be decreased by vertically discharging the slurry through a 90-degree elbow at a depth of 0.5 to 1 m (1.5 to 3 ft) below the water surface. Most water-column turbidity can be eliminated by using a submerged diffuser system at the end of the pipeline. This latter discharge configuration also maximizes the mounding tendency of the fluid mud dredged material,thereby minimizing its areal coverage over the disposal area".

Silt curtains can sometimes be used to control near-surface turbidity but not fluid mud (Figure 3). Turbidity levels in the water column outside the curtain, under certain conditions, can be as much as 80% to 90% lower than levels inside or upstream from the curtain (J.B.F. Scientific Corp. 1978). However, silt curtains are only effective in quiet waters. Effectiveness drops rapidly as currents, waves, and tides increase. Use of silt curtains is not recommended where current velocities exceed 50 cm/sec or about 1 knot (Barnard 1978).

Release of toxicants: Several studies indicate that (with some exceptions) there is not a significant release of potential toxicants, e.g., oils and greases, pesticides, PCBs and heavy metals, into the water column during the discharge of dredged material (May 1973b, Fulk et al. 1975, Chen et al. 1976, Lee et al. 1977, Schroeder et al. 1977). The common exceptions are ammonia, phosphorous, manganese, and iron. Burks and Engler (1978) have summarized DMRP laboratory investigations of releases of contaminants to the

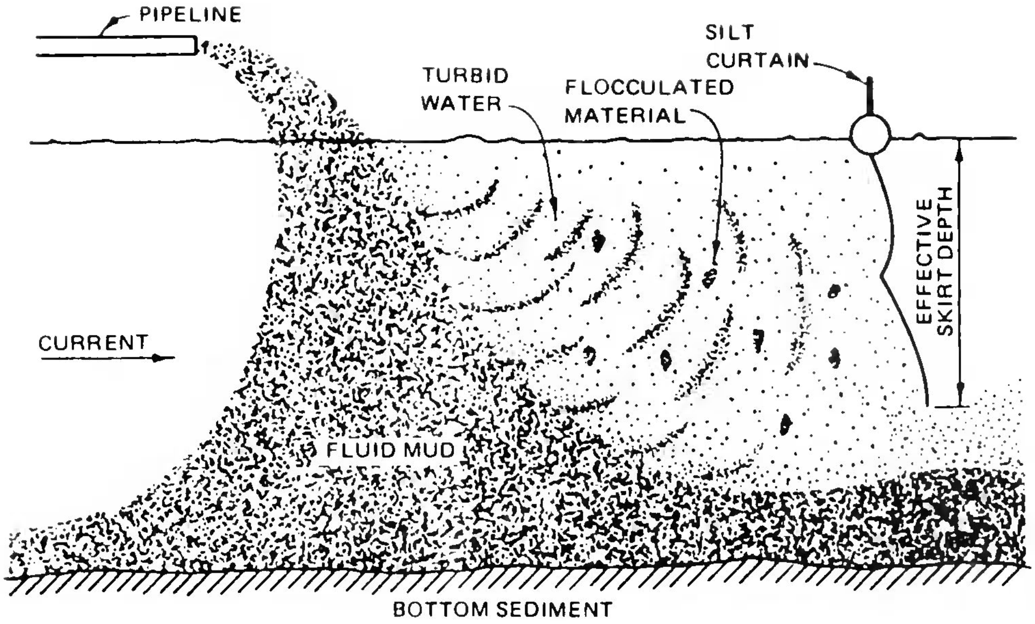

Figure 3. Processes affecting the performance of silt curtains in controlling dredged material dispersion (Barnard 1978).

water column. In contrast to the above cited studies, some recent studies, not dealing specifically with the discharge of dredged material, indicate that contaminants are more bioavailable than previously thought (Halter and Johnson 1977, and statements by Lynn A. Greenwalt; Director of the FWS; Harry M. Ohlendorf, Assistant Director of the Patuxent Wildlife Research Center, FWS; and Foster L. Mayer, Jr., Chief Biologist, Biology Section, Columbia National Fisheries Research Laboratory, FWS, before the U.S. House of Representatives Committee on Merchant Marine and Fisheries, on Problems with Dredge Disposal from New York Harbor 14 March, 20 May, and 21 May, 1980, respectively). In a laboratory study, yellow perch rapidly accumulated PCB's, mercury, selenium, and zinc from resuspended sediments collected from Saginaw Bay, Lake Huron (J.G. Seelye, R.J. Hesselberg, and M.J. Mac, unpublished manuscript, Great Lakes Fishery Laboratory, FWS).

We believe that much work needs to be completed before the complex dynamics of contaminant availability and movement within the ecosystem is understood.

Most potential toxicants are sorbed or bound to fine-grained sediments and thus tend to remain with the dredged material. None of the potential contaminants previously mentioned (i.e., ammonia, manganese, and iron) should cause acute water column impacts under normal dilution and mixing conditions. However, hydrogen sulfide is sometimes released from sediments and is highly toxic to aquatic organisms, even with substantial dilution. Hydrogen sulfide may be present in highly organic sediments that contain wood pulp fibers, such as occur in the Pacific Northwest (Serviz et al. 1969).

Chen et al. (1976) stated that "concerns regarding the release of a significant quantity of toxic materials into solution during dredging operations and disposal are unfounded. Some metals are released in the parts per billion range but others, with the exceptions of manganese and iron, show essentially no release pattern." The work done by Hoss et al. (1974) does indicate that larval fishes could be killed in situations where dilution is not substantial. Chen et al. (1976) also noted that clay, silt, and organic particles, temporarily suspended in the water column, will contain trace metals and hydrocarbons.

Emphasis is shifting to bioassessment techniques to determine long-term impacts of dredged material on aquatic life (Schuba et al. 1978). Tests should be conducted utilizing sublethal parameters as much as possible. Enzyme induction tests, physiological dysfunction, and pathological and biochemical changes have been useful in documenting cause and effect relationships of contaminants (personal conversation 12 March 1980 with Charles R. Walker, Fishery Ecology Research, FWS, Washington, D.C.). These types of tests are difficult to perform in practical field applications but should be considered as a desirable goal.

A specialized type of disposal that has limited application for directing toxicants away from critical areas consists of discharging into a strong current which carries away the dredged material. Disposal can be into a nearby channel or into the mouth of an outlet to the sea, utilizing outgoing tides. Limited use of this technique has not resulted in noticeable adverse environmental impacts (telephone conversation 5 February 1979 with Braxton Kaiser, Corps of Engineers, Charleston, South Carolina). Agitation dredging that entails bringing sediments into suspension by mechanical agitation, such as through the use of a dredge, and the subsequent removal by strong currents may occasionally be employed as a disposal alternative. Sidecasting is also an alternative technique in a dynamic environment. Sanderson (1976) describes the use of sidecasting in North Carolina inlets. The reader should remember, however, that if contaminants are present, agitation and suspension of soil particles will maximize the potential for release of contaminants to the water column.

Each project utilizing currents to remove sediments must be evaluated on its own merits. If sand must be removed from channels it appears to be more desirable, from an environmental standpoint, to leave the sand in the littoral zone rather than release it in deep water. Deep water disposal will lead to a deficit sand budget in the littoral zone, which in turn will affect littoral zone organisms and cause beach erosion. The scant available literature on impacts of agitation dredging leads to the conclusion that careful site selection for this technique will impose few environmental hazards if the material is unpolluted.

Nutrient release: There is often a significant release of nutrients and biostimulants during disposal operations, particularly ammonia, but also lesser amounts of forms of ortho-phosphates (Blom et al. 1976, Brannon et al. 1976, Schroeder et al. 1977). The greatest potential for detrimental conditions and accompanying blooms of unwanted algae from dredged material disposal appears to be in poorly-mixed estuarine waters where nitrogen is often limiting. In nutrient deficient waters, the addition of nutrients could actually be beneficial.

Dissolved oxygen: Short-term dissolved oxygen depletion due to dredging is seldom a problem (Slotta et al. 1974, Smith et al. 1976). At the discharge site, reduced oxygen levels are usually found near the bottom at the point of discharge, but are of short duration (Stern and Stickel 1978). However, long-term anoxia can occur when highly organic sediments are discharged. Adverse impacts are most likely to occur in poorly-mixed waters receiving highly organic dredged material, such as sediments taken from inner harbor areas.

Impacts on animal concentrations and migrations: The adverse impact of turbidity on concentrations and migrations of aquatic organisms is well documented (Darnell et al. 1976), but the role played by dredging is not well known. Potential impacts are very site specific. Dredging and disposal of dredged material could conceivably cause disorientation due to the confusion of organic smells and alteration of normal behavior due to physical disturbances such as noise of the operations and discharge of the solids. Suspended solids from dredging and disposal could also cause abrasion of gills which could result in chronic bacterial infections, coating of the gills (causing anoxia), and decreases in catchability of fish. Apparently, levels of turbidity created by natural occurrences (e.g., storms and floods) and levels from dredging do not normally cause direct mortality. However, laboratory tests have shown that concentrations of particulate matter greater than those normally occurring during dredging or natural events cause direct mortality (Hubert and Richards 1963, Brannon et al. 1976).

Bottom impacts. The potential impact of dredged material disposal on organisms living on or near the bottom is greater than potential impacts in the water column. Impacts associated with the presence of dredged material on the bottom include: (a) smothering and burial of organisms; (b) long-term changes in species diversity and biomass; (c) uptake of toxic organic compounds; (d) heavy metals uptake; (e) changes in water circulation; and (f) changes in sediment size and movement.

Sedimentation from disposal of dredged material can have strong negative impacts when the settling occurs in an area containing sensitive organisms. Areas of concern include coral reefs, seagrass beds, oyster reefs, and fish spawning or nursery areas. Sedimentation can also be a source of nutrients. Odum (1963) found an initial depression in productivity of Thalassia and Diplanthera because of sedimentation from dredging. However, in the following spring, high production values were exhibited by those beds not directly smothered by the dredged material. Increased productivity was attributed to the release of nutrients from the dredged material.

Fluid mud is mainly generated by pipeline dredges and can flow along the bottom driven by gravity or tidal currents (O'Neal and Sceva 1971). According to Masch and Espey (1967), silt and clay particles make up 80% or more of the total particulate matter of fluid mud. Benthic organisms are destroyed when fluid mud separates them from the overlying water upon which they depend for respiration and food (Diaz and Boesch 1977).

Due to a lack of studies, information about the recovery time from fluid mud impacts is not well known. Recovery in the tidal area of James River, Virginia, was nearly complete in 3 weeks but some adjustments were still occurring after 3 mo. Other less resistant or resilient communities would probably require a much longer recovery period (Diaz and Boesch 1977). A long-term potential impact of fluid mud is the later resuspension of sediments into the water column,thus increasing turbidity.

Organisms buried by more consolidated materials will require a longer interval to recolonize than organisms impacted by fluid mud. Recovery times for sites buried by consolidated materials have been reported to require from a few weeks to 2 yr or more. In many instances, predisposal assemblages of organisms will not reoccur if the substrate is altered by the addition of dredged material that is substantially different from the substrate covered. The new fauna may reach the original biomass but often will consist of different species. The greatest impact occurs when unlike material is deposited, i.e., sand on mud or visa versa. Polluted materials will retard recolonization indefinitely (O'Neal and Sceva 1971). Fine-grained materials are usually recolonized more rapidly than coarse-grained materials. One study of relatively clean dredged material in Rhode Island Sound indicated that after a recovery period the faunal assemblage was diverse, abundant, and contained species valuable as fish food (Saila et al. 1972).

Bingham (1978) reported on recovery of benthic organisms at a deepwater disposal site for contaminated dredged material in Puget Sound, Washington. The following observations were made:

(a) the greatest detrimental impact on benthos resulted from burial in excess of 0.5 m (1.6 ft);

(b) benthic repopulation was by horizontal migration;

(c) population density had not recovered in the center of the disposal area 9 mo after disposal;

(d) because of invasion of opportunistic species, species diversity was greater in the center of the disposal area 9 mo after disposal;

(e) at 9 mo both species density and diversity were greater at the margins of the disposal area than reference areas; and

(f) effects of the disposal operation were confined to the immediate disposal site area.

For additional discussion of impacts on benthic organisms see the DMRP synthesis reports by Hirsch et al. (1978) and Wright (1978).

Contaminants: Dredged material from harbors or other heavily industrialized areas may contain substantial amounts of heavy metals, oils and greases, pesticides, PCBs, and other toxic substances. These elements and compounds tend to be tightly bound to clay particles. Release to the water column is limited and controlled by complex chemical reactions such as pH and redox potential and by the presence of iron and sulfides. Therefore, most contaminants remain with the bottom sediments where they pose a long-term potential hazard to the ecosystem.

The uptake and biological significance of toxicants, such as PCBs, kepones, petroleum hyrocarbons, and heavy metals are not usually well understood. Halder and Johnson (1977) found significant uptake of PCB's by fathead minnows (Pimephales promelas) from sediments via the water column. However, patterns are not consistent and generalizations are difficult to make at this time. These toxicants persist as residues in tissue due to bioaccumulation (Stern and Walker 1978). Neff et al. (1978), in the laboratory, obtained an uptake of heavy metals 26.5% of the time from 135 exposures involving eight metals and five benthic invertebrates. It does appear that uptake of heavy metals is not nearly as common as once suspected but further research is needed. Blom et al. (1976), Brannon et al. (1976), Chen et al. (1976), Khalid et al. (1977), and Lee et al. (1977) provide state-of-knowledge discussions.

Pesticides, PCBs, and kepones biomagnify in organisms as these compounds pass to higher trophic levels (Nathans and Bechtel 1977, Horn et al. 1979). With the exception of mercury, biomagnification is much less common with heavy metals or petroleum hydrocarbons.

The presence of contaminants in dredged material indicates a potential for uptake, but there are many documented instances in which organisms exposed to contaminated materials did not exhibit uptake. Many factors control uptake. Sodium chloride, for instance, inhibits the availability of many heavy metals. However, in a Swedish estuary following dredging, there was an overall increase in concentrations of Hg, Cd, Zn, Pb, and Ni in the benthic fauna. The elevated level was starting to return to normal after 1.5 yr (Rosenberg 1977).

Hydrocarbons present at sublethal levels in dredged material have the potential to interfere with the olfactory senses of marine animals and affect food location, escape from predators, selection of habitat, and sex attraction (Diaz and Boesch 1977). Due to the many variables that affect the toxicity of potential contaminants, we agree with Hirsch et al. (1978) that whole sediment bioassays should be used to predict the toxicity of dredged material at the disposal site. We further urge that many of these tests consist of long-term evaluations of subtle sub-lethal effects.

In the course of our review, we have identified a significant data gap relating to contaminant availability and toxicity to the biota. While there is considerable information about the impact of individual contaminants on aquatic and terrestrial organisms, the bioavailability and toxicity of the contaminants found in dredged material is still relatively unknown. Few studies have been conducted within the context of dredged material disposal situations and, further, most tests have failed to measure synergistic effects. Contaminated dredged material usually contains many contaminants and, therefore, synergistic effects could very well be the rule.

Fate of deposits of dredged material: Post-disposal movement of dredged material has been shown to range from no movement (Gordon 1974), to moderate dispersal from the disposal area (Bassi and Basco 1974), to almost complete displacement from the disposal area (Maurer et al. 1974). In pipeline dredging, much of the dredged material may leave the disposal area at the time of disposal in the form of fluid mud (Bassi and Basco 1974). Material discharged from hopper dredges or from barges is less likely to be widely dispersed.

Factors affecting dispersal include grain size and other characteristics of the dredged material, currents, tides, storms, bottom topography, shipping traffic, and depth. Saila et al. (1972) discussed dispersion occurring at a dump site in Rhode Island Sound. Holliday (1978) summarized the processes affecting the fate of dredged material and Holliday et al. (1978) discussed models for predicting the short-term fate and long-term transport of dredged material. Mathematical models of both short-term and long-term transport of dredged material have been developed (Krone and Ariathurai 1976, Ariathurai et al. 1977).

Changes in circulation: Deposits of dredged material have the potential to alter estuarine circulation patterns, tidal prisms, and water exchange rates. In turn, these can decrease freshwater flow through the estuary, decrease saltwater penetration, sharpen salinity gradients, affect temperatures, alter nutrient budgets, and affect other physical or chemical parameters. These in turn affect living organisms (Odum 1970, May 1973b). Changes may be very subtle and difficult to predict.

A classic example of impacts of circulation changes occurred in South Bay near Brownsville, Texas. Dredged material from the Brownsville ship channel was placed along the northern end of South Bay. As a result, Boca Chica Pass filled in, circulation in South Bay became nonexistent, the average depth decreased from 1.2 to 0.4 m (3.9 to 1.3 ft), and the oyster population was destroyed. There was also a decrease in fish and invertebrate populations (Breuer 1962).

Although dredging-induced changes are often detrimental, as in South Bay, they could conceivably be beneficial by eliminating "pollution traps" through improved water exchange between a polluted estuary and the open sea (Odum 1970).

Continental Shelf Disposal

Continental shelves, like estuaries, are highly productive areas for marine fisheries. However, adverse impacts of dredged material disposal are not as severe to continental shelves as to estuaries because water over continental shelves has greater dilution, mixing, and assimilative capacities. Compared to estuaries, continental shelves are not the scene of as many critical physical-chemical-biological processes. An exception to the above statements is the impact of disposal on coral reefs. (See assessment of impacts at the dredging site--bottom impacts). Another disruption of an ecosystem was noted with disposal in the surf zone of a rocky kelp bed area in Oregon (U.S. Army Engineer District, Portland 1978).

Although adverse environmental impacts are of less concern on the continental shelf, other constraints such as transportation costs and available equipment become more critical. Much of the discussion of the previous section about estuarine disposal applies to continental shelf disposal. However, many impacts occurring in estuaries will be less severe or will not occur on the continental shelf. This discussion (and the section about deep ocean disposal) is brief because of a lack of studies and our desire not to repeat the same information contained in the section on estuarine disposal.

Water column impacts. Potential impacts to the continental shelf water column are similar to impacts to the estuarine water column. Except for some special cases, such as in the New York bight (Gunnerson and Wanson 1975), impacts to the continental shelf water column should be minimal to non-existent. In the New York bight, apparently the circulation is not adequate to dilute and disperse the large volume of waste material (of several types) that is disposed there.

Lee et al (1975), Blom et al. (1976), Brannon et al. (1976), Chen et al. (1976), and Burks and Engler (1978) discussed the release of nutrients and potential toxicants to the water column during disposal operations. Significant releases of manganese and ammonia can be expected. Lesser releases of iron, cadmium, zinc, and orthophosphate may occur. Normal dilution should reduce these materials to harmless levels, but there are possibilities of adverse effects over portions of the continental shelf with poor circulation. The most likely impact would be the stimulation of algae blooms by ammonia. Lee et al. (1977) found no significant water column impacts from offshore dumping at Galveston, Texas.

Although it can generally be concluded from the literature that dilution occurring with open-water disposal will render most contaminants harmless over the short term, bioaccumulation and biomagnification of some contaminants is known to occur. The following account is not from a dredging operation, but illustrates the point. In 1965, in the Netherlands, copper sulfate released in coastal waters killed large numbers of fishes and mussels. Dilution levels should have been safe, however, the chemical accumulated at high levels in certain links of the food chain. Korringa, as quoted in Merlini (1971: 465) commented that "...this case clearly demonstrates how erroneous it is to make a decision to discharge a pollutant into the sea on the basis of calculations of the eventual concentration of the pollutant following disposal and dilution." Another example is the accumulation of PCBs to levels of about 5 mg/g in certain fishes of the Great Lakes even though monitoring of Great Lakes water consistently indicated concentrations of 0.01 mg/l or less (U.S. Environmental Protection Agency 1976).

The work by Plumb (1976) indicates that stimulatory or inhibitory materials released from dredged sediments do not have a significant effect on algae when the rate of dilution at deep ocean sites (such as on the continental shelf) is considered. Dilution will prevent low levels of dissolved oxygen at the point of discharge from becoming a problem. Likewise, continental shelf disposal should pose no problems to concentrations or migrations of fishes. The literature does not document any instances of short-term impacts of dredged material to the water column in well-mixed waters.

Bottom impacts. The possibility of impacts to the bottom appears much greater than for the water column. Potential bottom impacts include smothering and burial of organisms, contaminant uptake, and physical changes in topography which could alter nearbottom currents.

Pratt (1979) discussed the monitoring of 10 dredged material disposal areas in New England waters. He noted that the greatest deleterious effects of dumping have been obstruction of trawling for shrimp and finfish and burial of ocean quahogs. On the positive side, throughout the region disposal sites became productive lobster grounds 1 to 3 yr after dumping ended. First (1969) and Valenti and Peters (1977) noted significantly greater assemblages of demersal fish and lobsters in the historic Eatons Neck, Long Island Sound, disposal area than outside the disposal area.

Although information is lacking, concerns over contaminant uptake are probably similar to those expressed earlier in the estuarine disposal section.

Disposal of dredged material on the continental shelf should have little impact on water movements except possibly for unusually deep accumulations of material such as in the New York Bight disposal areas.

First (1969) recommended deepwater disposal because bottom effects of waves and tidal currents decrease as depth increases, resulting in greater sediment stability with increasing depth. Oertel (1976) studied a disposal site off the Savannah River mouth. Six months after disposal the dredged material still occupied the disposal site but there was some redistribution of grain sizes forming sand ridges and some sediment movement due to storms.

Deep Ocean Disposal

Deep ocean disposal is not commonly practiced (Hawaii and Puerto Rico are exceptions) and is generally considered to be economically infeasible (Conner et al. 1979). However, as nearshore environmental concerns increase and available land becomes more scarce, deep ocean disposal may become a viable disposal alternative.

Because of the lack of historic deep ocean disposal, there is a dearth of information on impacts. Most of the discussion in this section is taken from An Assessment of the Potential Impacts of Dredged Material Disposal in the Open Ocean (Pequegnat et al. 1978), which is primarily a theoretical discussion of probable effects. Readers should review this comprehensive work remembering its theoretical nature. The authors concluded that "deep ocean disposal...is an environmentally sound alternative to presently unsatisfactory disposal operations" (p. 151). They also stated that "although there are multiple effects that dredged material can and will exert upon any region or ecological system, it is concluded generally that these impacts will be less severe in the deep ocean than elsewhere in the marine environment." This conclusion is supported by the following assertions: (a) there are large areas of ocean bottom and great volumes of water to receive and dilute any except the most hazardous wastes; (b) the deep ocean has a demonstrated assimilative capacity to receive huge volumes of sediment without losing its capacity to sustain normal life processes; (c) the capacity of the deep ocean to produce food for man is very limited and insignificant compared to rich estuaries and continental shelves; and (d) the lack of fishes on deep ocean bottom is attributed, in part, to the lack of benthic invertebrates. "On a worldwide basis, the average benthic biomass on the floor of the deep ocean is no more than 0.01% that of the continental shelf" (Pequegnat et al. 1978: 44).

The reader may refer to our sections about estuarine and continental shelf disposal for general effects on the aquatic environment. However, the applicability of this information to the deep ocean environment is unknown.

Water column impacts. We agree with Pequegnat et al. (1978) when they state that there is less potential for dredged material harming the water column than the deep ocean bottom. Impacts to the water column should be similar, in a very general way, to those impacts discussed in the sections on estuarine and continental shelf disposal, except that the dilution factor is greater.

There should be little concern for uncontaminated river sediments. River sediments appear to stimulate ocean productivity, a prime example being the rich fishery of the Gulf of Mexico down current from the mouth of the Mississippi River. Concern should be concentrated on the disposal of contaminated sediments. However, the present lack of experience in, and research about, deep ocean dumping leaves its effects on the water column unknown.

Bottom impacts. Pequegnat et al. (1978: 45) state that "the ultimate fate of the dredged material disposed in the deep ocean is the bottom sediments. Here, potentially toxic elements and compounds may be subjected to conditions that greatly differ from those in the overlying water columns and thereby may be released and made available to the benthic community. Thus, it is easier to visualize harmful impacts on the benthos than on the pelagical."

There should be little or no movement of deposits of dredged material on the deep ocean floor and likewise little effect on water circulation. However, definitive research is lacking.

Habitat Development

Habitat development is a disposal method that has not attained its full potential. Terrestrial, island, and marsh development techniques are moderately well-developed, although only the latter is being practiced to any great extent. Creation of aquatic habitat is possible but the technology has not been developed. Figure 4 illustrates a conception of habitat development. According to Smith (1978), factors to consider in evaluating the habitat development alternatives include characteristics of the dredged material, site selection, engineering, cost of alternatives, sociopolitical implications, and environmental impact. For a philosophical discussion of the pros and cons of habitat development from an ecological viewpoint see Lunz et al. (1978). Attention is given to the relationship of the habitat site to the total ecosystem.

Most of the following discussion is summarized from DMRP reports and the reader is referred to the appropriate sources for more details.

Terrestrial development. Terrestrial or nonwetland refers to mainland or large island areas that, normally are not flooded and are characterized by upland vegetation or a mixture of upland and wetland plants. We are treating islands separately even though most island habitat is terrestrial.

Terrestrial vegetation of varying value to wildlife will naturally invade both contained and uncontained disposal areas or it can be artificially developed and managed. Terrestrial habitat may vary widely and includes grasses, weeds, shrubs, and trees. The value to wildlife will depend on site characteristics (elevation and composition of the sediments) and the subsequent vegetative cover. Invading plant species often consist of vegetation of low value to wildlife.

Habitat can be developed to provide food and cover for mammals, birds, reptiles, and amphibians, or resting, feeding, or nesting areas for waterfowl. Small sites may be ideal for small animals, whereas larger areas may be managed for waterfowl or deer. Animal diversity and abundance will depend on accessibility of the site, suitability of feeding, cover, and breeding habitat, and competitive pressures imposed on adjacent habitats (Coastal Zone Resource Corporation 1976). Dames and Moore (1977) identified game and furbearing animals which they felt could benefit most from habitat development on upland disposal areas.

Land managers must decide whether to develop and manage for optimum conditions for only one or two species, or to manage for species diversity which features favorable conditions for a number of species (Hunt et al. 1978a). Local needs and constraints will help to determine the wildlife to be managed.

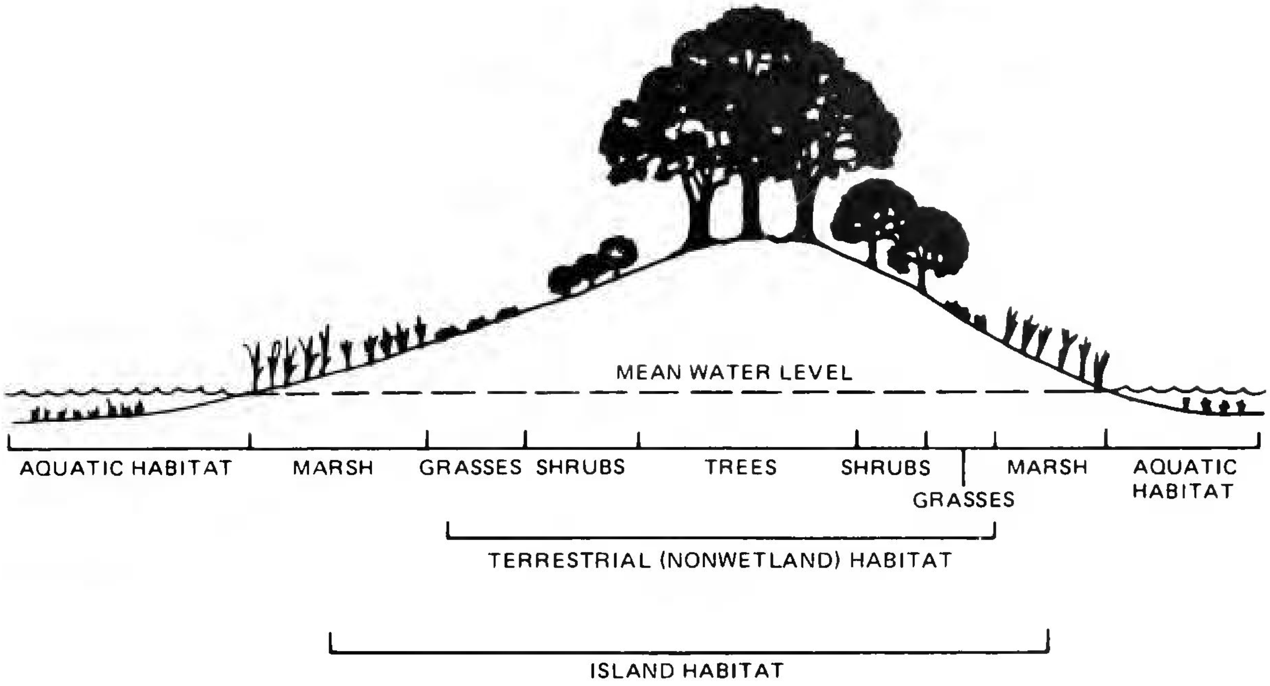

Figure 4. Hypothetical site illustrating the diversity of habitat types that may be developed at a disposal site (adapted from Lunz et al. 1978).

The species must be compatible with human use of the site or the surrounding area. For example, if the site is to be used as a park the animals must be tolerant of human disturbance.

Two general types of disposal areas are potentially available for terrestrial habitat development (Ocean Data Systems, Inc. 1978). These are an established dredged material disposal site where disposal has been completed or is still periodically occurring and a site proposed for deposition of dredged material. The former may be years old or relatively new, vegetated or unvegetated. The latter, before disposal, may be terrestrial or even an open-water site which will become a terrestrial site when dredged material is deposited.

Development of disposal sites will depend greatly on the local demand for such an area. Development techniques are relatively simple; standard agronomic and wildlife management techniques can be adapted to most terrestrial disposal areas. The initial expense is relatively small, particularly when compared to marsh development. However, retention of a particular terrestrial habitat will often require a long-term management commitment with small annual costs. Initial development and maintenance activities may include liming, fertilization, seeding, and mowing.

Smith (1978) identified the two primary disadvantages of terrestrial habitat development as being the preclusion of future disposal and possible necessity of continuing management. If a late succession stage (e.g., forest) is the objective, then future use of the site for additional disposal would not be compatible. However, if early succession stages are desired, periodic disposal would keep setting succession back to earlier stages. Management may require manpower and funds that are not readily available. Another potential constraint is that the value of habitat lost may exceed the value of the habitat to be established. Open-water or wetland habitat will often have a greater value to wildlife than terrestrial habitat that could be developed at the site.

A potential constraint to use of dredged material for upland habitat development is the presence of contaminants that are harmful to wildlife. Contamination could occur from effluent runoff, by vertebrates eating plants that have taken up contaminants, or by vertebrates feeding on soil invertebrates.

The greatest potential for upland contamination is situations in which, through the process of gradual drainage and oxidation, soils become acidic and heavy metals become mobile. Under acidic conditions, heavy-metal runoff and plant uptake are more likely to occur. In neutral or alkaline conditions, lightly to moderately contaminated dredged material can become effectively immobilized. For a thorough discussion of the contaminant potential of a variety of contaminated materials see Gambrell et al. (1978).

Hunt et al.(1978a) outlined in a step-by-step process the necessary engineering and plant propagation procedures for site selection and development. To identify objectives one must consider: the most appropriate management system; local and regional needs and opportunities; desired species needs; current and planned use of the site; available funding; and site- or project-specific constraints. Additional considerations include relation of the site to other habitats with which it may interact and potential sources of plant and animal colonizers.

Hunt et al. (1978a) discussed three methods of vegetation establishment: (a) allow natural plant invasion and establishment, (b) plant selected species, and (c) combine natural establishment and planned propagation.

The ability of propagules to reach the site is the most important factor determining the potential for natural colonization. Sources, distances, and modes of transportation are important. Physical and biological factors at the site, such as site size, soil type, and moisture, are also important determinants of establishment success.

Vegetation can usually be established within a year through planting and other standard agronomic practices. Advantages and disadvantages of natural establishment and planting are discussed in Hunt et al. (1978a).

Plant species are selected by first looking at vegetational needs of the target species. Candidate species can then be evaluated in light of adaptability to climate and substrate, growth requirements, availability, ease of propagation, management requirements, and costs (Hunt et al. 1978a). Summarized data is available on plants known to grow on dredged material sites (Landin 1978a, Ocean Data Systems, Inc. 1978). Also available is a study of successional patterns of plants and animals at terrestrial disposal areas (Coastal Zone Resources Corporation 1977).

As a general rule, native plant species should be used for habitat development (Ocean Data Systems, Inc. 1978) because: (a) the wildlife of the area normally depends on these plants and (b) the plants are adapted to the climate and to the physical and chemical properties of the local sediments. An exception to (b) is domesticated species of plants that are of greater value to feeding waterfowl (Crawford and Edwards 1978, Hunt et al. 1978b).

There are a number of engineering considerations that effect the ecology of a site and its value to wildlife. The size, configuration, elevation, and topography all affect wildlife use and suitability (Hunt et al. 1978a). Likewise, the presence or abundance and patterns of vegetation affect wildlife, e.g.,greater vegetative diversity generally leads to greater animal diversity.

Long-term site maintenance and management could range from simple monitoring of the presence of vegetation and wildlife use to intensive management of the site. Management activities can consist of the repair or removal of dikes or protective structures, erosion control, or vegetation management. Vegetation management may consist of fertilization, liming, cultivation, mowing, burning, pruning, and herbicide application (Hunt et al. 1978a).

Island development. Islands developed from dredged material have often been valuable to colonial nesting waterbirds, e.g., gulls, terns, skimmers, herons, egrets, ibises, cormorants, pelicans, and spoonbills (Figure 5). Some of these bird species are threatened or endangered. However, the establishment of islands has often eliminated valuable fishery habitat. The trade off of habitats must be clearly recognized. Additional impacts may include changes in circulation patterns, wind fetch, and tidal prism.

There has been little planning for bird use of man-made islands. However, a recent nationwide examination of bird use of dredged material islands