Figure 5. Dredged material islands are intensely utilized by colonial nesting sea birds such as this mixed colony of Sandwich and Royal terns. Photo courtesy of Waterways Experiment Station.

conducted by the DMRP has resulted in guidelines for the development and management of avian habitat (Soots and Landin 1978). Most of the following discussion is taken from the latter report and the reader should consult it for further information. A bibliography is also available (Landin 1978b).

There are over 2,000 dredged material islands throughout the United States navigational waterways. An estimated 2 million colonial nesting birds, out of a total contiguous United States population of 5 million, nest on dredged material islands (Soots and Landin 1978). For discussions of specific parts of the country see Buckley and McCaffrey (1978), Chaney et al. (1978), Lewis and Lewis (1978), Parnell et al. (1978), Peters et al. (1978), Scharf (1978), Schreiber and Schreiber (1978), and Thompson and Landin (1978).

Man-made islands vary in their value to colonial nesting birds from critical, e.g., in North Carolina, to relatively unimportant, e.g., along the upper Mississippi River (Soots and Landin 1978). Because of widespread destruction or premption of natural habitat along the Atlantic and Gulf coasts, dredged material islands are used more extensively than natural sites. Among the species using them, these islands are most important to gull-billed (Geolochelidon nilotica), common (Sterna hirundo), least (S. albifrons), sandwich (Thalasseus sandvicensis), and royal terns (T. maximus).

In many areas, traditional nesting grounds have been destroyed by man or else they are readily accessible to ground predators. Dredged material islands offer relatively good protection from ground predators and disturbances by man. In addition to use as nesting sites, dredged material islands furnish areas for loafing, feeding, and roosting. Habitat requirements of many species of colonial nesting waterbirds are quite specific and certain dredged material islands often meet the requirements of a particular species. For example, a newly formed, bare ground, dredged material island was used by terns in preference to barrier islands and beaches where predators and human disturbances were more likely to occur (Soots and Landin 1978).

Factors that determine nesting waterbird use of dredged material islands include: (a) the extent of isolation of the island from ground predators and human disturbance; (b) the habitat diversity found on the island; (c) the stability of the potential nesting substrate; (d) behavioral characteristics of nesting species including social facilitation; and (e) the feeding and foraging habitats of the nesting species (availability of nearby feeding areas).

Soots and Landin (1978) found little difference between the use of a dredged material island and a natural site. The critical factor is the availability of suitable habitat. The habitat may take years to develop through natural plant succession on a dredged material island after its formation or other additional deposition. An island that is isolated from ground predators will probably be used for nesting when it reaches a successional stage attractive to the species. Soots and Parnell (1975) also showed that avifaunal succession on dredged material islands in North Carolina was directly related to the type of vegetation found on the islands.

Soots and Landin (1978) noted that structure and density of vegetation determined which species of birds would use an island, and rates and patterns of plant succession determined how long an island would be of use to certain bird species before becoming available to others. Bare ground nesters only use an island for 1 to 3 yr before growth of vegetation causes them to abandon the site. Ground nesting species that prefer grass and herbaceous cover will use islands 2 yr of age or older depending on plant colonization and succession. Arboreal nesting species generally do not use a dredged material island until shrubs or trees develop. Sometimes succession of vegetation is arrested indefinitely by certain edaphic or climatic factors and, thus, may have long-term use by a particular species. The above factors should be considered when contemplating initial island construction or deposition on an existing island.

Dredged material may be used to establish new islands when there is a shortage of nesting habitat or to modify existing islands. Periodic disposal can be used to set vegetation back to an earlier succession stage (to benefit ground nesters). The configuration, size, and elevation can also be altered through disposal. Further disposal should be prevented on islands where arboreal species are being encouraged. Soots and Landin (1978) encouraged the management of existing dredged material islands, because potential adverse environmental impacts of disposing on an existing site are less than those of developing new islands.

Any management plan should include interagency cooperation to determine habitat needs of the area (which birds do we want to encourage or discourage and what type of habitat do they need?). There are several important considerations for new island development (Soots and Landin 1978).

(a) Site location - Isolation from man and predators is an important consideration. However, with protection, colonial waterbirds can live in harmony with man.

(b) Timing of development - Fall or winter construction will permit use of the island for nesting the following nesting season by bare-ground nesters.

(c) Size - Two to 20 ha (5 to 50 acres) are suggested as a suitable size for islands. However, least terns do well on islands smaller than 2 ha.

(d) Substrate - Requirements may vary with species. Generally coarser material makes better nesting substrate than fine material. A mixture containing shell is good for bare ground nesters.

(e) Slope - Flat to gentle slopes are preferred.

(f) Elevation - Should be sufficient to prevent flooding, but high elevations of fine-grained material should be avoided because of wind and erosion.

(g) Vegetation - Requirements vary with species. Plants can be established artificially or the developer can depend on natural colonization. Soots and Landin (1978) provided a comprehensive discussion of plant propagation and management. For additional related information see the previous section about terrestrial habitat development.

Wetland development. Techniques of brackish-water marsh development utilizing dredged material are fairly well developed (Garbisch 1977). Mangrove and freshwater swamps and freshwater marshes could probably be developed from dredged material but to date there has been little interest in developing them. Wetlands can be established under a wide range of conditions and often satisfy technical, economic, and social constraints. The value of a new wetland must always be weighed against the value of habitat replaced. Therefore, the desirability of wetland establishment is quite site specific and must be evaluated on a case by case basis. Some coastal areas have an abundance of marshes whereas other areas, e.g., southern California, have few marshes. The creation of a new marsh in certain areas may be a valuable method of dredged material disposal.

According to Smith (1978), consideration of habitat development involves a preliminary assessment of potential followed by a detailed evaluation of feasiblity. Factors to consider include characterization of the dredged material, site selection, engineering, cost of alternatives, sociopolitical implications, and environmental impact.

The following discussion of advantages of marsh creation are adapted from Smith (1978) but also includes additional comments of our own or from other references.

(a) Marsh development has considerable public appeal -- other disposal options, such as open water or confined disposal, are meeting with increased public resistance and are often unacceptable;

(b) Desirable biological communities can be created -- early indications are that artificially created marshes function similar to, and are as productive as, naturally created marshes. Fine-grained dredged material is very productive because of its relatively high organic and nutrient content (Barko et al. 1977). In many areas, marshes have been destroyed by man and artificially created marshes can be used to replace a portion of those lost (Palermo and Zeigler 1976).

(c) Marsh creation can be used to minimize adverse impacts -- marshes and other habitat lost to dredging projects can often be replaced with artificially created marshes.

(d) Marsh creation is frequently a low cost option -- if the marsh is created in a shallow-water, low-energy area, costs will be only slightly above that of open-water disposal. Costs could be considerably less than those associated with confined disposal.

(e) Marshes can also be created by reclaiming or developing an existing disposal area -- dredged material may be used to restore a marsh that is eroding (Environmental Laboratory 1978).

The following discussion of problems of marsh creation are adapted from Smith (1978) but also includes our thoughts.

(a) Availability of appropriate sites is limited -- optimum sites are in shallow water, have low energy, and are located near the dredging site. If long distance transport or protective dikes are required, costs will greatly increase.

(b) Marsh development will replace other habitats -- habitat of value to wildlife will be replaced with a different habitat also of value to wildlife. Reliable techniques for comparing the various losses and gains associated with conversion of one habitat type to another are in the developmental stage. Often, it is difficult for local authorities to reach a consensus on relative habitat values.

(c) Release of contaminants from the dredged material to the biota is a concern -- the potential that plants or animals may take up and release contaminants to higher trophic levels will be discussed in greater detail in the section about contaminant uptake.

(d) Subsequent deposition of dredged material on artificially created marshes is limited -- development of a marsh will usually preclude the subsequent use of that area as a disposal site. Often, State and Federal regulations and public opinion will prevent further disposal in wetlands. In contrast, many open water and confined disposal sites can be reused. Exceptions may occur in areas of continued erosion or where the initial disposal created a low marsh and subsequent disposal would create a higher marsh.

A marsh can be developed in stages,thus increasing the number of dredging cycles it can accommodate. By diking an area and utilizing cross dikes, one compartment at a time can be filled over a period of years.

Ecological considerations: In considering the addition of a marsh to a local ecosystem, planners should consider the impact of the marsh on the total ecosystem. For a discussion of ecological consequences of habitat development, the reader is referred to Lunz et al. (1978).

Site selection: Several factors should be considered in site selection. The value of the aquatic habitat at the disposal site is a strong consideration. Certainly, one should avoid seagrass beds, oyster beds, and other similar habitats.

Low wave energy areas are best suited for marsh development. High energy areas may require expensive protective devices. Vincent (1978) described a poorly chosen site located in a high energy situation, which also had poor foundation conditions for construction of a protective dike.

The distance that disposal material must be transported is of great importance in site selection. In general, the greater the distance the greater the cost. Equipment availability for long distance transport is also a factor. For a thorough discussion of criteria for site selection see Environmental Laboratory (1978) and Coastal Zone Resource Corporation (1976).

Engineering considerations: Dredged material for marsh development can either be confined or unconfined depending primarily on wave energy at the site and the grain size of the dredged material. The higher the energy and the smaller the grain size, the greater the need for protection. Hydraulically placed clays and silts from maintenance dreding operations will usually require containment, regardless of wave or current conditions. Sand can tolerate up to moderate wave energies without confinement (Smith 1978). Clay from "new work" dredging often will not require containment because it will "ball" and be resistent to erosion (conversation with R. T. Saucier, December 1979, WES, Vicksburg, Mississippi.)

Determination of final site elevation in terms of tidal range is critical and should be based on precise knowledge of elevational requirements of the plant communities. Final elevation of the marsh substrate is largely influenced by settlement and consolidation of sediments. For a number of other engineering and practical considerations see Coastal Zone Resources Corporation (1976) and Environmental Laboratory (1978).

Plant propagation: Marsh developers may choose between natural invasion and artificial propagation of plants. Natural invasion may be slow if there is not an abundant nearby source of propagules. Sprigging increases costs but can provide a quick cover and more rapid stabilization. Seeding is slower and not as dependable as sprigging but is less costly. In an area like much of California where natural colonization is very slow, sprigging or seeding may be preferred over natural colonization. Natural invasion occurs much more rapidly in freshwater situations than in saltwater systems. An artificial marsh developed in the James River, Virginia, became densely vegetated without artificial propagation within months following construction (Lunz 1977). A detailed discussion of plant propagation considerations and techniques is provided in Environmental Laboratory (1978). Other useful information can be found in Woodhouse et al. (1972), Kadlec and Wentz (1974), Wentz et al.(1974), and Garbisch et al. (1975).

Contaminant uptake: Heavy metal uptake by marsh plants and animals does occur. Uptake of other contaminants has only rarely been reported for plants, but has often been reported for animals. The most commonly reported heavy metal uptake and biomagnification involves mercury. Windom et al.(1976) studied a marsh contaminated with mercury and found uptake in the primary consumers, Littorina irrorata and Uca sp., as well as in the secondary consumers -- birds and mammals. Dunstan and Windom (1975) noted the tendency of Spartina alterniflora to take up and concentrate mercury. Rhan (1973) noted that S. alterniflora took up mercury from sediments and released it to the surrounding water through plant leaves.

Trollope and Evans (1976) reported concentrations of five heavy metals (copper, iron, lead, nickel, and zinc) in freshwater algae and Triniger (1977) found high concentrations of cadmium in both aquatic plants and algae. Banus et al. (1975) reported lead was taken up by S. alterniflora in concentrations that ranged from 5.4 to 23.2 mg/l. Lee et al. (1976) found that the several marsh plant species, in which uptake was studied, concentrated most heavy metals in below-ground portions. Lunz (1978) studied one artificial marsh and two natural marshes and found concentrations of several hydrocarbons and heavy metals in the soils. However, only nickel in the artifical marsh exhibited significant uptake into tissues of marsh plants. Lee et al. (1978) found that marsh plants growing on a wide range of dredged material disposal sites had heavy metal levels similar to values reported for natural marshes. Dunstan and Windom (1975) found lower concentrations of heavy metals in plants growing on dredged material sites than in plants in natural marshes. They also found lower concentrations of heavy metals (with the exception of mercury) in tissues of S. alterniflora than in the sediments supporting the plants' growth. Boyce (1976) states that it is not clear whether marsh plants will take up significant amounts of heavy metals from contaminated dredged material substrates, or for that matter what constitutes significant uptake. Apparently more work needs to be done to define the amount and significance of heavy metal uptake by plants and animals colonizing dredged material. Emphasis should probably be placed on the "toxic metals" i.e., lead, mercury, cadmium, and arsenic which are not needed by organisms, even in small amounts. Plants and animals lack homeostatic defenses against these metals. See Gambrell et al. (1978) for a discussion of the risks associated with various disposal methods for contaminated dredged material.

Laboratory and field tests were developed by the DMRP for predicting the potential uptake of heavy metals and other contaminants (Lee et al. 1978, Wolf et al. 1978). The laboratory test is not universally effective but will be useful in many situations. The field test is very practical and inexpensive.

Aquatic development. The development of aquatic habitat utilizing dredged material offers much potential, but has not been studied and developed (Smith 1978). Possible habitats that could be developed include tidal flats, seagrass beds, oyster beds, clam flats, and fish spawning areas. Wilson (1950) noted that disposal of dredged material into shallow water could develop firm bottom shoals that would permit setting of oysters or other mollusks.

An example of a valuable aquatic habitat developed inadvertently is the historic Eatons Neck Disposal Site in Long Island Sound. Dredged material and building rubble are furnishing habitat for a valuable fishery for lobsters and demersal fish (Valenti and Peters 1977).

Many potential habitats could be developed by raising the elevation of the bottom. However, sediment type is vitally important, because each the shellfish or demersal fish species requires certain characteristics in the substrate.

Smith (1978) listed the following advantages to aquatic habitat development:

(a) High production -- e.g., an oyster reef constructed to a depth of 1 m (3 ft) in water that formerly was 2 m (6 ft) deep will be more productive than the original bottom.

(b) Potential for wide application -- many potential situations can be envisioned in which aquatic habitat could be developed to replace communities lost to dredging activities. Aquatic habitat can also be developed in combination with marsh habitat.

(c) Complements other habitats -- a variety of habitats is preferred by most ecologists, i.e., open water, flats reefs, and marshes.

Lunz et al. (1978) discussed a number of uses of dredged material for aquatic habitat development. These uses include changing sediment type and covering contaminated bottom sediments with a cleaner material.

Smith (1978) stated that there is an inadequate understanding of techniques for achieving aquatic habitat development. He believes this can be overcome by careful site by site evaluation by local biologists and engineers.

Another major problem is that of potential harmful effects from contaminants. Gambrell et al. (1978) discussed limitations of aquatic disposal of dredged material; the greatest probability for release of contaminants from a disposal area will occur under high energy conditions (currents, waves, tides, and storms).

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PART IV

RIVERS

Compared to coastal dredging, little research has been conducted on impacts of river dredging. There are many data gaps in ecological impacts of river dredging. Most research was conducted in the upper Mississippi River and may only be partially applicable to other river systems.

ASSESSMENT OF IMPACTS AT THE DREDGING SITE

Water Column Impacts

Impacts to the water column of both "new work" and maintenance dredging are generally slight. Most severe dredging impacts are to the river bottom substrate. Turbidity from both "new work" and maintenance dredging is temporary and is usually less than turbidity associated with natural flooding. Most rivers that are used for navigation are naturally turbid and usually turbidity from dredging exeeds background levels for only a short distance downstream. Both Claflin (1973) and Held (1978) noted that runoff from the deposition area created more disturbance than was created by the cutter head.

Turbidity impacts clearwater streams, particularly those used by salmonids. There are numerous references on the adverse impacts of suspended particles (Stern and Stickle 1978). Impacts include interference with respiration, abrasion to the gills, pathological changes to the gill structures, changes in blood chemistry, and disruption of migration. However, there is little evidence that the excavation phase of dredging operations actually causes any of the problems listed. Fortunately, navigational dredging is rarely conducted in clearwater streams.

A minor concern is the entrainment of slow moving nekton. Dutta (1976) reported entrainment of as many as 26,000 salmon fry per day by a hydraulic dredge. It should be noted that this loss occurred when up to 20 million or more fry per day were passing through the area. Conducting dredging operations at slack periods of fish migration can minimize losses of juveniles and disruption of adult movement.

Bottom Impacts

Routine maintenance dredging causes some short-term disruption of bottom faunas, but there is little evidence that the disruption is long-term. However, the alteration of rivers through new channel construction or deepening projects has severe direct and indirect impacts on the entire river and floodplain ecosystem. Short-term impacts include direct destruction of organisms such as mussels, changes in bottom substrate, and downstream sedimentation.

The literature indicates that dredging removes 75-100% of the benthic organisms from the dredge cut (U.S. Army Corps of Engineers, San Francisco District 1975). With "new work" dredging, the replacement fauna may take 2 yr or more to recover and will be different from the original. The transitional fauna will consist of an abundance of opportunistic species; however, species diversity will be limited.

Long-term impacts are more subtle but potentially much more severe. These include changes in hydrology and stream gradient that impact the river, swamps, backwaters, and the entire floodplain (Simons et al. 1975).

The literature about ecological impacts of channelization of large streams is limited. Numerous references to channelization of smaller streams for flood control document many detrimental impacts to fish and other aquatic and terrestrial wildlife. Generally, channelization eliminates wetlands and backwaters, destroys fish cover, causes the water temperature to rise, increases sediment load, increases turbidity, and makes other physical-chemical changes to the stream and its floodplain. Darnell et al. (1976) provided a thorough discussion of channelization impacts. These changes are generally detrimental to game and forage fish and wildlife populations but increase rough (nongame) fish populations. In the absence of definitive research on the impacts of channelization on larger streams, we can assume that similar adverse impacts will occur. New channel construction may also be expected to result in accelerated industrial development which decreases aquatic habitat (U.S. Army Corps of Engineers, Office of the Chief of Engineers 1972).

ASSESSMENT OF IMPACTS OF DISPOSAL ALTERNATIVES

Riparian Disposal

Dredged material is often hydraulically placed above the normal water level in bottomland forests, old fields, or other floodplain areas near the dredging site. Impacts can range from slight to severe, depending on many factors. Trees vary in their resistance to siltation (Teskey and Hinckley 1977). Depending on the depth of fill and characteristics of the fill material, the plant community may be slightly to drastically affected. Siltation increases dieback and reduces stem height and diameter growth. Thick deposits of dredged material may result in the eventual death of most species of trees (Larson 1974). Willows (*Salix* spp.) are well adapted to survive covering by sand. They quickly develop adventitious roots. Cottonwood (*Populus deltoides*) and river birch (*Betula nigra*) also survive fairly well (Larson 1974). Willow and cottonwood are early colonizers of the wetter portions of the new fill material. In general, the new communities are less diverse, less productive, and less valuable to wildlife than the original community (McMahon and Eckblad 1975, Vanderford 1979). The soil is porous, subject to large fluctuations in temperature, and nutrient poor. Colonization by plants is slow. Ziegler and Sohmer (1977) reported that early colonizers of Mississippi River dredged material islands consisted of only two grasses, a sedge, and tumbleweed (*Amaranthus* sp.). Later a few vines and shrubs such as poison ivy (*Rhus* sp.), riverbank grape (*Vitia riparia*), and black raspberry (*Rubus occidentalis*) encroached from the fringes of surrounding forests. High exposed areas in Pool 9 of the Mississippi River were found to be virtually unvegetated after 35 yr (McMahon and Eckblad 1975). However, along the shore where moisture is available, dense stands of willows occur and provide shade for a variety of smaller plants (Larson 1974).

In most river floodplains, the long-term succession pattern proceeds from willow-cottonwood to mixed hardwoods, i.e., silver maple (*Acer saccharinum*), pin oak (*Quercus palustris*), and hickories (*Carya* spp.) (Klein et al. 1975). Similar succession will occur on dredged material deposits unless the elevation is high, in which instance succession will be retarded due to xeric conditions.

In the Pacific northwest, the pattern of succession is reported to consist first of grasses, then willows, elderberry (Sambucus sp.), and blackberries (Rubus sp.). Later, larger trees such as red alder (Alnus rubra), green ash (Fraxinus subintegerrima), and hemlock (Tsuga sp.) may appear (U.S. Army Corps of Engineers, Portland District 1975).

Brady (1976) concluded that it was better to dispose of dredged material onto early successional stages, such as weedy herbaceous plants or willow-cottonwood stands rather than into mature forests of later seral stages. The former will revegetate more quickly.

Stream Margin and Wetland Disposal

Frequently, dredged material is placed in shallow waters or wetlands where it forms islands or extends land masses (Figures 6 and 7) or it may be placed on existing islands or land masses but spills over into the backwaters. Productive shallow water habitat is changed to sandy, initially barren areas. The dredged material also may block running sloughs or feeder channels that feed fresh water through backwater areas, or the outwash may fill in backwater sloughs and lakes. In either instance, the productivity and useful life of backwaters is lessened (U.S. Army Corps of Engineers, St. Paul District 1974).

The findings of Colbert et al. (1975), Simons et al. (1975), and Grunwald (1976) indicate that on the Upper Mississippi River the long-term impacts of dredged material placement are often not immediately recognizable and are potentially more severe than the direct short-term impacts. Dredged material placed along the shoreline is subject to erosion and reintroduction to the stream course. The material is often carried into side channels where, when the current diminishes, it is deposited, blocking water flow to backwater areas or is carried into backwaters where it blankets biologically productive habitat. Fremling et al. (1979) noted several instances in which dredged material that had been transported considerable distances from the original deposit areas had blocked side channels or moved into backwaters. Ragland (1974), Schramm and Lewis (1974), and Terpening et al. (1975) demonstrated the high value of backwaters to fish and wildlife.

Strategically placed dredged material can be used to develop favorable habitat by creating lagoons or other quiet-water areas behind newly created islands (U.S. Army Corps of Engineers, Portland District 1975).

Coastal Zone Resources Corporation (1977) studied a historic disposal area along the Whiskey Bay Pilot Channel, an artificial channel of the Atchafalaya River in southern Louisiana. Dredged material was disposed parallel to the channel during construction in 1935 to 1936 and again in 1961 to 1962. The disposal area was originally swamp and bottomland forest with several small streams. Following disposal, the elevation increased and the area became nonwetland habitat.

An analysis of vegetational changes at the site and in other disposal areas in the Atchafalaya Basin indicated the following possible sere on disposal sites: (a) unvegetated dredged material; (b) ragweed (and other forbs); (c) willow-cottonwood or willow-sycamore-mixed forest; (d) sycamore-mixed forest; (e) red maple-sweetgum-sugarberry; and (f) sweetgum-sugarberry-oak.

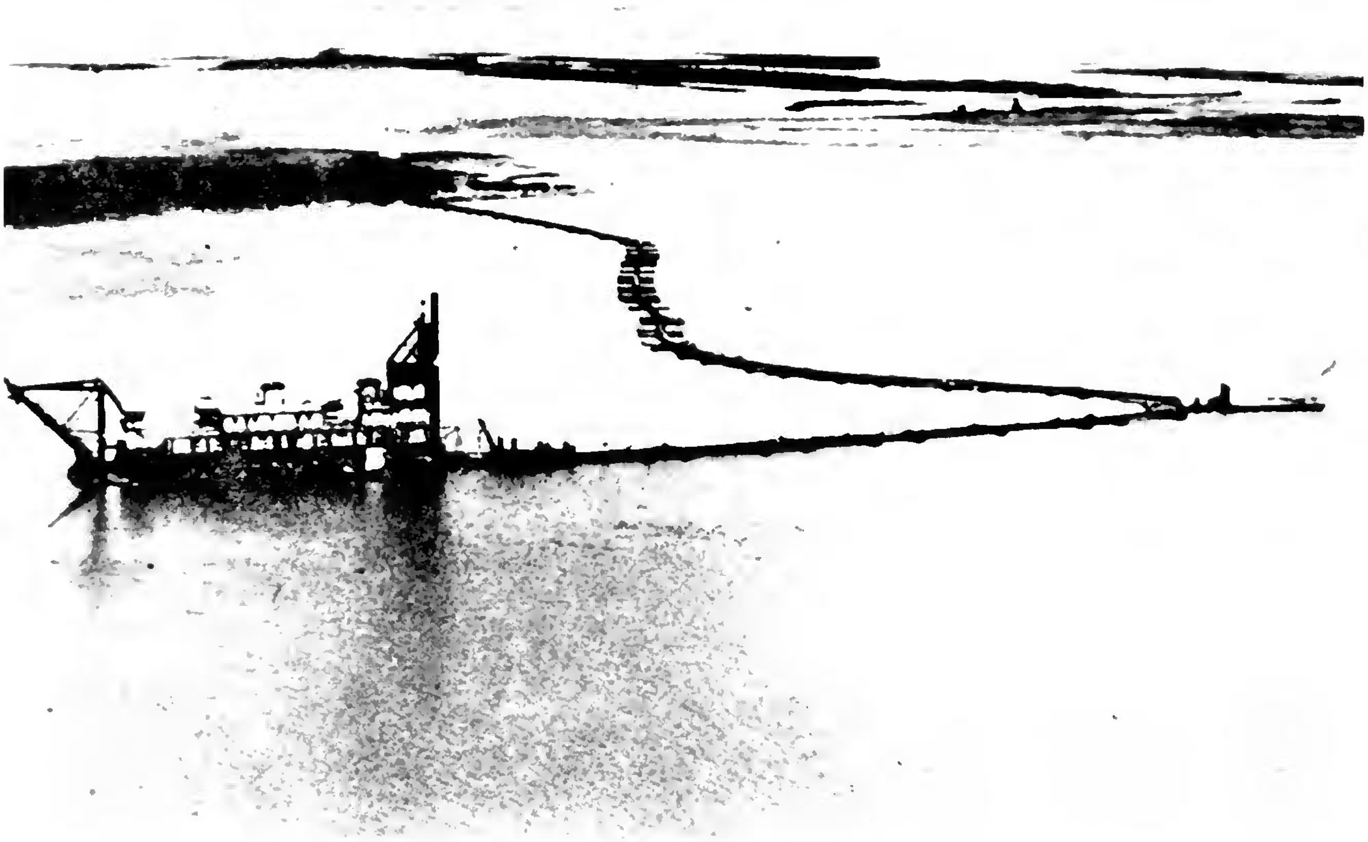

Figure 6. Pipeline dredge discharging along the edge of a river. Photo courtesy of Williams McWilliams, Inc.

Figure 7. Dredged material discharged from a pipeline dredge. Photo courtesy of FWS, Ecological Services, Lafayette, Louisiana.

Due to the influences of the two disposal periods and other factors, a mixture of successional types was present at the site. Birds, small mammals, and deer were abundant. The elevated area probably helped certain species of mammals, such as rabbits, survive the periodic flooding of the area.

On the negative side, the changed elevation and vegetation probably adversely impacted fish, aquatic mammals, and waterfowl(conclusions are partially our own subjectively derived from data presented).

Out-of-Channel Disposal

Dredged material from channel maintenance operations is often placed in areas adjacent to the navigation channel in medium to shallow depths within the river. Potential adverse impacts include turbidity, sedimentation, burial of organisms, changes in substrate composition and bottom topography, blockage or filling of side channels, and releases of noxious materials and nutrients.

Turbidity from disposal operations temporarily reduces light penetration (which impacts primary productivity) and flocculates plankton. Generally, these impacts appear to cause little impact. Increased stream turbidity is usually of short duration and confined to a small area (Great River Environmental Action Team I, Water Quality Work Group 1978). In clearwater streams, turbidity may act as a barrier to migrating salmon (Darnell et al. 1976) but dredging can be timed to avoid periods of migrations.

Other water column impacts include increased biological oxygen demand and release of noxious materials, such as sulfides, methane, ammonia, and heavy metals. Impacts should be minimal unless the disposal is in an area where dilution is poor. For reviews of turbidity impacts see Darnell et al. (1976) and Stern and Stickle (1978).

Great River Environmental Action Team I, Water Quality Work Group (1978) conducted a water quality study of downstream impacts of dredging and disposal at Mississippi River mile 827,immediately downstream from Minneapolis-St.Paul. They found that physical and bacteriological parameters returned to background concentrations within 1.3 km (0.8 mi) downstream of the disposal discharges. Chemical parameters returned to background within a much shorter distance. Impacts were generally localized due to dilution and the sorptive capacity of rapidly settling resuspended particles.

In our opinion, sedimentation is a much more serious concern than turbidity, but sedimentation impacts can be minimized through careful disposal. Sedimentation dramatically decreases hatchability and survival of fish eggs and fry (Hassler 1970); organic sediments reduce the oyxgen level (Phelps 1944); the abundance and diversity of benthic organisms are reduced, particularly mussels (Ellis 1936); and aquatic plants are adversely impacted (Langloise 1941).

Apparently, severe sedimentation impacts are rare from the disposal of dredged material into the river channel. Dredged material from navigational projects appears to pose the greatest sedimentation threat when it is placed in, or adjacent to, backwaters (Great River Environmental Action Team I 1979).

Due to the dynamic nature of rivers, changes in bottom topography are characteristic and frequent (Simons et al. 1974, 1975) and most organisms quickly adjust to perturbations (Johnson 1976). However, dredged material, placed in certain slackwater areas, such as near or on wing and closing dams, can change an irregular bottom to a sandy, smooth, and shallow bottom. The latter habitat is less productive of benthic organisms and offers much poorer habitat for fish than a deeper, rougher bottom (U.S. Army Corps of Engineers, St. Paul District 1974, Grunwald 1976).

Information is lacking about the burial of organisms by river dredging. Mussels are of primary concern in freshwater. The Corps of Engineers, St. Paul District (1974) reported that 10 yr may be required for recolonization by mussels. Rogers (1976) reported a low survival rate of clams (Sphaerium transversum and S. striatinum) buried with sand. Survival was somewhat better with the addition of silt or silt-sand mixture. Adult clam survival was inversely related to both particle size and depth of added substrate. Juvenile clams had higher survival rates than adults.

Marking and Bills (in press) studied the ability of three mussels -- pig-toe (Fusconaia flava), fat mucket (Lampsilis radiata luteola), and pocketbook (L. ventricosa) -- to emerge from 5 to 25 cm (2 to 10 in) coverage of sand and silt. The mussels emerged within a few hours or did not emerge at all. Those that did not emerge eventually died. The studies showed that the type of soil overlay made little difference in the emergence of fat mucket and pocketbook mussels but did affect the emergence of the smaller pig-toes. The emergence of the latter two species was prevented by 18 cm (7 in) or more of sand or silt but only 10 cm (4 in) of silt was sufficient to kill the pig-toe. The authors concluded that the ability of mussels to emerge from soil cover is related to species and size. Changes in substrate composition and bottom topography can alter the benthic fauna and affect fish use and concentrations.

In the Columbia River, Washington and Oregon, a decline in fish catch and species variety was noted at both dredging and disposal areas 40 days after dredging. However, at sites that were only slightly disturbed by dredging, there was an increase in catch (U.S. Army Corps of Engineers, Portland District 1975).

Dispersion and release of noxious material is a concern whenever a contaminated channel is dredged, but little is known of the actual impacts. The general contaminant level is probably less in rivers than in estuaries where harbors may be highly polluted. However, because the buffering capacity of salts is less in fresh water, there is a great potential in rivers for detrimental impacts from some contaminants such as heavy metals.

Dredged material from rivers may contain the following potential contaminants and biostimulants: hydrogen sulfide, methane, organic acids, orthophosphates, nitrogen in several forms including ammonia, oils and greases, pesticides, PCBs, and heavy metals. High levels of PCBs, oils, DDT, and dieldrin were found in harbor sediments of the Mississippi River at Memphis (Fulk et al. 1975). Settling tests indicated that these materials became suspended in the water column during agitation but under quiescent conditions concentrations returned to near background water column levels within 14 hr. Our conclusion from the study, which also included other freshwater sites is that river currents will carry suspended toxic materials for some distance before they settle out in quiet waters.

In the absence of specific information on releases and impacts of contaminated material in freshwater, the reader is referred to the discussion on contaminants in Part III - aquatic disposal in estuaries. Remember, however, the influence of salinity. Generally, toxicity increases as water becomes softer. Sodium, potassium, calcium, and magnesium have all been found in certain instances to be capable of antagonizing the ions of several heavy metals thereby reducing their toxicity (Tarzwell 1957). For additional discussions (of a general nature and not specific to rivers) see the section on "bioconcentration" in Morton (1977). The reader may also wish to consult the Appendix of this review.

Thalweg Disposal

Environmentally acceptable disposal areas are limited. The current common practice of shoreline disposal creates many environmental problems as discussed in previous sections. LaGasse et al. (1976) suggest that disposal in the thalweg or main river channel may be an environmentally acceptable alternative. Miller (1973) further notes that the thalweg is generally relatively barren of invertebrates and the U.S. Army Corps of Engineers, Portland District (1973) notes reduced turbidity and suspended sediment problems with thalweg disposal. However, caution is urged as Hawkinson and Grunwald (1979) have shown that catfish overwinter in deep water of the main Mississippi River channel. Commercial fishermen have also reported that the main channel is a valuable wintering area for fish (letter of 17 January 1980 from John P. Wolfin, U.S. Fish and Wildlife Service, St. Paul, Minn.).

Thalweg disposal consists of dredging a shoal area and depositing the material in the adjacent pool downstream or scraping a shoal (agitation dredging) and letting the current take the sediments downstream to the next pool. LaGasse et al. (1976) indicates this technique could be employed at certain sites during maintenance dredging and might have wide application for emergency dredging. A discussion of the practicality of this technique from the geomorphic standpoint is beyond the scope of this review. For detailed discussions the reader is referred to LaGasse (1975), Simons et al. (1975), and LaGasse et al. (1976).

Habitat Development

Terrestrial development. Dredged material is often deposited into the river margins or other shallow waters so that the disposal area becomes terrestrial. This destroys an existing habitat and the newly created habitat is often of marginal value to wildlife (McMahon and Eckblad 1975, Vanderford 1979). However, valuable wildlife habitat can be developed through the application of well-established agricultural and wildlife management techniques (Larson 1974, River Studies Center 1975, Smith 1978). Terrestrial habitat development can be used as an enhancement or mitigative measure at new or existing disposal sites. Smith (1978) further stated that regardless of the condition or location of a disposal area, considerable potential exists to convert it into productive habitat. Small sites in densely populated areas may be managed for small animals adapted to urban life. Larger tracts may be managed for a variety of wildlife including waterfowl, game, or endangered species.

Terrestrial habitat development may include such low cost procedures as liming, fertilizing, and seeding. It is generally compatible with subsequent disposal operations. In most situations, a desirable vegetative cover can be produced in one growing season (Smith 1978). Terrestrial habitat development often requires continual management. Lack of public ownership of the disposal area can cause management problems.

Smith (1978) provided general guidelines for terrestrial habitat development. Lunz et al. (1978) discussed considerations to help determine the need for habitat development and Hunt et al. (1978) provided detailed guidelines for terrestrial habitat development. Coastal Zone Resources Corporation (1977) also provided background information.

One should also consider possible contaminant uptake or runoff into nearby streams. The conditions for availability of heavy metals are maximized under the acid oxidizing conditions that are often present when formerly anoxic sediments are placed on dry land (Gambrell et al. 1977, Gambrell et al. 1978). Certain beneficial uses of dredged material, such as strip mine reclamation, filling barrow pits and quarries, and agricultural land enhancement (Spaine et al. 1978), will impact existing habitats and produce new habitats. In most circumstances, these types of projects will improve or have no effect on fish and wildlife habitats.

Island development. Reclamation of sandy dredged material islands and land extensions has been studied in the upper Mississippi River. The River Studies Center (1975) of the University of Wisconsin at La Crosse states that the establishment of vegetation on barren disposal areas is feasible but may be expensive. The most promising plant tested was the American beachgrass (Ammophilia breviqulata) which can be easily established by planting clones or plugs. Also recommended at lower elevations was the planting of willow cuttings to establish windbreaks parallel to the shorelines. Ziegler and Sohmer (1977) listed several species that have naturally colonized disposal sites in Pool 8 and some of these species may have a potential for artificial establishment. Larson (1974) recommended five measures which make dredged disposal piles more productive: (a) planting, (b) fertilizing, (c) mulching, (d) capping with mud (fine-grained dredged material), and (e) watering. The methods were only effective when three or more of the measures were used. McMahon and Eckblad (1975) found that whey[1] placed over the sand caused the formation of a moisture holding crust that permitted seed germination and plant establishment.

Recent DMRP studies (Soots and Landin 1978) have indicated intensive use of dredged material islands by coastal birds. However, a survey of the Upper Mississippi River (Thompson and Landin 1978) indicated no dependence on dredged material islands by waterbirds. It was noted, though, that if human disturbance was limited, and bare sand nesting areas were provided (by discouraging vegetation establishment), dredged material islands could be used by least tern (Sterna albifrons). Robinson (1970) noted that dredged islands could be placed in the lower (wide) end of navigational pools to lessen the wind fetch and create habitat for wildlife.

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[1] A by-product of the dairy industry.

Wetland development. To date, most wetland development from dredged material has consisted of salt marsh establishment. However, freshwater wetland development or enhancement offers considerable potential. In fact, freshwater marsh vegetation will quickly establish itself under favorable conditions; whereas salt marsh plants often have to be seeded or sprigged. In a greenhouse study, Barko et al. (1977) obtained good growth of freshwater marsh plants on fine-grained material and considerably slower growth on sandy material. In the James River (Virginia), at a freshwater tidal location, dense freshwater marsh vegetation quickly invaded a disposal area consisting of fine-grained material retained by a dike of sandy material (Lunz 1977).

Some general considerations for freshwater marsh development are: (a) type of dredged material including grain size and contaminants present; (b) site characteristics including elevation and hydrologic regime; (c)value of the habitat to be replaced or altered at the disposal site; (d) energy level at the disposal site -- can the site be protected?; and (e) is the proposed site within dredged material transport distance?. Size, shape, and orientation are important considerations and relate to the in situ volume and location of the material to be dredged.

In the absence of specific guidelines for freshwater marsh development, the reader is referred to the section on coastal wetlands habitat development and to Lunz et al. (1978), Smith (1978), and Environmental Laboratory (1978). For a discussion on potential contaminant uptake, see "contaminant uptake" in "wetland development" (Part III), remembering possible differences in uptake between freshwater and saltwater sites due to physical-chemical differences (Gambrell et al. 1977).

Studies of uptake of the contaminants in fresh waters are generally lacking. In an artificial marsh in the James River, Virginia, nickel, of several available metals, and chlorinated hydrocarbons, were taken up by marsh plants (Lunz 1978).

Fremling et al. (1976) and Nielsen et al. (1978) noted that the construction of a navigational pool at Weaver Bottoms, Wisconsin, in the Upper Mississippi River resulted in an elevated water level. The water overtopped the natural levees, converting natural marsh to wind-swept open water. They also noted possible ways dredged material could be used to aid rehabilitation of the marsh. Modifications to dredging operations could increase water clarity and decrease wind fetch which would make the area more condusive to aquatic plant growth. The Fish and Wildlife Work Group of GREAT I (Vanderford 1979) discussed the concept of rehabilitation of backwater areas of the Upper Mississippi River.

Aquatic development. At this time aquatic habitat development does not appear to have wide application in riverine systems. However, in the Upper Mississippi River, the opening or closing of cuts to side channels and backwaters to direct or obstruct water flows appears to offer considerable potential (Fremling et al. 1979). The modifications are designed to permit sufficient movement of freshwater through backwaters to prevent stagnation and winter-kills, yet prevent the movement of sediments into the backwaters.

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APPENDIX

GREAT LAKES[1]

ASSESSMENT OF IMPACTS AT THE DREDGING SITE

Water Column Impacts

Sly (1977) summarized dredging studies on the Great Lakes (with emphasis on Canadian waters) in which significant but short-lived increases in phosphorous, other nutrients, and metals were observed at dredged material removal sites.

In Cleveland Harbor (Lake Erie) only short-term adverse effects on water quality were noted (U.S. Army Corps of Engineers, Buffalo District 1969c). Dissolved oxygen levels in the vicinity of hopper dredging were lowered as much as 25%. However, in the Rouge River at Detroit, the dredging of grossly polluted sediments resulted in significant increases in the immediate area of the dredge of suspended solids, volatile suspended solids, chemical and biochemical oxygen demand, total phosphorous, and iron (U.S. Army Corps of Engineers Buffalo District 1969d). Overflow from the hopper bins caused the most severe pollution. In a test by the Corps of Engineers at a site which contained very fine-grained material in Saginaw Bay (Lake Michigan), it was found that half of the dredged solids washed overboard (International Working Group 1975).

Impacts to the water column (International Working Group 1975) are: (a) creation of turbidity and reduction of light penetration; (b) resuspension of contaminated materials in the water column; (c) dissolved oxygen depletion; (d) release of nutrients and other materials entrapped in the sediments; and (e) creation of floating scum and debris.

Chamberlain (1976) noted that dredging for dock construction at Nanticoke, Ontario, (Lake Erie) increased turbidity which adversely impacted fishes and probably restricted seasonal navigation patterns.

Bottom Impacts

New work dredging has a greater potential for damage to the benthos than maintenance dredging (International Working Group 1975). The change in substrate usually permanently alters the benthic community. Additionally, pools of stagnant water may be created due to "trenching" or overdredging.

A follow-up study of channel modifications of interconnecting waterways of the Great Lakes revealed that dredged navigational channels were nearly devoid of benthic invertebrates. Prop wash, maintenance dredging, and strong

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[1] Due to a lack of available research specific to the Great Lakes and an incomplete survey of reference libraries, information contained in this Appendix should be considered as incomplete and preliminary. Parts III and IV, Coastal Waters and Rivers, should be consulted for additional information that may be applicable to the Great Lakes.

currents apparently kept the inner portions of the channels scoured free of invertebrates (U.S. Fish and Wildlife Service 1977).

Maintenance dredging will of course remove or disrupt benthic organisms and prevent establishment of mature communities (U.S. Army Corps of Engineers, Buffalo District 1976). However, removal of polluted material and increased water circulation as a result of maintenance dredging can sometimes improve benthic communities (International Working Group 1975).

ASSESSMENT OF IMPACTS OF DISPOSAL ALTERNATIVES

Terrestrial Disposal

Terrestrial disposal of either confined or unconfined dredged material must be accomplished with attention to the relationships between sediment characteristics and subsequent land use (International Working Group 1975). Sites must be carefully planned to control drainage and seepage, possible groundwater contamination, effluent quality, and contaminant transfer to the external environment by wildlife vectors. Unconfined disposal of grossly polluted sediments is usually not considered acceptable (International Working Group 1975).

The literature concerning diked disposal areas in the Great Lakes indicates that the effluent quality varies greatly (Sly 1977). The Chicago District of the Corps of Engineers has stated that large amounts of highly polluted material are confined in disposal areas in the district but the sites border water bodies that also are highly polluted (Harrison and Chisholm 1974). In at least one instance in Lake Erie, seepage through the dike did not significantly affect water quality (U.S. Army Corps of Engineers, Buffalo District 1969e).

The length of detention time determines, to a great extent, the quality of the effluent from diked disposal areas. These disposal areas have often been ineffective in preventing the entry of contaminants into adjacent waters (U.S. Army Corps of Engineers, Buffalo District 1969a, 1969b, 1976). Engineering Science, Inc. (1977) found that only 0.4 mg/l of oils returned over the weir to the Cuyahoga River at Cleveland from material that was grossly contaminated with oil and greases (allowable discharge level was 10 mg/l). This finding substantiates other studies which indicate that, given sufficient retention time, oils and greases are not released from disposal areas in significant quantities. A disposal site at Grand Haven, Michigan, had a short retention time (less than 12 hr), the influent contained 39.5 mg/l of oils and greases and the effluent contained 11.5 mg/l, indicating inefficient removal (Hoeppel et al. 1978, Table 8).

High levels of PCBs were also being discharged, after a short detention time, from the Grand Haven site. The influent contained an average of 10.67 mg/l and the effluent contained 2.55 mg/l. Based on a composite of evidence from Grand Haven and six other nationwide land disposal sites, PCBs are apparently associated with suspended solids and are efficiently removed from the effluent when thorough settling occurs. At the Grand Haven site settling was not complete and PCB removal, therefore, was incomplete. In contrast, some of the other sites had good solids retention and consequently very efficient PCB removal. An additional study in Seattle (Hoeppel et al. 1978) showed that better than 99.8% of PCBs can be removed after only a short retention time by the use of flocculants.

Other potential pollutants that were not efficiently removed at the Grand Haven site included DDE and several forms of nitrogen and phosphate. Pollutants that were efficiently removed included DDD, DDT, manganese, zinc, cadmium, copper, nickel, lead, chromium, vanadium, and arsenic. Mercury was not monitored. Apparently, DDE is associated with fine clay particles while DDD and DDT are associated with larger particles and thus are more readily removed by settling (Hoeppel et al. 1978). Studies in Lake Erie and Lake St. Clair have shown mercury to be associated with fine particles (Mudrock 1979). Plants in Lake St. Clair showed limited uptake of mercury. Highest concentrations were found in the roots.

Evidence from Grand Haven and other sites (Hoeppel et al. 1978) indicates that contaminants in freshwater areas behave like contaminants in saline waters. However, settlement may be quicker in salt water due to the flocculation inducement by the salt; also the buffering capacity of salts may render certain contaminants less potent.

Island, Fastland, or Beach Disposal

Dredged material in the Great Lakes is often used to create islands or fastlands that become a part of the land mass, and for beach nourishment. General principles discussed in Part III - Coastal Waters should generally hold true for the Great Lakes and the reader is referred to that section.

Wetland Disposal

References on impacts of disposal on wetlands in the Great Lakes were not found. It is assumed that wetland disposal is rare in the Great Lakes area.

Nearshore Disposal

The greatest concern with disposal of dredged material in the Great Lakes has been the question of impact of aquatic disposal. Both short- and long-term impacts have been areas of concern.

Sly (1977) noted that disposal in shallow waters, which are strongly influenced by winds and waves, causes more resuspension of particles than disposal in deep water. Resuspension of particles will often lead to increased levels of nutrients and potential contaminants in the water column. Also, the shallow nearshore zone is usually more productive and of greater importance for spawning and nursery purposes than the deepwater portions of the Great Lakes.

In a disposal area outside the breakwater of Cleveland Harbor, the post-dump bottom sediments of the disposal area were characterized by increases in the same chemical constituents that were found in the harbor (U.S. Army Corps of Engineers, Buffalo District 1969c). Background levels in areas surrounding the disposal area were also relatively high. Disposal areas in the St. Marys River were characterized by unstable and constantly shifting sediments. Macroinvertebrate numbers were greatly depressed (U.S. Fish and Wildlife Service 1977).

Deepwater Disposal

Traditionally, deepwater disposal of dredged material has been the most frequent disposal method. This was usually economically advantageous over confined or unconfined land disposal or confined shallow-water disposal. However, increasing concern about impacts to the water column and bottom sediments from contaminants has resulted in prohibition of the dumping of "polluted" materials into open waters. The definition of what constitutes polluted materials is difficult and controversial. A prime problem is the lack of information about the mere presence versus the actual impact of contaminants on aquatic organisms.

Several Great Lakes studies indicate that open-water disposal influences the water column for only a few hours because of rapid particle settling and dilution (Fulk et al. 1975, Sly 1977, Sweeney 1978a, Wyeth and Sweeney 1978). With the exception of ammonia, manganese, and zinc, there does not appear to be a significant release of contaminants to the water column during the descent of the dredged material to the bottom. Other studies have indicated that dredged material deposited in deepwater may continue to influence overlying waters for as long as 5 yr, apparently through resuspension (Sweeney et al. 1975, Sly 1977).

Overall, Sly (1977) noted that although dredging and ship turbulence caused local turbidities the impacts were small in comparison to those resulting from wind and wave action. Both Langlois (1941) and Chandler and Weeks (1945) found that turbidity in Lake Erie rose from an average of 40 mg/l to over 200 mg/l following disturbance of the bottom by 64 km/hr winds.

Field studies have indicated that impacts of dredged material disposal to phytoplankton and zooplankton are insignificant (International Working Group 1975, Sly 1977). However, stimulation of algal growth has been demonstrated in the laboratory. Large releases of phosphorous and nitrogen have occurred, at least for a few hours, following disposal (International Working Group 1975).

Disposal of dredged material affects the distribution of fish. Fish may either be attracted to the area of disposal or repelled (International Working Group 1975). Sweeney (1978b) noted a 2- to 30-min absence of fish following disposal. The time of absence varied with species. Turbidity, chemicals of various kinds, changes in substrate, and changes in fish-food organisms--all affected by disposal--influence fish distribution. Sweeney (1978b) noted 100% mortality of fish eggs within 250 m (270 yd) of a disposal site at Ashtabula in Lake Erie.

Dredged material has changed the composition of the benthic communities for short periods but long-term, subtle impacts are unknown. Beneficial impacts can include improvement of fishery habitat, e.g., disposal mounds may be used for spawning areas and polluted bottom sediments may be covered with cleaner materials (International Working Group 1975). In most instances, the dredged sediments will not be of a suitable grain size or free enough of contaminants for the above benefits. Most adverse impacts appear to be due to smothering and change in substrate. The extent and duration of impacts depended upon species composition, quantity and type of materials deposited, and the duration of disposal activity (International Working Group 1975). Recovery generally required a few months but was much longer for gastropods. Sweeney (1978b) noted near recovery in 1 yr, but the community structure was altered. There was an increase in oligochaete abundance along with decreases in many other common groups (e.g., nematodes, chironomids, and isopods). Several pollution tolerant species became abundant within and near the disposal areas.

The ultimate impact of contaminants associated with dredged material disposed in deepwater ecosystems is still unresolved. Tainting of certain benthic organisms by oils, greases, and phenols is known to occur (Sly 1977). Disposal of dredged material in the deep waters of the Great Lakes does not appear to influence water circulation as much as disposal in constricted marine estuaries. Danek et al. (1977) noted buildups of deposited material in mounds of up to 45 cm (18 in) high but a severe storm later eroded much of the new sediments.

Habitat Development

Compared to marine environments, little work has been done with habitat development in the Great Lakes, consequently much of the discussion in this section is untried ideas or random observations rather than documented studies.

Terrestrial development. The reader is referred to Part III - Coastal Waters.

Island development. Colonial nesting sea and wading birds have made good use of dredged material islands in the Great Lakes (Sharf 1978). Natural nesting sites were in short supply.

Another apparent beneficial use for dredged material islands in the Great Lakes is for protecting nearby shore areas from wave action. Islands will protect shallow-water areas and allow the development of marshes or protected fish spawning and nursery areas (personal communication, 4 December 1975, Richard Hoppe, FWS, Green Bay, Wisconsin).

Wetland development. The reader is referred to Parts III and IV - Coastal Waters and Rivers for discussions that may be adapted to the Great Lakes.

Aquatic development. Dredged material has sometimes provided mounds or irregular substrates around which fish concentrate and are utilized for spawning in the Great Lakes (personal communication, 1 December 1975, Thomas Yokum, FWS, Ann Arbor, Michigan). Large portions of the Great Lakes have smooth unvarying bottoms with fine sediments. These areas neither attract and concentrate fish, nor provide spawning areas. The construction of artificial spawning reefs for species such as lake trout and walleye appears to be a possible use of dredged material. However, since most dredged sediments are fine grained, topdressing with some type of coarse material would likely be necessary. Also, the toxicity of dredged material is a major consideration. Relatively clean materials would have to be used.

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KENNETH O. ALLEN AND JOE W. HARDY

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U.S. FISH AND WILDLIFE SERVICE
NASA-SLIDELL COMPUTER COMPLEX
1010 GAUSE BOULEVARD
SLIDELL, LOUISIANA 70458

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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 breif 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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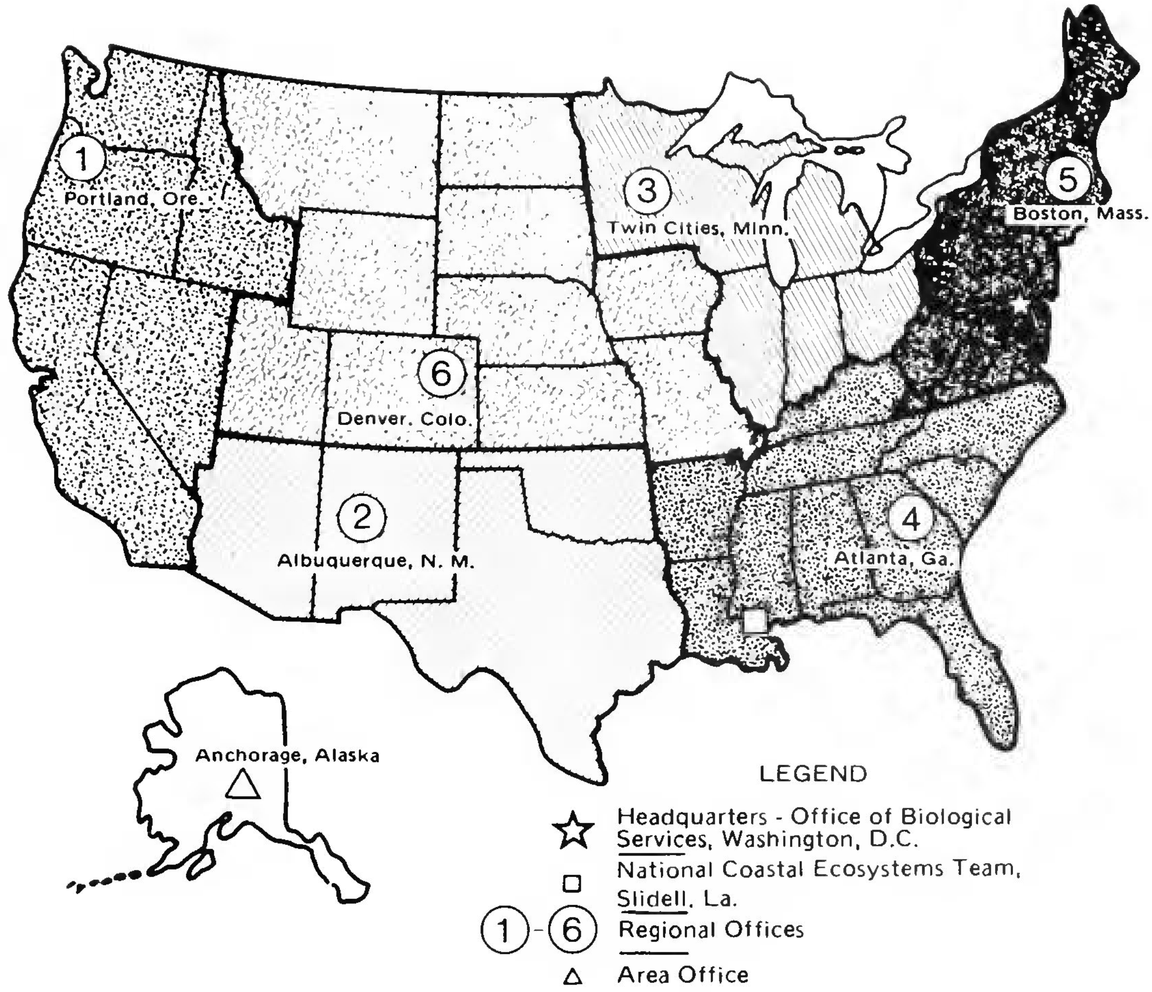

U.S. FISH AND WILDLIFE SERVICE
REGIONAL OFFICES

REGION 1
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U.S. Fish and Wildlife Service
Lloyd Five Hundred Building, Suite 1692
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Portland, Oregon 97232

REGION 2
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 1306
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ALASKA AREA
Regional Director
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, Alaska 99503

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