CSIR REPORT
T/SEA 8613

Earth, Marine and Atmospheric Science and Technology

Aard-, Mariene en Atmosferiese Wetenskap en Tegnologie

CSIR

WNNR

EFFECT OF DREDGING ON ESTUARINE ENVIRONMENTS ALTERNATIVE DISPOSAL SITES AND DREDGING GUIDELINES

by
P Badenhorst

August 1986

EFFECT OF DREDGING ON ESTUARINE ENVIRONMENTS
ALTERNATIVE DISPOSAL SITES AND DREDGING GUIDELINES

by

P Badenhorst

SEDIMENT DYNAMICS DIVISION
COASTAL ENGINEERING AND HYDRAULICS
NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY
COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

CSIR REPORT T/SEA 8613

Stellenbosch, South Africa
August 1986

ABSTRACT

Guidelines for dredging in estuaries have been formulated on the basis of a comprehensive review by Morton (1977) of literature (520 scientific and technical articles) on the physical, chemical and biological effects of dredging and spoil disposal in estuaries and of alternative spoil disposal methods. This report is a final version of a document submitted to the Estuarine and Coastal Research Unit Steering Committee in September 1985.

CONTENTS

CONTENTS (cont.)

1. INTRODUCTION

Morton (1977) presented a comprehensive review of literature on the physical, chemical and biological effects of dredging and spoil disposal in estuaries and of alternative spoil disposal methods. Five hundred and twenty scientific and technical articles on dredging and spoil disposal were screened. The main conclusion on dredging and disposal can be summarized as follows from Morton (1977):

Physical: An important effect is the change in circulation patterns that results when dredged channels and spoil mounds block and reroute tidal currents, induce shoaling or alter flushing rates. Another important effect is the uncontrolled redistribution of sediments eroded from the spoil mound at the disposal site.

Biological: The direct burial of organisms and the destruction of habitats (altering their physical and chemical characteristics) are the two most obvious effects. These effects can, however, be reduced by careful timing of the dredging and placement of the spoil.

Disposal sites: Alternatives to open-water spoil disposal include the use of diked or confined disposal areas, construction of marshes and spoil islands and treatment and inland transport of dredge spoils for landfills. The most promising of these is the construction of marshes and spoil islands (as yet not feasible in practice).

In Chapter 2 a summary of the various effects of dredging on estuarine environments is given. Chapter 3 contains a summary of alternative methods of dredge spoil disposal with conclusions in Chapter 4. Recommended dredging guidelines for each dredging application are given in Chapter 5.

2. DREDGING EFFECTS (Morton, 1977)

When evaluating this literature review it must be borne in mind that in the USA 230 million m^3 of sediment per year is dredged for maintenance purposes from over 16 000 km of waterways and about 1 000 harbours. An additional 60 million m^3 per year is dredged for new projects.

2.1 Physical

The physical effects of dredging and spoil disposal on the estuarine environment can be summarized as follows:

(i) temporary increases in turbidity at both dredge and disposal sites,

(ii) changes in bottom topography with resulting changes in water circulation patterns, and

(iii) changes in the mechanical properties of the sediments at the dredge and disposal sites.

It is very important to note that the relative significance of these effects on a given estuarine system is a function of the ratio of the dredged area to the total bottom area and contained water volume.

The two basic types of dredges are mechanical and hydraulic. The use of mechanical dredges is limited and, generally, hydraulic types are used.

2.1.1 Turbidity

During dredging bottom sediments are mechanically disturbed and resuspended, creating discoloration of the water and reduction of light penetration at the disposal site. A surface turbidity plume is also created. The larger, heavier particles settle rapidly but the finer material is transported away by local currents.

2.1.2 Bottom topography and circulation patterns

Physical modifications in bays or estuaries can disrupt the existing hydrological regime. Tidal currents can be channelled into dredged channels, thus altering the usual transport patterns or can be diverted by physical barriers created by the spoil mounds. Such changes can, for example, cause erosion, change the influx of salt water, change the circulation and cause salinity stratification.

2.1.3 Mechanical properties of sediment

The mechanical properties of the sediments at dredge and disposal sites have seldom been monitored. A decrease of median grain size was observed at one site while at another disposal site there was an increase in median grain size. A decrease in porosity at the spoil site was also observed.

2.1.4 Immediate loss and dispersal of dredge spoil during dredging and disposal

The uncontrolled loss and redeposition of sediments that occur during and after dredging and spoil disposal can create two important problems: refilling of the dredged channel and (if the dredge spoil contains pollutants) contamination of nearby areas.

2.1.5 Factors controlling the long-term fate of dredged materials deposited at unconfined disposal sites

The movement and stability of the spoil is controlled by:

a) the grain size of sediments;
b) the degree of consolidation of the sediments;
c) the bottom current velocities;
d) the degree to which dumped materials penetrate and intermix with existing bottom materials;

e) the biogenic reworking of the sediments by benthic organisms (bioturbation); and

f) the chronic exposure of turbulence (propellors or wave action).

2.2 Chemical

Dredging and disposal are likely to produce changes in the chemistry of the water overlying the dredging and disposal sites for two reasons. Firstly, undisturbed estuarine sediments typically exhibit a gradient from oxidized surface deposits to increasingly reduced sediments in the deeper layers; the deeper, reduced sediments create an oxygen demand when they are exposed to the aerobic environment of the overlying water body and become oxidized. Secondly, it is generally assumed that the chemical constituents associated with the surface sediments are in dynamic equilibrium with the overlying water, whereas those associated with the deeper sediments are not. As the deeper sediments are mixed with water during dredging and disposal, the potential for remobilization of their chemical constituents increases.

Dredging and spoil disposal also produce changes in the chemistry of the sediments at both sites. The deep sediments that remain exposed after dredging may be oxidized and the dredged sediments become physically and chemically altered when they are mixed with water during dredging and disposal. As surface sediments at the disposal site are buried under organically rich dredged spoils, they become anaerobic.

Oxygen depletion and release of growth stimulants or contaminants can have detrimental effects on the biota living in the immediate vicinity of the dredging or disposal sites. To predict these impacts on the local biological communities, one must first identify exactly which chemical changes are likely to occur and then estimate their relative magnitude and importance. Limitations in the present state of knowledge, however, preclude such estimates.

The effects and/or tests for heavy metals, nutrients, organic compounds, inorganic compounds, various gaseous forms, pesticides, etc. are discussed under the headings **Factors influencing the relative availability of contaminants in polluted dredge spoils, Dissolved oxygen, Organic, Nutrients** and **Transfer of contaminants across the sediment-water interface.** No definite guidelines or safety levels are recommended.

2.3 Biological

Estuaries have rich supplies of nutrients that can support dense populations of phytoplankton which, in turn, provide food for zooplankton, larval fishes and benthic organisms. Many aquatic species use these very productive areas as breeding grounds, nursery areas or home territories. Many of these organisms, especially year-round residents, can tolerate wide ranges of variation in depth, salinity, temperature and suspended sediment load. Because estuarine systems are diverse, dynamic and always changing, the interactions of these organisms with their environment are complex and difficult to understand. The physical and chemical effects of dredging and spoil disposal described earlier (for example, resuspension of bottom sediments and release of nutrients, trace elements, hydrocarbons and heavy metals) in turn affect estuarine organisms and their interaction with their environment. Qualitative description, let alone quantitative description, of these impacts is far from complete. Current understanding of these effects is too limited to allow prediction, with any assurance, of whether dredging and disposal will contaminate a man-ended food chain, eliminate a rare and endangered species, or have undesirable, irreversible impacts on a biological community.

2.4 Benthos

Sessile, crawling and burrowing organisms (for example, algae, oysters, lobsters and polychaete worms) which live in or on the bottom sediments and make up the benthic community are commonly monitored because of their intimate contact with the dredged sediments. They are also used as indicator organisms because, being less mobile than fish, they are not likely to escape or selectively avoid affected areas. Furthermore, their relatively long life-spans make them useful as indicators of part perturbations. A third reason for monitoring the benthos is that it provides a crucial link in the detritus-based food chain.

2.4.1 Gross effects

Direct burial by spoils discharged in large quantities within the short time interval of spoil deposition is the most obvious effect on benthic organisms. Another critical effect of dredging and dumping is habitat destruction resulting from change in the physical and chemical character of the bottom sediments, loss of vegetative cover, filling in of spawning grounds or change in circulation patterns at the dredge or disposal site.

2.4.2 Effects of suspended sediment on filter feeders

Although opinions differ it seems as if most marine animals can withstand exposure to high concentrations of suspended solids for short periods. Prolonged or serious exposure to suspended solids do, however, affect the animals and in some cases cause mortalities.

2.4.3 Community response

Various studies are referred to, and the findings can be summarized as follows:

- Small-scale, short-term projects have less impact on benthic communities than large-scale, long-term projects.

- The hydrology of the disposal and dredging sites are important in that a high degree of flushing rapidly dilutes and carries away the suspended solids, thus minimizing the physical and chemical effects on the benthic community.

It must be remembered that natural fluctuations in population size caused by seasonal migration or rapid repopulation by opportunistic species can mask the immediate effects of dredging and dumping on the distribution of benthic organisms.

2.4.4 Animal-sediment relationships

It appears that particle size distribution, organic content and prevailing hydrographic conditions are important in influencing the distribution of benthic organisms.

2.4.5 Indicator species

Benthic organisms are suitable indicator organisms because of their size, relatively long lifespan, limited mobility and widely varying physiological and morphological traits. It should be remembered, however, that when using benthic organisms as biological indicators their presence or absence should not be seen as absolute evidence of a pollution problem.

Primary Production: phytoplankton and rooted plants

Primary production (the amount of carbon fixed by plants during a given period of time over a given area) originates primarily from phytoplankton, benthic algae and rooted plants which ultimately provide the food source for marine organisms. In general, drastic reductions in primary production caused by dredging and dumping are seldom observed.

Zooplankton

Zooplankton includes not only animals that spend their whole lifecycle as plankton but also larval and juvenile forms of benthic organisms and fish that are only temporarily planktonic. It seems likely that some zooplankton populations are sensitive to specific circulation patterns which can be significantly altered by either spoil removal or disposal.

Fish

Care should be taken during dredging and spoil operations to protect breeding grounds and nursery areas. In general, because they can avoid unsuitable areas fish are less likely than benthos to suffer from the effects of dredging and dumping.

Bioconcentration

Dredging and disposal of contaminated sediments can cause the redistribution and remobilization of toxicants adsorbed to the sediments. The danger of this pollution lies in the fact that persistent pesticides are concentrated, cycled and magnified in the food web. This accumulation and storage of toxic elements in the tissues of organisms is called bioconcentration. The reports on the subject are very contradictory because of the complexity of the biological, physical and chemical variables.

Bioturbation

Bioturbation is the physical and chemical impact of the biota on their benthic environment. Many filter-feeding benthic animals (clams, mussels, scallops, barnacles and oysters) cause suspended sediments to be deposited many times faster than they would settle in response to gravity alone. On the other hand certain benthic species (bottom-feeding clams and fish such as mullet) have a destabilizing effect on the bottom sediments.

3. ALTERNATIVE METHODS OF DREDGE SPOIL DISPOSAL (Morton, 1977)

The most commonly used method of handling polluted spoil is by placement in dikes. Other methods include:

- filling in of marsh areas (no longer considered and not to be recommended in view of the value of marsh areas)
- the use of dredged materials to create new marsh areas and spoil islands
- using dredge spoil inland for reconditioning or reclaiming land
- the burial of polluted spoil beneath a layer of clean sediments.
- deep ocean disposal (not discussed in the review).

3.1 Diked Disposal of Dredge Spoils

Spoil placement in diked enclosures, although expensive, has been the preferred alternative means for disposing of polluted spoils. It is, however, important to note that the dikes must be properly designed and built in order to prevent dike failure.

3.2 Dewatering Dredge Spoils

One likely approach to reduce the volume of dredge spoils is to improve spoil dewatering techniques. Dewatering the spoil not only reduces the volume but also improves the engineering properties, making it more acceptable as landfill. Placing spoil in layers and allowing for evaporation seems to be one of the most effective methods.

3.3 Sand and Gravel Production

The method used for separating sand and gravel from spoils to reduce the volume and create a marketable product depends on the characteristics of the materials dredged, the dredge site and the total quantity of material involved.

3.4 Creation of Artificial Habitat

The construction of artificial habitats such as spoil islands and new marsh areas is one of the more feasible alternatives to open-water spoil disposal. Johnson and McGuinness (1975) prepared comprehensive guidelines for the placement of material.

3.5 Agriculture Enhancement

The use of dredge spoil to increase the productivity of lands only marginally suitable for agriculture does not seem to be very successful. It is virtually untried in the USA and because of various constraints such as variation in soil type and spoil characteristics the extrapolation of research results to other areas is not advisable.

3.6 Rehabilitation of Strip-mined Areas

This is an interesting but less promising alternative because few strip-mines are located near major dredging operations.

3.7 Construction Materials

Dredge spoil has been used for brick making and to produce ceramic materials. The principle drawback to this alternative is that significant proportions of dredge spoil probably will not be suitable for this purpose or that it is too expensive.

3.8 Burial with "Clean" Materials

The successful burial of polluted dredge spoil depends on:

1) minimizing suspension and dispersion of polluted material during emplacement;
2) minimizing the surface area of the spoil;
3) maximizing the area covered by a limited volume of covering material;

4) preventing resuspension by waves and tides;
5) limiting upward diffusion of interstitial water;
6) preventing exposure of benthic animals to polluted materials.

It is important to identify the benthic organisms - especially burrowing types - likely to recolonize the spoil mound to determine the optimum depth of clean sediments to be used.

4. CONCLUSION

Sediments dredged from areas near large cities are often polluted with heavy metals, pesticides, organics and petroleum wastes.

The two most important physical impacts of dredging and unconfined, open-water spoil disposal are: (1) the changes in bottom topography that alter circulation patterns (channel tidal currents), induce shoaling, reduce flushing rates; and (2) the filling in of a dredged channel or a nearby fish spawning ground, clam bed or oyster reef that could result from the long-term erosion of the spoil mound and redistribution of the eroded sediments.

A less important physical impact is the reduction in light penetration caused by the surface turbidity plumes that occur during dredging and disposal. Turbidity plumes, however, usually disappear within a few hours after dredging and disposal have been completed.

The most critical, yet least understood, chemical effect of dredging and spoil disposal is the release of contaminants from polluted dredge spoils. This release may occur immediately as the deep, reduced sediments are mixed with water overlying the dredge and disposal sites, or it may occur gradually over a long period after the spoil is in place at the disposal site.

Direct burial and habitat destruction (for example, a change in the physical and chemical character of the bottom sediments) which are the two most obvious effects of dredging and spoil deposition on benthic communities, can be minimized by careful timing of the dredging and placement of the spoils. Exposure to toxic contaminants adsorbed to sediments cause a variety of physiological and behavioral disorders in estuarine biota. But understanding of how various organisms are affected by different doses of a contaminant is limited because of the complexity of the processes controlling the remobilization and uptake of the various contaminants and because of the variability in response between species and between different life stages of the same species.

5. DREDGING GUIDELINES

From Morton (1977) it is clear that dredging and dredge spoil disposal can have physical, chemical and biological effects on the environment in which these activities are taking place. It is, therefore, recommended that for each dredging application the following be investigated:

1) The reason for dredging and the scale of the operation, for example,
   a) sandmining
   b) channels for boating or marinas
   c) removal of excess sediment
   d) reinstating open water areas.

2) Method of spoil disposal, for example,
   a) removal for building purposes
   b) reinstating beaches
   c) dumping
   d) pumping

3) The physical effects of (1) and (2), for example,
   a) change in flow patterns
   b) change in tidal prism
   c) change in estuary mouth dynamics
   d) change in supply of sediment to beaches.

4) The biological effects of (1) and (2), for example,
   a) area of habitat destroyed
   b) rate of recolonization
   c) expected changes in habitat.

5) The chemical effects of (1) and (2), for example,
   a) organic content of sediments
   b) heavy mineral content of sediments
   c) toxicant levels in subsoils.

From the above investigations conclusions on the effects of the dredging and spoil disposal can then be made with recommendations of conditions under which a dredging operation may or may not be approved.

REFERENCES

JOHNSON, L.E. and McGUINNESS, W.V. Jr (1975). Guidelines for material placement in marsh creation. US Army Eng. Waterw. Exp. Stn., Vicksburg, Miss., DMRP (Dredged Materi. Res. Program), Contract Rep. D-75-2. 189 pp.

MORTON, J.W. (1977). Ecological effect of dredging and dredge spoil disposal: a literature review. US Fisheries and Wildlife Service, Technical Paper 94.