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The Impact of Dredging on Coastal Environments

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Abstract: Dredging is the act of digging out and removing material from underwater by means of a machine equipped with a continuous revolving chain of buckets, a scoop, or a suction device. Dredging and the disposal of dredged materials have the potential to cause physical and biological damage, particularly when removed sediments are contaminated with toxic substances. This study has been conducted to assess the environmental effects of dredging and dredged material disposal and to discuss improved dredging techniques friendlier to the environment using dredging data during the construction and the maintenance works at Elsukhna Port Egypt from 1999 till 2006. Environmental concerns related to dredging specifically center on elevated concentrations of selected trace elements such as cadmium, mercury, and lead as well as phosphate, nitrate, ammonia, oil, and pathogenic micro-organisms. Both mechanical and hydraulic dredging techniques are used, which introduce significant quantities of sediment into the water column immediately adjacent to the operating dredge. For mechanical operations in areas of moderately fine-grained cohesive sediments, concentrations of suspended materials adjacent to the dredge have been observed to exceed background levels by more than two orders of magnitude. Similar variations have been observed adjacent to an operating cutter head dredge with concentrations varying as a function of the size and relative production of the dredge, while hopper dredge overflows appear to have the potential of producing the maximum perturbation of suspended material. Dredging also affects channel depth which alters local circulation and sediment transport. Changes in mixing and gravity circulation can affect the distribution of dissolved oxygen and other water-quality parameters, and the relationships between changes in channel geometry and changes in circulation and channel shoaling have been detailed in a variety of studies. The studies indicate that while modifications in channel configuration have the potential to alter local circulation characteristics, the physical effects can be predicted with reasonable accuracy using appropriate hydraulic and numerical models. With the increasing incidents of sediment contamination by toxic compounds, a variety of advanced dredging systems has been developed. Such systems have the potential to effect significant reductions in the turbidity associated with dredging while providing increased removal efficiency relative to the more conventional systems. From this study, it was concluded that from an environmental standpoint, the primary difficulties associated with procedural and institutional matters are the lack of responsiveness to the information about environmental effects regarding dredging and the lack of assessment of the implications for present criteria. In the case of dredging and dredged material disposal, it appears that far more is known about environmental effects and probable causes than is incorporated in regulatory criteria and environmental practices.

Key words: Dredging, dredged material disposal, sediments, contaminated toxic substances, hydraulic/mechanical dredging operations, cutter head dredge, hopper dredge.

INTRODUCTION

Dredging and dredged material disposal can biologically and physically harm the environment, particularly when dredged sediments are contaminated with toxic substances. A dredged channel causes changes in a tidal area’s geometry, affecting local circulation and other flow patterns. Moreover, dredging and disposal activities directly disrupt bottom-dwelling communities and agitate potentially toxic sediments from the seafloor, dispersing contaminants. Thus, research has sought to increase awareness of the physical, biological, and public health implications of dredging and the disposal of dredged materials.

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Sediment deposits found within most ports can be divided into two primary classes: deep sediments, typically representing the major fraction forming the sediment column's lower layer; and surficial sediments, a more mobile fraction found at or near the surface of the sediment column and typical of incoming sediments. The former have been in place for a longer period of time as the latter have been caused by the relatively recent industrial age. Surficial sediments are of primary concern for most dredging projects because their deposition rate dictates the extent and frequency of maintenance dredging. The frequently elevated levels of contaminants in these sediments (as indicated by concentrations of oil and grease, trace elements, and synthetic compounds) leads to concerns about potential short-term and long-term effects associated with the mobilization, dispersal, and uptake of the contaminants from the re-suspension by dredging as well as from the disposal of dredged sediments. In contrast, deeper sediments are infrequently disturbed or displaced; they typically display a chemical composition that differs slightly from the earth's average crustal materials in the drainage basin and exhibit little if any evidence of activities.

The combination of factors affecting sediment transport within coastal port facilities favors the establishment of a controlling channel depth representing a condition of equilibrium between flow-associated transport energy and sediment supply. Dredging to increase water depth beyond the controlling values disturbs this equilibrium by modifying the flow regime and generally causes acceleration in deposition rates to force the system's return to equilibrium. Measurements were taken throughout the dredging works of the New Port of Elsukhna from 1999 till 2001 and during the maintenance dredging works from 2003 till 2006 to establish the desired depth followed by a continuing cycle of maintenance dredging to maintain channel depth and to counter accelerating deposition as the system attempts to regain equilibrium.

Dredging and dredged material disposal concerns center on elevated trace element concentrations (cadmium, mercury, lead) as well as synthetic compounds such as polychlorinated biphenyls (PCBs) and polynuclear aromatic hydrocarbons (PAHs).

Other concerns include phosphate, nitrate, ammonia, oil, pathogenic micro-organisms, and at times the sediment itself.

Techniques and Methodology:

Field data measurements were carried out during the dredging works at the New Port at Elsukhna and during the maintenance works which included:

1. Analyze dredging location and quantities to be dredged, considering future needs.
2. Evaluate dredge plant requirements, considering compatibility of the dredge plant with potential disposal alternatives.
3. Determine the physical and chemical characteristics of the sediments.
4. Evaluate potential disposal alternatives.
5. Identify pertinent social, environmental and institutional factors.

Analysis of the bulk concentration of constituents was used to conduct a chemical inventory of a sediment sample. The results of the analysis were expressed on a dry weight basis (as milligrams of a chemical constituent per kilogram of dry sediment) or parts per million (ppm) by dry weight.

It should be emphasized that bulk sediment analysis is not directly correlatable with water quality or environmental effects. The bulk analysis reflects the total fraction of a chemical in the sample to include those fractious that are biologically unavailable to organisms or not easily released to water in dissolved form.

With the increasing incidents of sediment contamination by toxic compounds, a variety of advanced dredging systems has been developed. Mechanical systems employing closed buckets and hydraulic systems using skirted horizontal augers in shallow water and pneumatic pumps in deeper areas have been used in combination with a variety of electronic microprocessor-based monitoring arrays to dredge highly contaminated materials. Such systems have the potential to effect significant reductions in the turbidity associated with dredging while providing increased removal efficiency relative to the more conventional systems. Although such systems are finding general application in selected areas, their use is not widespread, and the majority of available dredges are "classic" or well-established systems. This situation appears to be the result of the conservative character of the dredging industry, uncertainty about the future needs for advanced dredging techniques and availability of the required funding, and the acceptability of conventional dredges for most projects.

The management philosophy governing dredged material disposal must emphasize the selection of sites and procedures to minimize sediment dispersion discharge at offshore sites and reduce toxic particle leakage from coastal containment sites. A containment policy could minimize the area in which adverse effects might occur, complement evaluations of the adverse effects, and possibly permit future hazardous material removal if the effects proved unacceptable.

Discussion and Analysis:

Many studies have been conducted to assess the environmental effects of dredging and dredged material disposal.

A review of the literature resulting from previous studies provides reasonably clear indications of the short-term effects of dredging and disposal activities but often raises as many new questions about long-term effects. The data suggest that it is possible, using existing equipment and procedures, to design and execute a dredging project in which the short-term effects are both minimal and acceptable. Specification of the associated long-term effects is more difficult. This body of information provides a useful first-order picture of the range of environmental effects associated with dredging and disposal processes.

It should be noted that both mechanical and hydraulic dredging operations introduce significant quantities of sediment into the water column immediately adjacent to the operating dredge. For mechanical operations in areas of moderately fine-grained cohesive sediments, concentrations of suspended materials adjacent to the dredge have been observed to exceed background levels by more than two orders of magnitude, as shown in Figure (1) below.

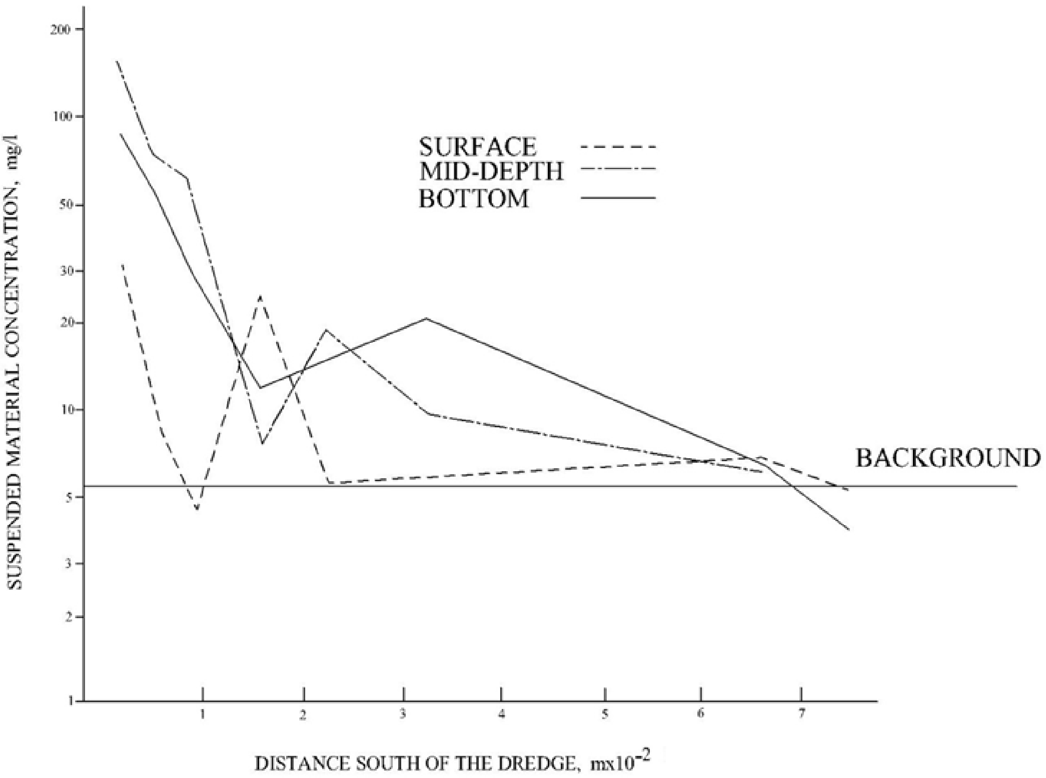

Fig. 1: Suspended material concentrations during Elsukhna Port dredging operations

Similar variations have been observed adjacent to an operating cutter head dredge with concentrations varying as a function of the size and relative production of the dredge as shown in Figure (2) below.

Hopper dredge overflows appear to have the potential of producing the maximum interruption of suspended material. Observations at several locations indicate concentrations adjacent to the overflow port in excess of 100 gm/l, or more than five orders of magnitude above the background, as shown in Figure (3) below.

The materials suspended by the operating dredge are distributed downstream by the local transport field and display concentrations varying as a function of mass-settling properties, free-stream velocity, and associated turbulent diffusion characteristics. Observations indicate that for representative estuarine conditions, this combination of factors favors rapid deposition of the re-suspended materials. The sediment plume represents a relative near-field feature displaying characteristic long-stream spatial scales of less than 2000 meters. Examples of this can be seen in Figures (4) and (5) below.

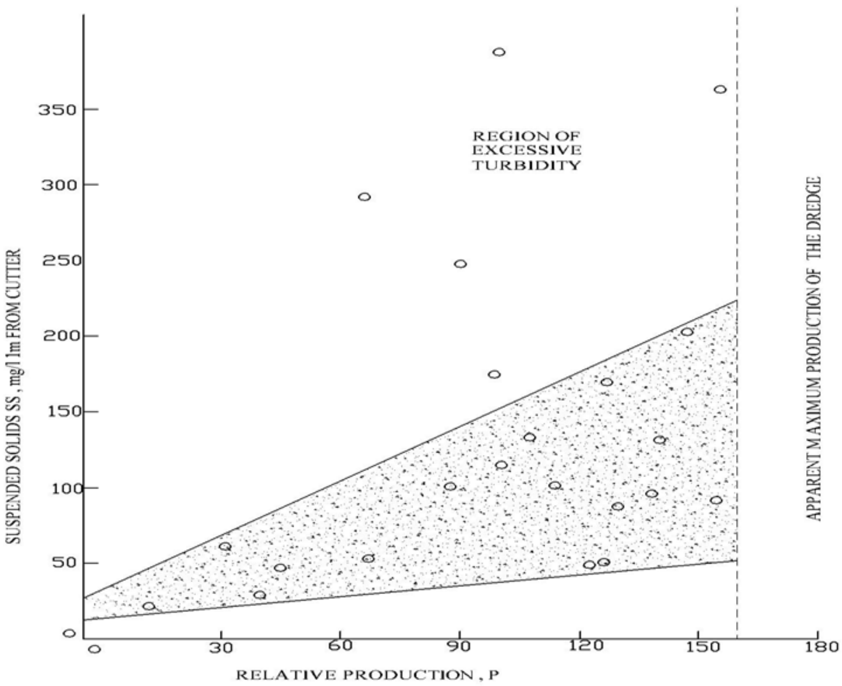

Fig. 2: Relationship between the concentration of suspended solids 1m from the cutter and the relative production of a 61cm cutter head dredge

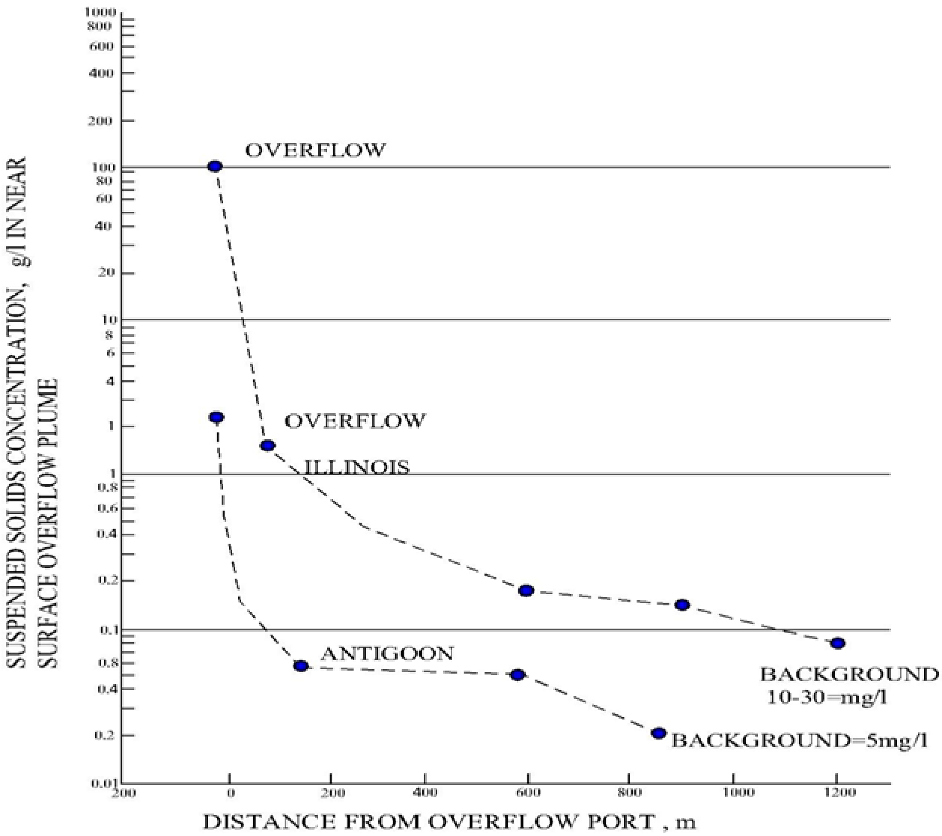

Fig. 3: Relationship between concentration of suspended solids in the Near-Surface overflow plume and the distance (in m) downstream for the two dredges in operation

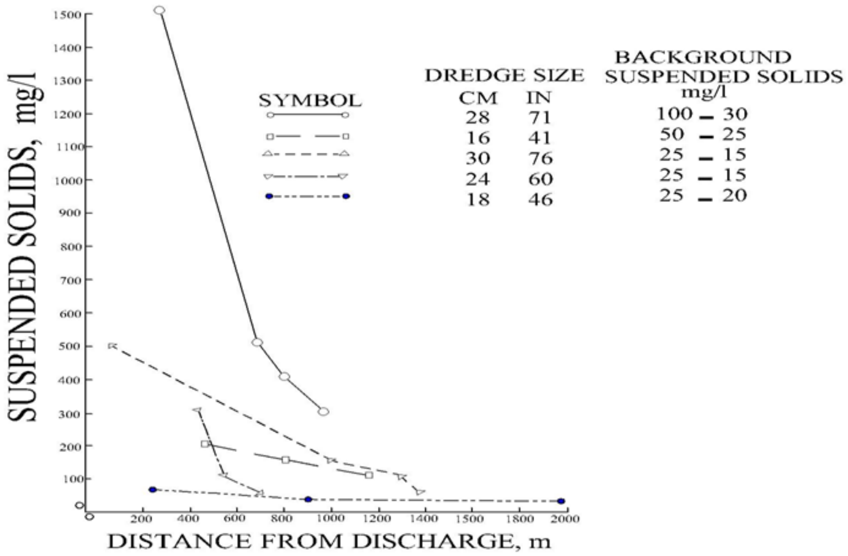

Fig. 4: Relationship between suspended solids concentration along the plume centerline and distance down current from several open-water pipeline disposal operations at Elsukhna Port

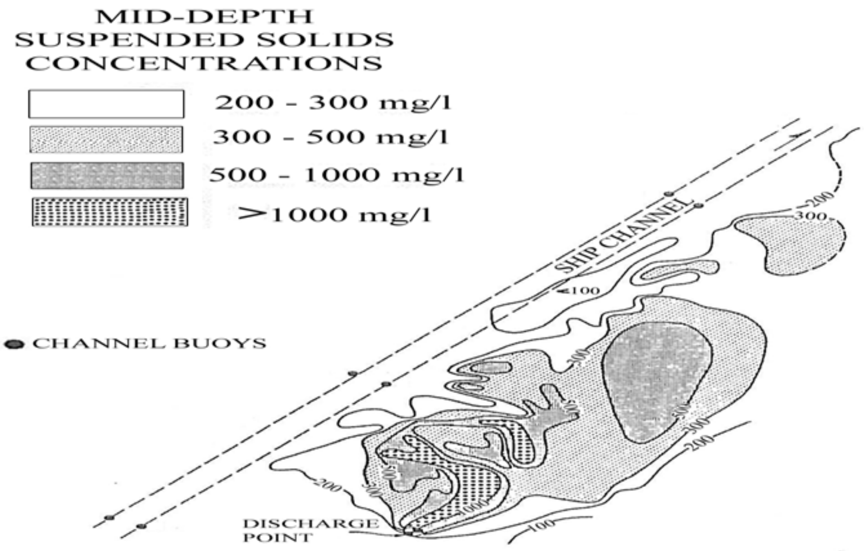

Fig. 5: Mid-depth turbidity plume generated by a 71cm pipeline disposal operation in Elsukhna Port. Current is generally toward Northwest

It can also be noticed that in addition to the solid particulate phase, the operating dredge also directly and indirectly alters the concentrations of dissolved nutrients and selected trace elements within the waters in the immediate vicinity of the dredge. Studies of these constituents indicate elevated concentrations above the background within an area representing approximately thirty percent of the total suspended material plume. Over the remaining area of the plume, dilution and particle favor a return to background levels.

In addition to the variety of relatively short-term effects, dredging operations may induce a number of longer-term effects associated primarily with modifications in local circulation and sediment transport. These effects are most likely to be significant within estuarine areas, where altered contours can increase the degree of salinity intrusion and alter vertical mixing, leading to a modification in the density structure and associated gravitational circulation and causing a re-positioning of the areas of maximum sediment accumulation.

There is no doubt that undesirable effects can accompany salinity intrusion in specific conditions. These are associated primarily with new construction dredging and not with routine maintenance dredging. As a result, plans proposing major alterations in depth should include consideration of the associated modification in salinity intrusion in sufficient detail to permit resolution of changes induced by dredging.

Previous studies show that the rates at which these alterations proceed vary substantially from region to region: times for re-establishment of a stable community range from one and a half to twelve years. In some areas, recovery times are long compared to dredging intervals, resulting in a continuing state of instability within the benthic community. The overall result of these variations for estuarine productivity has not been demonstrated and appears negligible in most cases, owing to the small areas affected. For large new construction dredging projects, the potential for such changes should be carefully assessed.

The best strategy for the disposal of contaminated dredged material is one that contains the particles, confines the contaminants to the particles, and isolates the deposit and associated contaminants from plants and animals or other. These conditions can perhaps be approached most closely by burial beneath the seafloor under a cap of clean sediment. All the major elements of a subaqueous burial operation have been demonstrated in the field, including the intentional construction of a compact deposit and the successful capping of fine-grained dredged sediment under a sand cap. Indeed, a small operation to bury contaminated dredged mud in a submarine pit under a sand cap has been done successfully. Available field studies and continuing laboratory tests indicate that the caps are apparently effective in containing contaminants. Although the limiting criteria for a successful burial operation are not well known, a successful large-scale operation could be carried out as long as the conditions, materials, and techniques are not significantly different from those of the capping operations that have already been completed. Before the burial operations could be routinely used in a wide range of conditions and materials, however, generally applicable criteria need to be developed concerning, for example, the spread of dredged sediments along the seafloor during the discharge process, the geotechnical conditions that allow capping, and the migration mechanisms of specific contaminants.

The placement of dredged materials in open-water disposal sites has the potential to induce a variety of short-term, acute, and longer-term, chronic environmental effects. The short-term effects are confined to the period of disposal and result primarily from direct burial of marine organisms or their exposure to increased concentrations of suspended materials, trace elements and other contaminants, and nutrients. The majority of these effects can be reduced or eliminated by proper site selection and project timing. Studies of longer-term effects have considered rates of re-colonization and the character of the subsequent biological community, variations in contaminant body burdens within these organisms, reproductive success, and a variety of sub-lethal but persistent effects such as alterations in genetic structure. This latter set of effects is by far the most difficult to assess and consequently is the least well-known. As in the case of dredging-induced re-suspension, a number of field studies have shown that the open-water disposal of dredged materials by hydraulic pipeline as shown in Figure (6) below or hopper barge produces increases in suspended-material concentrations that are short-lived and that the primary effects of these short-lived increases are confined to the immediate vicinity of the discharge point. During hydraulic placement of materials by an outfall pipe, suspended-material concentrations vary as a function of mean grain size and production rate with values decreasing rapidly with distance downstream. Typically, the suspended material concentrations return to the background within approximately 2000 meters of the point of discharge [see Figures (1) and (3)] and within a few hours after the discharge operation ends.

The discharge of materials from a hopper creates a descending jet of sediment with a trailing wake of entrained waters and suspended particulates, as seen in Figure (7a and 7b) below.

The water-column distributions of these latter materials will vary as a function of the sediment mass characteristics, particularly the degree of cohesion. On impact with the bottom, a fraction of the descending mass will be redirected upwards, and an additional volume of sediment will be introduced into suspension from disturbance of the bottom. The energies associated with the combination of descending and ascending sediments slowly dissipate, and the cloud of materials settles toward the sediment-water interface. In water depths of approximately twenty to fifty meters, this process typically results in a well-defined pile of sediment having a conical core and displaying symmetrical axial dimensions equal to approximately thirty percent of the water depth. Investigations have shown that the distributions of suspended sediments resulting from both hydraulic discharge and barged disposal can be predicted reasonably well by analytical models.

Conclusions:

From an environmental standpoint, the primary difficulties associated with procedural and institutional matters are:

1) The lack of responsiveness to the information about environmental effects regarding dredging and
2) The lack of assessment of the implications for present criteria. In the case of dredging and dredged material disposal, it appears that far more is known about environmental effects and probable causes than is incorporated in regulatory criteria and environmental practices. As a result of this study, the following conclusions can also be drawn:

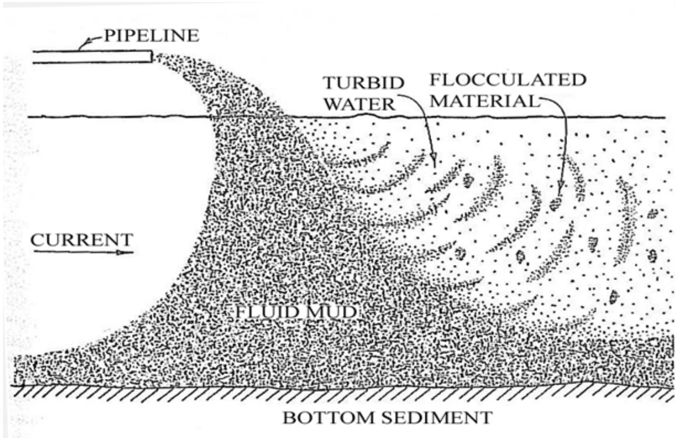

Fig. 6: Schematic of a typical pipeline discharge

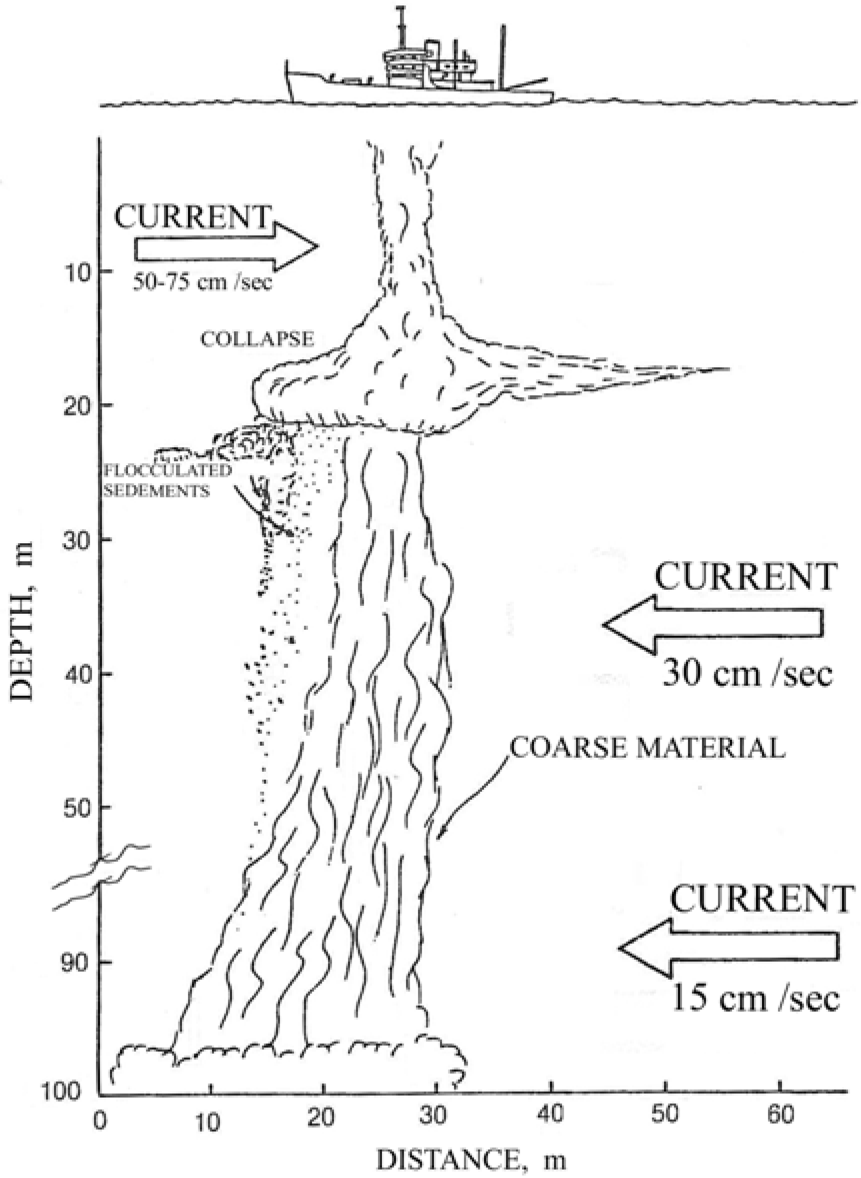

Fig. 7a: Characteristics of the descending mass of sediment discharge from a hopper dredge

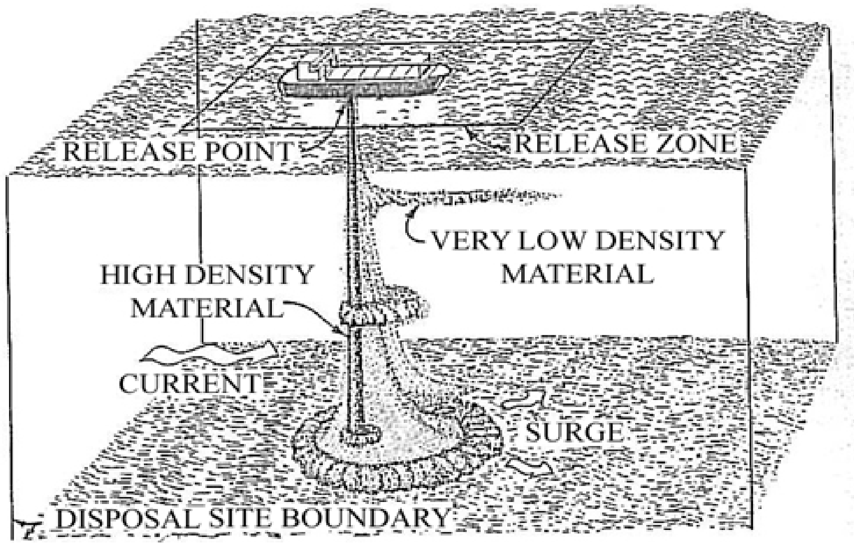

Fig. 7b: Bottom dump disposal of dredged material from a hopper dredge

- Streamlining the regulatory process has the potential to improve not only port management but also the incorporation of scientific results in environmental criteria.
- Port dredging and disposal operations have the potential to induce a variety of short-term and long-term environmental effects and the majority of these effects can be predicted.
- Even within the category of unknown effects, sufficient data exist to permit definition of the potential range of effects that might occur in extreme conditions and to select management strategies that minimize the probability of adverse effects.
- Overall, the effects associated with a proposed dredging project can be reasonably well-defined and controlled.
- Major concerns remain regarding the disposal of contaminated sediments containing moderate to high concentrations of toxic materials.
- Since contaminants constitute a relatively small percentage of the materials removed during maintenance of existing berths, channels, and maneuvering areas, and an even smaller percentage of the sediments associated with new construction dredging, their presence should not represent a major impediment to future port management or development plans if dredging and disposal methods can be matched to their location, type, and amount.
- Increasing salinity intrusion by channel deepening may lead to encroachment of salt into local supplies of groundwater.
- A significant increase in salinity above pre-project levels and an associated increase in sedimentation rates, particularly of the finer-grained materials, will favor a permanent modification in the composition of the benthic community.

REFERENCES

Brannon, J.M., R.E. Hoeppel and D. Gunnison, 1984. "Efficiency of Capping Contaminated Dredged Material," Dredging and Dredged Material Disposal, R.L. Montgomery and J.W. Leach, eds. (New York: American Society of Civil Engineers), 2: 664-673.

Herbich, J.B. and S.B. Brahme, 1983. "Literature Review and Technical Evaluation of Sediment Re-suspension During Dredging," Report No. COE-266, Texas A&M Research Foundation, College Station, Texas.

Openheimer, C.H., 1984. "Environmental Effects of Dredged Material," Commissioned paper for Committee on national Dredging Issues, February 1984.

SDC Final Report, 2005. North Elsukhna Port, RSPA.

Sequeiros, O., Y. Nino and M. Garcia, 2007. "Erosion of Finite Thickness Sediment Beds by Single and Multiple Circular Jets." Journal of Hydraulic Engineering, 13(5): 495-507.

Work, P., F. Fehrenbacher and G. Voulgaris, 2004. "Near-shore Impacts of Dredging for Beach Nourishment." Journal of Waterway, Port, Coastal, and Ocean Engineering, ASCE, 130(6): 303-311.