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ENVIRONMENTAL EFFECTS OF DREDGING OPERATIONS:

A LITERATURE REVIEW

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for:

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ABSTRACT

Scientific publications in the Canadian and U.S. Literature to 1974, dealing with biological effects from chemical contamination of water and sediment by dredging, are reviewed. Environmental effects from changed bottom contours are not covered.

RESUME

Les publications scientifiques du Canada et de les Etat Unies jusque'en 1974, concernant les effects biologiques de la contamination chemique de le'eau et du sediment par une drague, sont discutées. Les effects environmentales par le changement du contour des rivieres ne sont pas discutées.

LITERATURE REVIEW ON THE EFFECTS OF DREDGING

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INTRODUCTION:

This report has been prepared as one segment of the Environmental Protection Service input into assessment studies of the proposed Vancouver International Airport expansion. Its objective was to review the literature available concerning the effects of dredging on the aquatic environment. The review was completed in April, 1974. The information was used to design specific studies of the proposed dredging activities under review; however, because of the general usefulness of the information in this paper, it has been reproduced separately.

The information in this report has been divided into several categories. With respect to full-scale dredging operations, publications dealing only with the physical-chemical aspects of water quality have been distinquished from those that are concerned primarily with biological parameters. Articles dealing with both aspects are usually discussed under the topic which the author emphasizes the most; however, some of the more important articles are discussed under both headings. A third heading reviews the results of laboratory studies related to the dredging. Of particular significance in the dredging literature are two reports: the Mobile Bay Study, and the U.S. Army Corps of Engineers Study. Because of their comprehensive nature and their relevance to this work, they are presented under separate headings.

HYDRAULIC DREDGING TECHNIQUES

Dredging is of major importance to the economy and commerce of most industrial ports. As population, industrial development and world trade have increased tremendously in the past decade, so has the necessity for maintaining artificial harbours and ship channels. In the Great Lakes, about eleven million cubic yards of sediment are dredged each year in 115 harbours (U.S. Corps of Engineers, 1969). In British Columbia, the Fraser River is extensively used for navigation and maintenance of the channels necessitates the annual removal of about 3 million cubic yards of sediments by dredging.

In addition to the construction and maintenance of navigational channels and harbours, dredging is used extensively in landfill operations. Such programs permit the creation of "prime" land which coupled with maintenance dredging programs, provide a convenient means of spoil disposal.

Dredging is also conducted to obtain economically valuable materials and these programs are also often coupled with maintenance dredging programs. For instance, in British Columbia, a large percentage of the sediments obtained from the Fraser River are clean sands. Those sediments are pumped ashore and utilized in the preparation of concrete and cement. Also, buried shell, an almost pure source of calcium carbonate, is dredged from estuaries along the Gulf of Mexico.

The most economical means of conducting large land-fill operations is to use a hydraulic pipeline dredge. A hydraulic pipeline dredge, commonly called a pipeline dredge, consists of a large centrifugal pump mounted on a specially designed barge. Bottom materials are brought up to the pump through a large suction pipe and are pumped from the dredge to the disposal area through a pipeline. Hydraulic dredging is described in detail by O'Neal and Sceva (1971) and their description is condensed below.

A sketch of a pipeline dredge is shown in Figure (1). The suction pipe is lowered to the bottom on a large hinged ladder that extends forward from the front, or bow, of the barge. The dredging depth is controlled by cables than can raise or lower the ladder. The bottom of the suction pipe is generally equipped with a revolving cutter-head (see Figure 2) that breaks up the bottom materials so that they can be drawn into the suction pipe. The cutter-head is turned by a shaft that extends down the ladder from a power source on the barge. On some dredges, the cutter-head is replaced by a water jet that breaks up or loosens the bottom sediments.

The dredge pump is usually a large-capacity, single-stage centrifugal type that has sufficient clearance to pass anything that can move through the openings in the cutter-head and enter the suction pipe. The pipeline, extending from the dredge to the shore or to an area of water disposal, floats on pontoons. To move coarse material through the pipe, a fluid velocity of at least 12 feet per second (fps) is necessary. Consequently, the larger the discharge pipe, the greater the pump capacity required. The fluid volume moving through a 24-inch pipeline at 12 fps is about 17,000 gallons per minute (gpm) or 37.5 cubic feet per second (cfs); with a 28-inch pipeline the volume is 23,000 gpm or 51 cfs. The pipeline can reach several throusand feet from the dredge and can be extended for greater distances by using booster pumps to overcome friction head losses.

During the dredging operation, the dredge is held in position by anchors, swing lines, and spuds. Spuds are long, heavy timbers that are hung from masts near each corner of the stern of the dredge. They pass through openings in the vessel and can be raised or lowered independently. When dropped alternately, they penetrate into the bottom sediments, and serve as a pivot for the dredge.

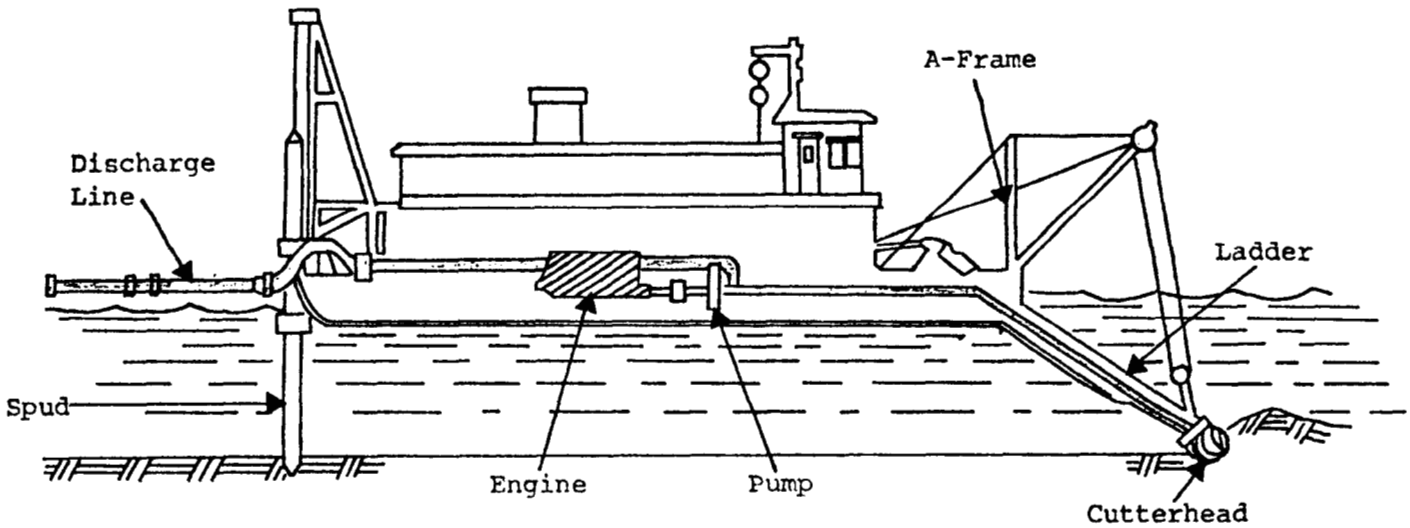
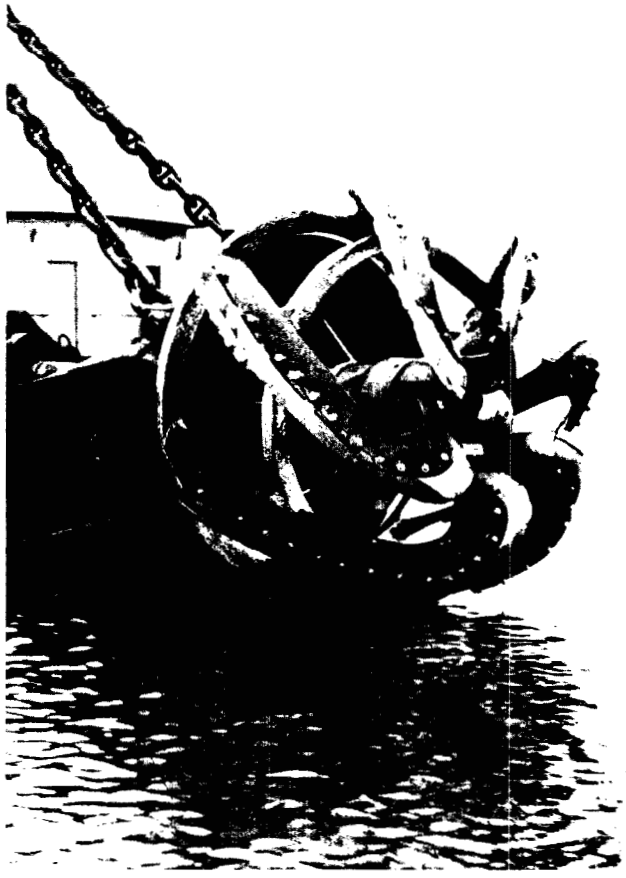


FIGURE 1 SKETCH OF HYDRAULIC PIPELINE DREDGE



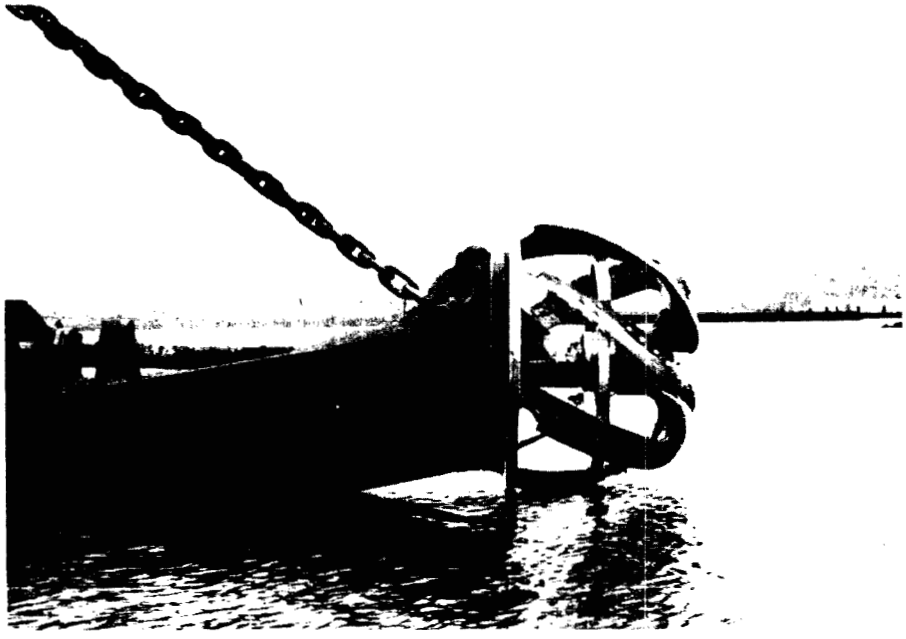


FIGURE 2 PHOTOGRAPHS OF PIPELINE DREDGE CUTTERHEADS

Pipeline dredges are measured by the diameter of the suction pipe ranging from small 4-inch sand pumpers to large 36-inch dredges. They are generally towed to the dredging site. The pipeline is assembled and survey markers are established to orient the dredge. When in position, the spuds are dropped, and swing lines and anchors are put out. The anchors are on each side of the dredge; swing lines from these anchors can be tightened or loosened so as to swing the bow or suction end of the dredge back and forth in a small arc. During dredging, only one spud is in place at a time. This permits the dredge to move forward as it swings back and forth by "walking" from one spud to the other. When ready, the pump and cutter-head are started and the ladder lowered to the desired depth. Bottom sediments and water are pumped through the pipeline in slurry form (approximately 15 percent solids) to the disposal area. Dredging can be an almost continuous operation except for occasional changes in anchor positions and additions of sections to the pipeline, however it is customary practice to break the pipeline or move the dredge from a navigation channel to permit passage of a vessel.

The chief advantage of a pipeline dredge is the large volume of material that can be moved in a short period of time. Other advantages include the ease of on-shore spoil disposal, the simultaneous dredging and disposal operation, and the flexibility to perform a variety of dredging operations. Other dredging techniques such as those using buckets or draglines are not as efficient for moving large quantities of material.

Pipeline dredges are presently used in the Fraser River, British Columbia, for maintaining navigation channels. The sediments are pumped ashore and utilized by the cement industry. In these on-shore disposal programs the dredging spoil is contained in a dyked area. In this manner the inital inflow receives some retention before the waste water overflows back into the river. As the dyked area becomes filled with material, the retention

time in the dyked area becomes less and the concentration of suspended material discharged becomes greater. To prevent erosion of the dyke from overflow, large diameter pipes extend through the dyke to serve as a spillway.

PHYSICAL AND CHEMICAL EFFECTS

A large majority of the available literature related to dredging operations deals with changes in chemical and physical water quality during and subsequent to the disposal of dredged material (spoil). These studies have arisen because the spoil is often obtained from polluted harbours and is then dumped into an open water dumping ground. Thus, the thrust of many reports is related to the impact contaminated sediment may have to the area receiving the spoil.

In this regard, extensive studies have been conducted in the vicinity of the ocean dumping ground off New York (Anonymous, 1970). Separate bottom areas have been designated as dumping sites for municipal sewage sludges and industrial wastes, and for the dredge spoils. These dumping grounds have been used for many years. Data showed dissolved oxygen depressions in the bottom water above the spoil depsoits of 2 to 3 mg/l below bottom DO values in uncontaminated areas. The organic content of the sediments was high, with values to 11.5 percent on a dry weight basis. Significant levels of heavy metals and pesticides were found, and the sediments had a distinctive petrochemical odour.

The effect of resuspension of sediments on dissolved oxygen was investigated in Arthur Kill, New Jersey (Brown & Clark, 1968). Arthur Kill is a long, narrow tidal channel which separates Staten Island from mainland New Jersey. The area is heavily industrialized and numerous domestic and industrial wastes are discharged into the Kill. The bottom material generally consists

of a black, soft, oily silt which smells of chemicals, oils and hydrogen sulfide. Periodically, dredging operations are conducted to maintain the navigation channel. The material is excavated with a clam shell bucket and loaded into a hopper barge for ocean disposal. During two routine surveillance surveys when dredging was in progress, discoloured water and depressed oxygen levels were observed. These reduced oxygen levels, which were attributed directly to resuspended bottom deposits, varied from 16 to 33 percent below the 6 to 8 milligrams per liter (mg/l) normally encountered.

O'Neal and Sceva (1971) investigated the effects of dredging on water quality in Washington. They concluded that the disturbance of bottom material by pipeline and grapple dredging and the discharge of spoil materials can significantly reduce dissolved oxygen levels, cover or smother bottom organisms, and release toxic compounds in localized areas. Open water disposal from a pipeline dredge produced little or no change in surface water quality. Oxygen was zero in the mudflow near the bottom. The chief visible effect from pipeline dredging was the turbidity plume created by spoil disposal. They observed the submarine mudflow around an open water dredge discharge and partially described its properties. Emptying of hopper dredges created little visible effect on water quality. They discussed retention of spoil by dyking. They observed that the settling rate of sediments is more rapid in salt water than in fresh water and felt that development of a healthy benthic community is inhibited when volatile solids content of bottom sediments was 10 percent or higher. They recommended adoption of guidelines based on sediment criteria for determining acceptability of sediments for dredging and recommended restrictions on where and how dredging and spoil disposal can be done.

A number of studies have been directed towards considering alternative means to dispose of polluted spoils. Recently Jeane and Pine (1973) evaluated the effects of spoil disposal (260,000 cu. yds.) in a 2-cell settling basin, with overflow weirs. Predredging conditions were determined and compared with receiving water conditions during the hydraulic dredging. In-situ bioassays using juvenile chinook salmon were also performed. The receiving water was affected only in the immediate vicinity of the dredge and the settling basin. The authors conclude that adequate settling basins with properly designed overflow weirs can significantly reduce the adverse effects of spoil disposal on water quality.

A large number of studies have been conducted in various bays and estuaries in the Gulf of Mexico. The majority of these have been associated with shell dredging operations (dredging of unprocessed clam and oyster shells as a pure source of calcium carbonate) or with maintenance channel dredging.

Wilson (1950) studies the effects of shell dredging in Copano Bay, Texas. He found that suspended solids of 33 to 58 g/l may be found near the discharge of a suction dredge and that suspended material caused by the dredge dissipated rapidly. The heavier material such as larger shell fragments and coarser sand was deposited in the immediate vicinity of the discharge. Turbidity from the dredge which was above background levels extended out 300 to 900 feet on most occasions. On one occasion suspended material above background levels was found 1800 feet from the dredge. He stated that the direction of movement of suspended material was in the direction of the current and that the amount which moved away from the dredge decreased with distance. Material transported beyond 900 feet was very slight. In other directions, no suspended material was detected beyond 600 feet from the dredge. A considerable amount of the material placed in suspension settled into the cut from which it was taken.

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Hellier and Kornicker (1962) did a before, during and after study of sedimentation from a hydraulic channel dredge in Redfish Bay, Texas. They did not measure the dredging directly but attempted to measure silt deposition by placing coloured gravel chips on the bottom at various distances from the operation. The gravel was put out at least 9 months before dredging and core samples were taken before dredging, 1 week and 18 months after dredging. They reported 22 to 27 cm of sediment deposition within one-half mile of the dredge, but effects at greater distances were negligible. They felt little sediment sorting occurred during dredging.

Mackin (1962) studied canal dredging in Louisiana. He found that silt was carried a maximum of 1300 feet and that at distances greater than a few hundred feet, turbidities did not exceed those attained at times under natural conditions. He calculated that only about one percent of the spoil was transported away from the immediate vicinity of the discharge. Fine material was lost in the natural turbidities at distances over 1000 feet and had the same effect on the environment as the materials put in suspension by natural conditions. Turbidities produced by shrimp trawlers were not excessive, but they were greater than those produced by the dredge at distances of 300 feet from the spoil discharge. Turbidity levels outside the influence of direct spoil deposit did not harm oysters. He considered it unlikely that dredge spoil would significantly reduce dissolved oxygen and stated that the factors which control silt deposition had not been properly considered in previous studies.

Masch and Espey (1967) studied shell dredging in Galveston Bay, Texas using an engineering approach. Shell dredges resuspended considerable quantitites of sediment which formed density layers near the bottom. These layers were formed when dredge wash waters contained high concentrations of fine sediments with more than about 80 percent by weight of particles in the silt

and clay size. These sediments tended to flocculate into density layers when the concentration was greater than about 10 g/l. Dredges operating in sands were not expected to produce such density flows. The movement of density layers is controlled to a large extent by gravity and the layers are capable of moving in directions other than that indicated by either bottom or surface currents.

Movement by gravity and tidal action is possible until the layers are consolidated to concentrations of about 175 g/l. They stated that oyster reef topography may play an important role in the movement and settlement of these layers. Reefs protruding above the bay bottom tended to deflect or resuspend density currents and were not as susceptible to sediment deposition as surrounding areas. Old dredge cuts and trenches could be used to control and trap dredge sediments moving as density layers. They concluded that the control of dredging operations cannot be based solely on a distance limit but must, in each individual case, consider type and amount of burden sediments, number of dredges to work in the area, and local conditions of reef topography and bottom currents. If dredging is controlled in a prescribed manner, it can be done very near live oyster reefs and exposed shell with no damage.

Windom (1972) evaluated environmental changes resulting from dredging activities in a salt marsh estuarine environment of the southeastern Atlantic Coast. He investigated the chemical response of salt marsh sediments to the deposition of dredged materials and the water quality response to the dredging and deposition of sediment. He tentatively concluded that in natural and relatively unpolluted areas dredging has no significant effect on water quality whether dyked or undyked confinement techniques are used. In addition, he stated that water quality impairment caused by dredging activities in polluted areas in marine environments does not necessarily bear any simple relation to

the composition of the sediments. In order to evaluate the possible effects on water quality of dredging in a particular area, specific information must be obtained in that area. No general criteria can be set up for dredging in marine waters until a significant variety of dredging situations has been studied in order to have broad experience in possible water quality effects due to dredging activities. The time that the water mixed with the dredged material is allowed to stay in an enclosed spoil area will greatly influence the quality of the effluent from the spoil bank. Dredging of "polluted" sediments does not necessarily impair water quality in estuarine environments.

Bardarik, Alden and Shema (1971) studied the effects of sand and gravel dredging on aquatic life at three dredging sites on the upper Allegheny River. They found no effect on riffle benthos or fishes. There was a limited increase in suspended solids but the pH, alkalinity, specific conductance, biochemical oxygen demand, nitrate, ammonia, and dissolved oxygen were unaltered by the dredging operations.

EFFECTS ON BIOLOGICAL ORGANISMS

Unfortunately, there is a notable lack of information immediately relevant to effects of dredging disposal on aquatic organisms. Most biological field studes at disposal sites have been, for the most part, "after the fact" and consequently are of limited comparative value.

The most useful and complete studies available in this regard are those conducted by Cronin et al who studied the gross physical and biological effects of over-board spoil disposal. The dredging problem involved disposal of over 1 million cubic yards of spoil predominantly silt and clay in water depth of 3-6 meters.

The study projects consisted of geology and hydrography, phytoplankton, adult fish and their eggs and larvae. An interim report was published by Biggs (1968).

In these studies, fine sediments released as a semiliquid by a channel dredge increased turbidity over an area of 1.5 to 1.9 square miles around the disposal site. Over most of the area the suspended sediment load was within the range of natural variation observed, but in a different season from observed natural maxima. Suspended sediments in the top 10 feet of water were carried in a tide-related plume to a maximum distance of about 3.1 miles but virtually disappeared within two hours after pumping ceased. Total phosphate and nitrogen were increased in the immediate vicinity of the discharge to about 100 times ambient levels, but limited field experiments did not show any detectable effects on photosynthesis by phytoplankton. Little or no oxygen sag occurred except near the discharge. At least one foot of spoil material was deposited on an area five times or more as large as that of the defined disposal site. Approximately 12 percent of the deposited sediment disappeared from the spoil pile within 150 days. No gross effects of dredging or spoil disposal were observed on phytoplankton primary productivity, zooplankton, adult fish or their eggs and larvae. There was a reduction of about 70 percent in the average number of benthic individuals per square yard and about 65 percent in the benthic biomass in the spoil disposal area accommpanied by a marked reduction in the number of species present. After one and one-half years, numerical abundance, biomass and species diversity had recovered to approximately the levels before dredging. Individual species varied greatly in susceptibility to damage and in recovery patterns. An erratic series of species fluctuations occurred at the site of dredging in the channel. After one year the channel had about the same number of individuals as before dredging, but not as

many species were present. The sediments were not known to contain any highly toxic metals, oils, or other deleterious materials. It was recommended that quantitative laboratory studies be done on the effects of sediments on important estuarine species to investigate effects not ascertainable by field methods. It was further recommended that sites considered for future dredging and disposal should receive individual consideration in relation to ecological impacts, drawing both upon related research in other areas and from adequate knowledge of local conditions.

Similar conclusions were drawn earlier for the same area after a study conducted by the Virginia Institute of Marine Science (1967). Sedimentological data from bottom cores were given as they may apply to disposal of spoil. Studies of benthic fauna before and after dredging showed a population reduction of aerobic fauna followed by a dramatic increase by the following summer. It was concluded that spoil deposited in deep estuarine areas has an immediate but not a lasting effect on benthic fauna.

Harrison (1967) reviewed the effects of dredging and associated spoil disposal in lower Chesapeake Bay. Spoil dumped from a hopper dredge appeared to have only a transitory effect on the populations of infauna and epifauna. Resettlement of benthic organisms in both the areas of dredging and spoiling was very rapid. Animal collections taken in the spoil area one month after dredging showed a marked decrease in numbers of animals and species. Recovery of the infaunal population was relatively complete after six months. It was found important to differentiate between transitory high populations of juveniles at certain seasons and normal faunal distributional patterns when attempting to assess the effects of dredging or spoil deposition on benthic organisms by means of before and after faunal surveys. He also monitored deposition of sediment on oyster

grounds 0.8 to 2.0 miles from a dredging site before and after dredging. The changes in bottom level he observed were due to natural sedimentation rather than dredge spoil.

Leathern et al, (1973) studied hydraulic dredging and spoil disposal behind the inner breakwater in Delaware Bay, during 1972. The project involved the disposal of almost 200,000 cubic meters of spoil. They found the disposal to have an impact on several kilometers from the operation site with low dissolved oxygen and a decrease in the density and diversity of benthos. After 3 months however, repopulation of benthos had occurred in some areas.

In the study of the ocean dumping ground off New York (Anonymouse 1970) referred to previously, it was found that a large area over and around the dredge spoil area was essentially devoid of benthis organisms. This absence of macrofauna can be attributed to four factors:

a) toxic effects of sludges
b) smothering of adults and juveniles by continuous disposal
c) the creation of a physical environment which adversely affects the normal development of eggs and larvae
d) avoidance reactions by adults of areas contaminated with spoil.

A smilar case was cited for dumping ground in Bellingham Bay, Washington (Anonymous, 1967). An area in central Bellingham Bay had been used for years as a dumping ground for organic sludges and debris removed from the inner navigation channel and a log ponding area. Bottom samples showed an area approximately one mile in diameter had volatile solids concentrations over 10 percent. Both the total number of organisms and the species diversity were severely reduced in this area.

Hydrogen sulfide toxicity caused by the dredging of cedar bark deposits was considered responsible for mass mortalities of stickleback and shiner in Alberni Inlet on Vancouver Island, B.C. (Hourston & Herlinveaux, 1951). The dredging operation, was conducted to remove deposits of cedar bark dropped there by a shingle mill long since gone.

In the shell dredging study (Wilson, 1950) at Copano Bay, Texas discussed in the previous section, oysters were subjected to very high concentrations of suspended silt in the laboratory and it was stated that if such levels were maintained in the water for a long period it would be detrimental to oysters. No correlation was found between amount of spat set and distance from the dredge or with amount of suspended material in aquaria. The author noted that dredging may be beneficial to oyster production by building firm spoil piles which catch spat and produce oysters and by digging deeper areas, thereby, facilitating water circulation in shallow bays.

Ingle (1952) and Ingle, et al (1955) studied shell dredging in Mobile Bay, Alabama. In the first paper, damage to fish and motile crustaceans was not observed even within 75 to 150 feet of an active dredge. Shellfish suspended from the dredge were unharmed. Silting effects were observed on the bottom out to a distance of 150 to 1200 feet from the discharge. They suggested that dredging stirs up organic detritus which may be beneficial to shellfish and crustaceans and mentioned that shrimp were apparently more abundant in waters muddied by dredging. In the second paper the authors were concerned with inorganic and organic nutrients, carbohydrates, fats and proteins contained in the muds. An attempt was made to determine if muds contained toxic components and if mud in suspension was harmful to fish life. No toxicity, including hydrogen sulfide, was found but high mud concerntrations killed fish held

in tanks by clogging their gills. Fishes were thought to avoid these high concentrations and to be unaffected in the open bay. High turbidity created by dredges was limited to a small area in the vicinity of the discharge.

Odum and Wilson (1962) studied dredging of an intracoastal channel near Redfish Bay, Texas and found that respiration exceeded photosynthesis in the dredge tailings, possibly because of organic matter in the dredged sediments. Photosynthesis was not diminished much during, or after, dredging as compared with data from a previous year and the additional respiration due to extra organic matter did not apparently interfere with normal production. They hypothesized that high production and dense grass found after dredging may have resulted from release of nutrients.

Odum (1963) measured chlorophyll A and diurnal oxygen production over grass beds in Redfish Bay, Texas before and after the dredging of an intracoastal canal. The cause was uncertain, but he found productivity temporarily decreased and an imbalance of respiration over photosynthesis which may have been associated with dredged silt in the spring. The following year he found growth to be exceptional and suggested that nutrients released by dredging may have been the cause.

Taylor and Saloman (1968) described how extensive dredging and filling in Boca Ciega Bay, Florida has degraded water quality and adversely influenced plant and animal production. A total of 3500 acres of estuarine areas worth $1,4 million annually have been physically eliminated by development of the coastal area for residential use.

Sykes and Hall (1970) surveyed the benthic mollusks in dredged and undredged areas of Boca Ciega Bay. Species were fewer in number and variety in the soft sediments in dredged canals than in the predominantly sand and shell sediments in undredged areas.

Stickney (1972) studied the effects of intracoastal waterway dredging on ichthyofauna and benthic macroinvertebrates in a Georgia river estuary. No effects of dredging could be demonstrated on motile organisms capable of being captured by otter trawl. The patterns of seasonal occurrence and dominance of specific organisms appeared to be consistent regardless of whether or not dredging occurred in the area sampled. Control stations often showed more variability in diversity during the period immediately before, during and after dredging than did the experimental stations.

LABORATORY INVESTIGATIONS

A laboratory investigation of pulluted sediments from Bellingham Bay, Washington was undertaken to assess toxicity to young salmon (Servizi et at, 1969). Sediments from the inner harbour were found to consist of pulp fibres undergoing decomposition with a consequent production of hydrogen sulfide. When collected, the sediments were devoid of normal marine life. These sediments created turbidity, exerted an oxygen demand and were toxic to sockeye salmon smolts due to a high concentration of hydrogen sulfide. Sediment concentrations greater than 1 percent were lethal to smolts, and a concentration 0.1 percent appeared to be the threshold of visible distress. These sediment concentrations represented initial hydrogen sulfide concentrations of 2.3 and 0.3 ppm, respectively. Air exposure of the harbour sediment, as might occur during dredging and transport to the disposal site, was not adequate to eliminate hydrogen sulfide. Washing, as might occur during marine disposal and resettling, did not prevent subsequent hydrogen sulfide formation.

McCoy and Johnston (no date) studied sedimentation of soils collected from proposed shell dredging sites in Albermarie Sound, North Carolina. They considered a chlorinity content of 19.5 ppt as full strength sea water and suspended soils in

0, 5, 10, 15 and 25 percent of this concentration. They found that the mud settled faster in salt water than in de-ionized water and that a 14 mph wind would keep sediment in a jar suspended. On this basis they concluded that sediments disturbed by a dredging operation can be expected to settle in salty water during low or no wind velocity and became resuspended by winds of approximately 14 mph or greater, thereby, creating an "accumulated turbidity" which could detrimentally affect an acquatic habitat.

White (1966, ref. May, 1973), did laboratory experiments on the formation and movement of dredge sediments as density currents in a 40-foot long by 1-foot deep by 4-inch wide flume. He found that the formation of density layers depended primarily on the concentration of suspended sediment allowed to build up at the source. Water currents tend to prohibit the formation of density flows by turbulent mixing and by sweeping the sediment away before it builds up a sufficient concentration for layer formation. Currents promote movement of density layers only slightly by interfacial shear. Density layers were observed to flow against the current and sometimes even uphill. However, gravity is the primary force which controls movement of the density layers. Dykes and trenches were used to promote deposition of sediment from density flows in the experiments.

Gustafson (1972) supplied data from pilot laboratory studies and discussed the fallacies connected with turbidity and resuspension of sediments by dredging. He stated recent regulatory actions concerning dredging were taken in ignorance of the effects of turbidity and in spite of the fact that turbidity created by winds and tides dwarf those of man's activities. Suspended clays attract bacteria and remove oils, pesticides, sewage products (except nitrates), and metals from the water. He demonstrated the probability that metals adsorbed to clays are not released when clays are resuspended and that organic

molecules are not liberated in amounts sufficient to cause ecological concern. Pilot experiments to determine whether metals could be digested off the clay by clams were inconclusive, but his opinion was that the metals would not be digested by the clams. Several beneficial effects of turbidity in addition to adsorption were present.

The conclusions of many of the reports reviewed stressed the need for biologically assessing sediments to be dredged. Gannon & Beeton (1971) attempted to develop laboratory procedures for such an assessment. The work was conducted as part of the U.S. Corps of Engineers studies for Great Lakes Harbours. The procedures developed utilized a toxicity and a selectivity index for individual sediment samples using benthic invertebrates, various phytoplankton, benthic invertebrates, various phytoplankton, benthic algae and various zooplankton.

Techniques similar to these have recently been evaluated by POLLUTECH (Pollutech, 1974) in a study of the response of various benthic invertebrates to sediments collected from three harbours in Lake Ontario. It was concluded that much more development work was required to establish a useful toxicity and selectivity procedure for the evaluation of potential dredging sediments.

CORPS OF ENGINEERS STUDIES

The most comprehensive survey of spoil disposal practices is a series of "pilot" studies conducted by the U.S. Army Corps of Engineers (1969) in the Great Lakes area. The purpose of the program was to investigate all alternative disposal methods such as along-shore dyked areas, disposal onshore at some distance inland, treatment methods, and evaluating pollution abatement results. Eight harbours were selected for this study:

Great Sodus Bay Harbour, New York
Buffalo Harbour, New York
Cleveland Harbour, Ohio
Rouge River, Michigan
Indiana Harbour, Indiana
Calumet River and Harbour, Illinois
Green Bay Harbour, Wisconsin
Toledo Harbour, Ohio

For each harbour, quantity, composition, and degree of pollution of sediments, methods of dredging and disposal of sediments, and location, exposure, and depth of disposal areas are factors that were considered. Because of the importance of this work, each study will be summarized individually.

Great Sodus Bay Dredging Study

This project involved hopper dredging in a navigation channel in Great Sodus Bay, with spoil disposal in Lake Ontario. The material excavated was lightly polluted with volatile solids from 0.5 to 3.0 percent. Sampling was conducted in both the dredging and spoil disposal area. The results indicate no significant change in the benthic biology or the water quality characteristics in the project area. One conclusion was that the load on a spoil area cannot necessarily be determined by sampling in the excavated area. During the hopper dredging work in Great Sodus Bay, much of the turbidity-producing fraction and the dissolved and volatile material was lost through the over-flow. It was then dispersed by lake currents, or deposited in areas adjacent to the channel, and did not reach the spoil area.

Buffalo Harbour Study

The Buffalo River is dredged annually with a clamshell dredge. The sediments are considered highly polluted and toxic. The

pilot project involved disposal of about 100,000 cubic yards in an alongshore dyked enclosure, approximately 1000 feet by 1000 feet. The shoreline forms the eastern boundary; an existign dyke forms the northern boundary; and the west and south dykes were constructed with open hearth slag. Because the slag was expected to act as a filter, there was no provision for overflow. In 1967, dredgings were removed from the dump scows with a clamshell dredge and deposited in the enclosure. No water was added as in hydraulic disposal. Consequently, the sediments were neither disturbed nor segregated by size. Sediment and water samples were collected in the vicinity of the dyked areas before, during, and after dredging. Available data showed no changes in water quality outside the enclosure.

Cleveland Dyked Dredging Disposal Area Investigation

The study evaluated two methods of spoil disposal into a completely dyked basin in Cleveland harbour. The dyke, which was constructed from 286,000 tons of limestone and dolomite, was designed to act as a filter. The storage volume inside the dykes was approximately 300,000 cubic yards. A slip was constructed adjacent to the enclosure for use both as an unloading point and as an intermediate storage site for spoil.

The first method of spoil disposal tested was the direct removal of material from scows and transfer into the basin by simultaneous jetting and pumping. Forty-one scow loads totalling 45,500 cubic yards were transferred in this manner. The average pumping time per scow was slightly over two hours. A 5:1 ratio of water to sediment was necessary to permit pumping. In the second method for disposal, the spoil was dumped into the adjacent slip by bottom dump scows. A hydraulic dredge completed the transfer into the basin. The volume of materials handled in this manner was the same as that for the first method.

Water quality sampling showed no significant effect on the lake from seepage through the dyke. The data indicated over 95 percent retention of all constituents measured. In the case of disposal method two, adverse effects were found in the vicinity of the slip. These changes were attributed to discharge from the slip, rather than seepage through the dyke. Turbidity plumes up to 1400 feet long were observed. These were through to be caused by prop wash from the tugboats. Depressed oxygen levels were also measured 300 to 400 feet from the slip after spoil dumping. Chemical constituents in the bottom sediments increased near the mouth of the slip.

A portable water treatment plant was evaluated as a means of further treating the supernatant from the disposal area. Treatment procedures tested included:

- coagulation, filtration, and disinfection;
- coagulation only;
- coagulation and filtration; and
- filtration only.

The combination of coagulation, filtration, and disinfection was most effective in reducing turbidity, chemical oxygen demand, and nutrients.

Pilot Study of Rouge River Dredging

The purpose of this study was to determine the degree and extent of pollution caused by dredging in the Rouge River in Detroit and by spoil disposal on Grassy Island in the Detroit River. A hopper dredge was used and the spoil was pumped ashore into the holding basin. Sediments in the project area were grossly polluted with volatile solids varying from 11 to 35 percent (dry weight basis). Grease and oil concentrations were in the range of 10 to 40 grams per kilogram.

The dredging caused significant increases in suspended solids, volatile suspended solids, chemical and biochemical oxygen demand, total phosphorus, and iron in the immediate area of the dredge.

Overflow from the hopper bins caused the most severe pollution. After passage of the dredge the dissolved oxygen levels decreased with time as long as the stirred-up material remained suspended. In the Detroit River near the spoil area, no significant changes in water quality could be attributed to the spoil disposal.

Indiana Harbour - Inland Steel Landfill Lagoon

In this project material was removed from the highly polluted Indiana Harbour Canal and disposed in an 80-acre lagoon along the shore of Lake Mighigan. The lagoon was 20 feet deep and was surrounded by an impervious dyke. A gap 12 to 14 feet deep and 150 feet wide was provided for the entrance of loaded barges. The water quality was monitored to determine the effectiveness of the dyke in retaining contaminants within the lagooon.

Bottom samples taken outside the lagoon showed that little of the heavy organic material escaped. Water quality was noticeably degraded in the gap and a quarter mile from the entrance. The primary effects were increases in suspended solids, oil and grease, ammonia nitrogen, organic nitrogen, and total phosphorus.

During the project the Corps of Engineers attempted to use an air curtain across the gap to contain surface films and polluted materials. The results were inconclusive because the supply of compressed air was inadequate.

Calumet River Pilot Project

The Calumet River Pilot Project involved land disposal of material from the Calumet River in a 91-acre site. Material was excavated by clam-shell and transported by scows to a temporary disposal site. This temporary spoil area was a basin or "pocket" surrounded by a submerged dyke. When sufficient material had accumulated, a hydraulic dredge was used to excavate the basin and pump the spoil to the permanent disposal site.

The following conclusions were based on the sampling program:

- The operation of the clam-shell produced no significant changes in water quality. The only parameter showing a significant increase was turbidity, which rose from 20 Jackson Turbidity Units (JTU) above the dredge to 39 JTU below.

- The submerged dyke in the temporary spoil area was effective in minimizing water quality degradation. Parameter values immediately outside the dyke showed no significant increase above background.

- The detention time in the final settling basin was insufficient to effectively reduce the turbidity and suspended solids to a degree which would have been possible with improved control of the drainage.

- The final settling basin was not effective in improving the chemical quality of the drainage from the spoil.

Green Bay Pilot Study

In this study, 632,000 cubic yards of dredge spoil were used to fill a 380-acre dyked basin and to construct a dyke enclosing a 230-acre spoil area in the shallow waters of Green Bay Harbour. The project used a temporary spoil site in the bay consisting of a 200 foot by 750 foot sump excavated to a depth of 25 feet below natural bay bottom. Material dredged from

the Fox River channel by clam-shell was transported by scow to this temporary site. It was them moved by hydraulic dredge to the 380-acre basin. Some channel areas were excavated directly by hydraulic dredge with spoil disposal in the large dyked area.

The data collected show that only turbidity and suspended solids were effectively controlled by the 380-acre dyked area. Turbidity in the outfall was usually less than 25 JTU. Chemical constituents such as phosphorus, ammonia and organic nitrogen, and chemical oxygen demand increased through the pond. In the temporary sump, significant increases above background were noted for conductivity, alkalinity, turbidity, suspended solids, total phosphorus and total nitrogen. Turbidity levels in the channel near the sump went as high as 300 JTU compared to background levels of about 15 JTU.

Toledo Harbour Project

The materials dredged from the Maumee River and the inner 5 miles of Maumee Bay channel at Toledo are placed in a dyked enclosure in the bay. Dredgings from the outer 12 miles of the channel are disposed of in an open water area of Lake Erie.

In general, the site effects of dredging are a function of the normal pollutional characteristics of the Maumee River. The percent volatile solids are in the order of 7-10 percent (w/w).

Prior to November, 1967, the dyked area did not limit the overflow of suspended sediments effectively. Some changes were made to the enclosure including raising the overflow weir to allow ponding to occur within the enclosure. These changes were effective in reducing the overflow of suspended matter, nitrates, phosphates, sulfates and chlorides.

MOBILE BAY STUDY

One of the most comprehensive studies to date with regard to dredging in estuaries, is that by May (1973) for Mobile Bay, Alabama. Three hydraulic pipeline dredges were monitored and rigorous, predredging data was generated. They found that almost all dredged material disposed of in open water settles very rapidly and enters dredge cuts or is transported by gravity along the bottom as a flocculated density flow separate from the water column. All other measureable sediment transport does not exceed natural levels caused by normal winds beyond about 1600 feet or less from the discharge. Suspended solids are temporarily increased to high levels over a limited area but this causes little deleterious environmental effect. There is a limited, temporary reduction in macroscopic benthis organisms in areas affected by dredging.

The widespread visible turbidity sometimes produced by dredges does not exceed natural levels caused by freshets or normal winds beyond a few hundred feet from the discharge. The visible plume has little relationship to distribution of dredged sediments and it does not measurably increase silting. Turbidity measurements have little useful application in dredging studies because the actual concern is with the amount of solids suspended in the water.

The concentration of materials normally found in typical esturine sediments has little relationship to the effect on water quality except for reduced compounds which can create an immediate oxygen demand. However, this demand is mostly limited to the density flow near bottom. Because of rapid settlement, volatile solids are of little importance to dredging situations unless they are high enough to have already degraded water quality.

SUMMARY

In summary, it can be said that the most serious problems arise when highly industrial harbours, bays, or channels are dredged. Such was the situation described for New York Harbour (Anon., 1970), Bellingham Bay, Washington, (Anon., 1967), Arthur Kill, New Jersey (Brown & Clark, 1968), and various industrialized Great Lakes areas (U.S. Corps. Eng., 1969). These harbours are highly polluted and receive industrial wastes containing organic and/or toxic components. Bottom sediments are effective traps for many organic and inorganic materials because of sorption and ionic processes and consequently the sediments in these harbours become highly contaminated. In maintaining these harbours for navigation, they must be continually dredged and in previous years the dredged spoil was disposed of in open water dumping grounds.

Resuspension of the contaminated sediments was found to produce toxic conditions and/or create an oxygen demand and the disposal areas were generally devoid of benthic organisms.

Fish toxicity of sediments obtained in the vicinity of pulp mills was observed by Servizi et al, 1968 and by Hourston & Herlinveaux, 1951. In both cases, the toxicity problem was related to the release of hydrogen sulfide upon resuspension of the sediments.

The U.S. Corps of Engineers (1969) conducted a series of "Pilot Studies" in order to investigate alternate means of dredge spoil disposal. They concluded that disposal into onshore dyked areas with adequate overflow drainage could minimize the problems associated with dredging contaminated sediments. However, contaminants being leached from the sediments can still enter the receiving waters via the discharge from the dyke overflow.

O'Neal and Sceva (1971), after investigating dredging on water quality in Washington, recommended the adoption of guidelines

based on sediment criteria for determining acceptability of sediments for dredging and recommended restrictions on where and how dredging and spoil disposal can be done.

In areas not highly industrialized, the problems associated with dredging are usually restricted to particulate matter, that is, Turbidity, Suspended Solids and sedimentation or siltation. Observations concerning turbidity and suspended solids during dredging programs are reported by Wilson (1950), Mackin (1962), May (1973), Cronin et al (1970) and Biggs (1968). In general, it can be said that:

- problems were more extensive when sediments containing a large percentage of fines were dredged;
- the concentration os suspended matter decreased with increasing distance from the dredge outlet;
- Problems rapidly disappeared whrn the dredging programs were complete.

There are a number of reports concerning the impact of dredging on biological organisms. One of the most comprehensive is that by Cronin et al (1970), describing a dredging program involving the disposal of over 1 million cubic yards of sediment in Chesapeake Bay. In general, no gross effects were observed for phytoplankton productivity, zooplankton, adult fish, free-floating fish eggs and larvae.

The most serious problems arise when the sediments suspended during dredging, settle and smother the benthic communities. In the study by Cronon et al (1970), a 70 per cent reduction in benthos was observed in the disposal area. After 1 year, however, repopulation of the area by benthic organisms was complete.

In considering dredging in estuaries, White (1966), Masch & Espey (1967) and May (1973) applied basic concepts of estuarine sedimentology in considering the settleability of dredged sediments. When sediments enter the upper part of an estuary, the coarse materials settle out rather quickly in the absence of a suspending force. The finer particles remain in suspension longer, but in salt water these fine sediments flocculate rapidly and settle out. As the concentration becomes greater near the bottom due to rapid settling, the settling flocs tend to interfere with one another and there is a decrease in the settling velocities of the particles. Thus a "mud flow" develops which tends to flow as a density current. Mud flows can occur when the dredged sediments contain substantially high concentrations of silt and clay materials. If conditions near the discharge point are such that the Suspended Solids builds up when dredging such fine sediments, hindered settling will begin when concentration is about 1 percent and the slurry will not consolidate until the concentration reaches about 17 percent (Masch & Espey, 1967).

Thus the above authors observed that the predominant factors of dredge spoil dispersion in estuaries are those which contribute to, or influence, the formation and movement of these flocculated density layers and mud flows. It was observed that the mud flows tend to move according to gravity rather than current direction.

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