POLLUTION STUDIES OF THE PROPOSED VANCOUVER INTERNATIONAL AIRPORT

Volume II - Effects of Dredging on Water Quality

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SECTION 1

INTRODUCTION

1.1 Terms of Reference

Estuarine dredging operations have many potential negative impacts. These can be classified as follows (modified after Slotta and Williamson, 1974):

Changed topography - Alteration of currents, tides, salinity, regimes, and water quality

Removal of benthic organisms and plants - significant animal kills, alteration of important habitats, increased sediment instability.

Release of particulate matter - increased turbidity and sedimentation rates, release of soluble pollutants.

This report will deal with increased turbidity, sedimentation rates, and release of soluble pollutants which could be caused by dredging and placement of landfill for the proposed Vancouver International Airport (VIA) expansion. Separate reports have been prepared which deal with biological effects (Taylor, 1974; Environment Canada, Fisheries and Marine Service, 1975); and changed topography (Giovando, 1975; Webster, 1975)

1.2 Background of the Study

At present, the Federal Ministry of Transport is considering five different concepts involving land reclamation for the proposed airport expansion. These concepts have been discussed in detail elsewhere (Environment Canada, 1975). Briefly, Concept One involves a parallel runway configuration as initially considered by the Ministry of Transport and involves the reclamation of about 68 acres. Concept Two entails an alternative development plan requiring the reclamation of 234 acres. Concept Three represents a longer term and larger development, and requires the reclamation of 508 acres, while incorporating Concept Two as an initial stage. Concept Four is an extended version of Concept Two, involving the reclamation of 627 acres of land. Concept Five is also a longer term development incorporating Concept Four as an initial stage and involves, in total, about 1,494 acres.

1.3 Dredging Operations

The degree to which the proposed dredge and fill procedures will affect water quality in the Fraser River estuary will ultimately depend on which concept is chosen. This is due in part to the relationship between water quality and,

1) The area affected by the dredge and fill procedures,
2) The length of time that the area will be adversely affected (ie. the length of time during which the actual dredge and fill procedures will occur),
3) The quality of sediments used for fill purposes (the choice of a concept requiring a maximum amount of fill could force the use of less desirable borrow areas),
4) The degree of disruption of the present flow regime (as discussed by Pollutech, 1974 and Giovando, 1974).

It is proposed (Isfeld and Wu, 1974) that sand be obtained by suction dredge from one or several of eight borrow areas on the North Arm and Middle Arm of the Fraser River and Sturgeon Banks. Proposed borrow areas and the priorities for their utilization are presented in Figure 1, (Priorities from Isfeld and Wu, 1974). The rationale involved in the selection of these sites consists of a fusion of economic and ecological factors, the major criteria being promixity to fill site and low silt content of the proposed borrow material (Pollutech, 1974). The amount of sand and the time required, depend on the concept chosen. Isfeld and Wu (1974) supply the following data, with timing based on an assumption of 700 cubic yards (C.Y.) of fill per hour, 24 hours per day, five days per week (E.O. Isfeld, personal communication).

Concept One:	2,357,000 C.Y. ; 5-6 months of operation
Concept Two:	5,325,000 C.Y. ; 14 months of operation over 1-1/2 years
Concept Three:	12,151,000 C.Y.; 27 months of operation in two phases of about one and one-half years each.
Concepts Four and Five:	Are no longer under active consideration (I. Jones, personal communication), but would have required the following (E. O. Isfeld, personal communication).
Concept Four:	13,760,000 C.Y.; Three years of operation for a single dredge unit or utilization of more than one unit over a shorter time span.
Concept Five:	27,760,000 C.Y.; No estimate of dredge operation time.

The proposed dredge and fill operation involves the use of the hydraulic pipeline dredge method, commonly termed the pipeline dredge method. O'Neal and Sceva (1971) give a complete description of the operation of the pipeline dredge technique. A general literature review on pipeline dredging, as well as a brief discussion of problems associated with other dredging projects is included in Appendix III.

The chief advantages of a pipeline dredge are the large volumes of material that can be moved in a short period of time and the simultaneous nature of the dredging and disposal operation. Other dredging techniques, such as those using buckets on draglines, are not as efficient for the movement of large quantities of material and hence have been deemed uneconomical for a project of the magnitude proposed here (E.O. Isfeld, DPW personal commun.).

Hellier and Kornicker (1962) have suggested that the pipeline dredge is possibly the least disruptive, in terms of water quality, of the dredging methods now in use, but this assertion is not an established fact. O'Neal and Sceva (1971) have pointed out the water quality problems (eg. turbidity, suspended sediment and chemical contaminants) are associated primarily with the area receiving the spoil in pipeline dredging operations. The magnitude of these problems is dependent upon flow conditions, circulation, volumes and whether or not settling basins are provided. Thus, the focus of this report was directed toward the proposed land reclamation sites off the north end of Sea Island, the area which will receive the spoil. E.O. Isfeld (DPW personal communication) reports that present plans for land reclamation at the Sea Island site call for the establishment of an erosion resistant berm or dyke system, likely two-stage, prior to the fill operations. Spillways will be constructed to avoid the erosion of dyke walls by over-flow. It is also predicted that once in operation, the hydraulic dredge will be capable of pumping 20,000 gallons per minute (gpm). Of this 20,000 gpm, it is likely that approximately 10-15% (by volume) will represent sediment load to be deposited. (O'Neal and Sceva, 1971).

Even with the proposed borrow sites carefully selected for "good" fill material, it has been estimated (Langly, 1973) that the spillway discharge will have an approximate sediment load of 100 parts per million (ppm). This high value is due in part to the relatively high velocities attained in the pumping phase. (H. Wu, DPW personal communication). This value was determined during a study on Fraser River bed loads and can be considered, at best, a mean value for hydraulic dredging using borrow material containing 0-10% silt/clay. Thus, the value can be considered slightly higher if borrow areas of higher silt/clay content are utilized. The constituents of this 100 ppm level have not been investigated, but are thought to be represented by a very high percentage of silt (H. Wu, DPW, personal communication).

It is expected that as the dyke-enclosed area is filled, some materials larger than silt will be spilled and settle in the immediate area of the discharge pipe.

SECTION 2

EXPECTED CHANGES IN TURBIDITY AND SUSPENDED SEDIMENT CONCENTRATIONS

2.1 Background Data

Background data on existing turbidity and suspended sediment levels in the area of the Fraser River estuary are sparse (see Hoos & Packman, 1974, for a review of the relevant literature). Table 1 lists some of the existing data, all of which pertain to the Fraser River. Visual observation indicates that timing and levels of turbidity will be similar at Sturgeon Banks, for although larger suspended particles will have settled out by the time the Fraser River water reaches Sturgeon Bank, wave action, upwelling currents, and a larger concentration of organic matter in the water will add to the suspended sediment levels of water on the banks. Representative of existing studies is a report produced for the International Pacific Salmon Fisheries Commission (Servizi and Burkhalter, 1970), which lists turbidity measurements recorded at Hell's Gate. It shows maximum readings of more than 180 Jackson Turbidity Units (JTU), in 1966 and 1968 and in excess of 240 JTU in 1967. The report indicates that turbidity maximums preceded maximum discharge by about four to five weeks and thus reached a maximum in May decreasing gradually into September. Turbidity during the October through February period was generally between 15 and 30 JTU.

2.2 Effects on Suspended Sediment Levels in Marine, Estuarine and River Waters

The transport and subsequent deposition of suspended particles is primarily dependent upon the turbulent motion of the water and the friction between the particles and the water (Leopold et al, 1964). The resultant spatial position of the particles in the water column is determined by:

1) The net result of turbulent motion and vertical mixing, which causes the particles to rise and,
2) gravitational attraction which causes them to settle (Leopold et al, 1974).

The settling velocity depends upon the size, morphology and specific gravity of the particles and on the specific gravity, temperature, and viscosity of the water through which they settle. The turbulence of the water, in combination with various tidal and run-off currents, as well as the roughness of the bottom, substantially alters the ideal settling velocity (Leopold et al, 1964). These various factors, when combined, result in a system that is very complex. A study encompassing several years would be necessary to produce a model of the Fraser River estuary accurate enough to predict changes in turbidity and sediment load due to dredging procedures associated with the proposed VIA expansion. This factor should be borne in mind when examining the following comments, which tend towards qualitative rather than quantitative projections.

During the period March through September, the calculated spillway discharge of 48.1 ft^3sec with an expected sediment load of 100 ppm will have very little effect on the sediment load in the estuarine area. The Fraser River discharge during this period, as outlined, ranges from 150,000 to 300,000 ft^3/sec (Murray et al, 1972) and suspended sediment loads are well in excess of the 100 ppm spillway discharge level identified previously. The problem will be more acute during the period October through February, when the spillway discharge can be thought of as contributing to a larger proportion of Fraser River run-off, and more important, the suspended sediment concentration will be greater than in the waters it is flowing into by the range approximated by 50-80 ppm. Suspended sediment levels in the Fraser River during this period are thought to be about 20 to 50 ppm. Data presented in Table 2 and Figure 2 show that flocculation of fines is enhanced by increasing salinity and that much of the flocculation occurs within the first few hours. The presently silty nature of some of the Sturgeon Banks area indicates settling can occur here, and it is felt much fine material will be deposited in this area. Based on observations of the Fraser River plume (Hoos and Packman, 1974), the remaining suspended material will not be visible beyond the 15°/₀₀ isohaline (see figure 3).

The area around the Iona Sewage Treatment Plant outfall is already an environmentally degraded area (B.C. Research 1973), viz. contaminated sediments, reduced benthic communities and most likely higher than background levels of suspended solids. Others have suggested that directing the spillway discharge into the Iona Island Sewage Treatment Plant discharge channel would ensure a more rapid dispersion and dilution of both types of effluent. However, every effort should be made to contain the degraded sediments in the vicinity of the Iona Island STP outfall. Resuspension of degraded sediments could be caused by the introduction of the spillway flow and the erosion concomitant with the creation of random drainage channels in the tidal flat by the spillway discharge during low tide. This situation should be avoided, and it is recommended that the spillway discharge be directed in an alternate direction.

The dredge and fill procedures are not expected to have significant effects on the suspended sediment levels of the Fraser River itself. During peak river discharge periods, no water originating from the Sturgeon Bank area can be expected to enter the North Arm of the Fraser (Fjarlie, 1950). In other words, no movement of water "contaminated" with spillway discharge can be expected to move up the North Arm of the Fraser. During non-freshet periods, the situation is usually quite different. Giovando (1974) points out that water from the Bank's area adjacent to Sea Island may reach the mouth of the North Arm during flood tide, with possibly some penetration of this water into the North Arm. This water would be removed on the succeeding ebb tide. The level of "contamination" of the water must be considered as being very slight, (<1 ppm), due to the effect of mixing and dilution of any body of water moving out from an area adjacent to Sea Island. During non-freshet periods spillway discharge released at low tide might be expected to be carried into the Middle Arm of the Fraser, but considering the suspended solids concentrations mentioned above (<1 ppm) this is expected to have minimal effects.

Consideration should be given to the fact that approximately 50% of the time the spillway discharge will be flowing out into the Bank at low tide levels. This should make little or no difference to the quantity of solid material eventually suspended in the estuarine waters. Again, this is due to the fine nature of the discharged suspended sediments. It will dictate what area of the Bank receives a disproportionately high load of fine material. This, however, will be an extremely localized, short term effect on water quality due to the mixing capability of the Bank's area' however, the fines deposited may have serious effects on intertidal fauna and vegetation, depending on the amount of material dredged.

A second tidal effect will be the formation of random channels formed by spillway discharge at low tides. Direction of the spillway discharge toward the Iona Island STP outfall channel will create random erosion patterns and disrupt contaminated sediments already located in this area. The location of spillway discharge outlets should take into account this potential disruption. The best area for locating the spillway discharge appears to be the naturally turbid Fraser River.

SECTION 3

EXPECTED CHANGES IN CHEMICAL WATER QUALITY

3.1 Introduction

The practise of preparing environmental impact studies prior to major dredging and landfill procedures is relatively new. As such, criteria for what constitutes a "good" dredge material have been drawn up in a relatively ad hoc fashion. Recently, the United States Environmental Protection Agency (EPA) outlined in a report by O'Neal and Sceva (1971), a set of guidelines, based on sediment qualities for determining the acceptability of sediments for dredging. These criteria are listed along with the guidelines adopted by the Ontario Ministry of the Environment (basically the same guidelines as EPA with a few exceptions) in Tables 4 and 5. Both assume dumping of dredged material in open water.

There are many problems associated with these guidelines. First, they are to be used when dredged material is to be disposed of in open water, whereas, at VIA they will be confined by a dyke. They are incomplete in that they include only seven parameters; they are based on the investigation of dredging procedures carried out in the State of Washington and, as such, are limited in scope; little supportive data are presented for the choice of standards; and although bottom sediments are effective traps for many organic and inorganic materials because of physical entrapment, sorption, or ionic processes, as May (1973) points out, there is little, or no, known correlation between the concentrations of various chemical constituents within sediments subject to dredging and disposal operations and consequent effects on water quality. Also, several of the listed parameters, most notably volatile solids and chemical oxygen demand (COD), provide little meaningful information when applied to sediments in a reasonably well flushed marine environment. It was with this in mind that the United States Army Corps of Engineers devised an elutriate test in which samples of sediment are mixed 1:4 with receiving water (water collected from the area of proposed spoil deposition). After filtration, various parameters of the elutriate sample are compared to the same parameters in the "pure" receiving water sample. Spoil is said to be contaminated if the elutriate differs from the receiving water by a factor of 1.5 for a given parameter. This factor and more particularly the 1:4 dilution ratio appear to be chosen somewhat arbitratily, however, the rationale behind this test seems logical. It will allow more quantitative predictions delineating the consequences or changes in water quality as a result of hydraulic dredging operations.

This section of the report presents a synthesis of the findings of a contracted study of dredging on water quality (Pollutech, 1974) and the results of supplemental sediment analyses conducted by the Environmental Protection Service. These latter data have been correlated with available information on dredging and water chemistry in order to present potential changes in chemical water quality.

3.2 Sediment Analysis

3.2.1 Background

It is unfortunate that baseline data on the water quality for the Sturgeon Bank area have been infrequently recorded. The only published data relating to water quality in this area is contained in the B.C. Research Study (1973) (Table 3). Fraser River data is reproduced in Table 10.

It should be noted that the various values monitored in water quality fluctuate markedly from season to season and are affected tidally and seasonally but primarily by the effluent from the Iona Island Sewage Treatment Plant.

In order to acquire a more complete knowledge of baseline values, systematic monitoring carried out for a number of years would be required. Any attempt to assess the impact of dredging on water quality, with reference to water chemistry, therefore, becomes a difficult task.

3.2.2 Parameter Selection

Parameters under scrutiny in this study were chosen on the basis of the following criteria:

1) Constituents of the water column that have, in similar dredge and fill projects, been observed to undergo marked changes,
2) Constituents (notably metals and metal complexes) which have a documented history of toxicity to marine organisms.

3) Substances which, in view of the nature of the area under study, might be expected to concentrate in the sediments in abnormal amounts,
4) Parameters for which meaningful and practical analytical procedures exist.

Total Kjeldahl Nitrogen, COD, volatile contents and total organic carbon (TOC) give indications of organic content of the sediment. The importance of this aspect is discussed further in this section. Nitrogen and Phosphate determinations are of greater value and concern in conservative bodies of water, however, localized pockets of high nutrient concentrations could cause undesirable effects in the estuarine environment. Metals are very likely the most critical parameter within the scope of this report, as many are known for their toxicity to fish and other marine organisms. Also, certain metal complexes are active reducing agents.

Ammonia is excluded as a parameter. Practical analytical techniques involved in the determination of this parameter produce difficult-to-interpret results.

3.2.3 Nutrients

Generally, nutrient levels in the study area are well below EPA or OME guidelines (Tables 4 and 5). Sediments around the Iona STP outfall are known to be contaminated by both Nitrogen and Phosphorous, but the proposed borrow sites are not in this area. Sediment analyses carried out by Benedict, Hall and Koch (1973) on samples from the North Arm, as well as EPS analyses carried out for this report, have also shown that there is no appreciable contamination of the sediments by nitrogen.

However, Total Phosphate and Nitrogen concentrations increased in the elutriate test samples (Tables 7, 8, 9). The elutriate test for total phosphate in North Arm samples showed a very slight contamination represented by an increase in Phosphate of a maximum 0.05 ppm in the receiving water. Sturgeon Bank sediments exhibited, as expected, a more marked contamination. Total phosphate concentration levels increased an average of 0.3 ppm in the elutriate samples using sediments from Borrow Area IV (Sturgeon Bank), (Table 7).

A correlation between these values and actual increases in nutrient concentrations during filling procedures can not be made. It is, however, quite evident that within a limited area (less than the approximately 5,000 sq. yd. of severely degraded area adjacent to the Iona Island Sewage Plant outfall) there will exist a region of higher-than-back-ground nutrient levels if the discharge is to Sturgeon Bank.

Nutrient levels in waters of the area generally are at a maximum from August to April, and at a minimum from May through July (Anderson, 1964). This is due, in part, to seasonal changes in primary productivity and also to seasonal changes in discharges, including run-off, to the Fraser River. Thus, any increases in phosphate concentrations will be of greater concern during Spring and early Summer, ie. during periods when phosphate concentrations are relatively low. A summer depletion of nitrate has also been measured, so that due consideration would be similarly warranted for the introduction of nitrogen to waters in the study area from May through July.

Detailed studies utilizing 15 foot core samples would be required to establish a correlation between the nutrient ratios (N/P) limiting primary productivity in the study area and nutrient assimilation by aquatic organisms. There is an inconsistency between EPA, and OME guidelines and the elutriate test, in that sediments uncontaminated according to EPA and OME guidelines, when added to receiving water, increase nutrient concentrations beyond 150°/₀₀. We are not certain of the significance of increased nutrient levels on Sturgeon Banks; primary production will be increased in general, although in the immediate area only emergent plants will benefit because of turbidity inhibiting phyto-plankton growth. Nuisance growth of unsightly algae is a possibility.

3.2.4 Oxygen Demand

The best background data available on oxygen levels for the area under study originates from the B.C. Research Study, 1973, on the sewage outfall area (see Table 3). Values are reported averaging 93% saturation for samples collected June 9, 1973. Westwater Technical Report Number Two (Benedict et al, 1973) reports oxygen values for the Fraser River, North and Middle Arm as being in the same range as is indicated in the B.C. Research Report (1973).

The elutriate test for COD (Tables 7, 8, 9) illustrates that the spillway discharge water will reduce DO content in a localized area. The maximum elutriate COD levels from the Sturgeon Bank area was found to be 40 mg/l.(Table 7) Maximum COD values on elutriate samples from Borrow Sites 2 and 8 were only 18.1 and 25.2 mg/l respectively. This lower demand for oxygen placed on receiving waters by North Arm main channel sediments (Borrow Site 7) is indicated by the extremely low[1] levels of Volatile Solids Content, Kjeldahl Nitrogen, Total Organic Carbon (TOC) and COD found in these sediments (Table 4). It is evident that Volatile Solids Content, COD and particle size correlate strongly and it should be noted that the North Arm tidal flat sediments (Borrow Sites 6 and 7) are generally of lower "quality" than the main channel North Arm sediments. The critical differences seem, however, to be limited to the surface (1.0 to 1.5 ft.), as indicated by inspection of Tables 4 and 5. Thus, condemnation of the tidal flats region as a borrow site, based on oxygen demand, may not be warranted.

The scale of this DO reduction can be better appreciated when COD values of the elutriate test are compared to the average value associated with urban storm run-off water (111 mg/l), evaluated by Weikel (1971). The Iona Sewage Treatment Plant discharge, with a permitted[1] average flow of 70 MGD, has a permitted biochemical oxygen demand (BOD) of 100 mg/l.

Pollutech (1974) mentions the possibility of mud flows occuring due to this project. This is unlikely since mud flows associated with spoil deposition have been observed to occur only then the "fines" portion of the dredged material is greatly in excess of the coarser segment (O'Neal and Sceva, 1971). Mud flows result in greatly reduced dissolved oxygen.

1. Compare values for analyses of Phase VII and VII sediments with EPS and OME guideline values

2. Pollution Control Board Permit.

3.2.5 Metals

Metals are a concern because of:

1. Their direct or indirect toxicity to organisms
2. Their tendency to accummulate in the tissues of organisms
3. The possibility exists that metals, as well as other contaminants, display sub-lethal effects.

Possible levels of toxicity of metals are indicated in the following list of lethal concentrations prepared by the American Fisheries Society (AFS). These figures are not to be taken as applying to Sturgeon Banks biota, but are an indication of the sensitivity of aquatic life to heavy metals. The synergystic action of metals is discussed elsewhere.

Cd	-	0.003 mg/l
Cr	-	0.05 mg/l
Cu	-	0.01 mg/l
Pb	-	0.01 mg/l
Zn	-	0.01 mg/l
Hg	-	0.02 mg/l

Industrial and other trade wastes are the primary sources of metals in municipal sewage effluents. And due, possibly, to the industrial nature of the Lower Fraser Basin, the sediments adjacent to the Iona Island Sewage Treatment Plant outfall are definitely contaminated with respect to most trace metals (B.C. Research, 1973).

Table11 shows the level of contamination in Sturgeon Banks. It is interesting to note that with the marked sediment contamination in the area close to the sewage outfall, only iron was on concentration high enough to be detected in the overlaying water (B.C. Research, 1973). EPS analyses, including elutriate tests confirm and supplement this observation, indicating that in most cases trace metals in sediments are not released upon even violent mixing with water (see Tables 7, 8 and 9). May's report

(1973), based on observations on dredging in Alabama waters, also supports this view. The only contradition to this "trend" appears in the case of iron[1]. Previous studies (Hall, K.T., unpublished data, Pollutech, 1974) reveal that high iron (as Fe) levels are consistent for most sediments in the Sturgeon Bank area.

Background iron levels for the Fraser River, North Arm waters, range from 0.20 mg/l - 0.85 mg/l Fe, as reported by Westwater (Benedict et al, 1973) (Table 11). These values were recorded during non-freshet periods. The elutriate control samples show a very low iron concentration (0.05 mg/l) Fe in the water. Whether or not the iron level in the control is indicative of a low concentration of iron in the estuarine waters during freshet is not known, and further investigation should be undertaken. The elutriate test using Sturgeon Bank samples exhibited maximum increases in Fe concentrations of 0.36 ppm from sample site 13, increases of 0.30 ppm and 0.27 ppm from Site 12 and 14, but no increase in concentration from Site 11, or from sediment samples taken from the North Arm.[1] The increase in iron concentration after elutriate testing is thought to be due to the suspension of colloidal iron complexes, most likely iron oxides, (R. Swingle, DOE personal communication). These compounds are not noted for their toxicity and thus should present no real problem during the dredge and fill procedures.

In all elutriate tests no trace metals other than Fe solubilized to any appreciable extent. This suggests that dredging and fill procedures should not add any significant amount of dissolved trace metal contaminants to the waters in question, however, sediment carried over the spillway will contain undissolved metals. Some strata of the North Arm channel sites had Lead and Zinc levels higher than EPA guidelines based on studies in Washington.

1. The very high concentration of Fe in the sediment of borrow sites 2 and 8 (Table 4), is representative of a more vigorous digestion of the sediment samples.

As Pollutech (1974) has pointed out, these high levels could be indicative of a natural phenomenon. The Westwater Technical Report (Bawden et al., 1971) does not indicate that organisms from the Sturgeon Bank area are notably contaminated with respect to zinc. It cannot, however, be overlooked that the highest zinc levels indicated in the Pollutech (1974) study came from sediments showing highest COD and volatile solids content levels, indicating a correlation between certain metals and the organic content of the sediment. A report by D.W. Hood et al., (1966) also points to this correlation.

Mercury concentrations deserve special scrutiny in this study, because:

1. It is known that mercuy in various inorganic and organic forms is readily converted to methyl mercury, the form most readily incorporated into biological tissues, in the presence of high bacteria concentrations (Thomas, 1972, Olson et al., 1973). The area adjacent to the Iona Island Sewage outfall is certainly one of high bacterial levels (B.C. Research, 1973).

2. Bawden et al., 1973 indicate that organisms from the Sturgeon Bank display a marked contamination of mercury.

All analyses of sediments from the proposed borrow area for the Airport Expansion project show low levels of mercury, but contamination of benthic fauna (many being detritus feeders) in this area points to concentration of mercury in the organic component of the sediment, (Parsons and Bawden,1973). This property of mercury is supported in studies by R.L. Thomas (1972). He also states that mercury is relatively inert with respect to quartz and feldspars, the major components of the North Arm and Sturgeon Bank sediments. In the present study, sediments showing a higher proportion of silt content also revealed higher mercury levels.

The elutriate tests performed on North Arm sediments revealed that between 0.02 and 0.20 ppb of mercury was added to the receiving water. This produced a maximum of 0.32 ppb mercury concentration. This is well below the 20 ppb mercury concentration known to be toxic in fresh water, however, mercury retention and accumulation in organisms is a factor which must be considered. Certainly, mercury levels in organisms on Sturgeon Banks will increase as a direct result of dredging operations associated with the proposed VIA expansion, if the outfall is directed to this area.

3.2.6 Analysis of Chlorinated Hydrocarbons

The well-publicized "dangers" of chlorinated organic pesticides in the environment has stimulated much research in this field, but as yet little is known about the behaviour of these compounds. Olaffs et al (1973) have, however, demonstrated that most pesticide resides rapidly enter sediments. Their studies and others like them have been hampered by a lack of sensitive testing procedures for the detection of pesticide levels in waters and sediments.

Studies on sediments from the Lower Fraser River system have shown sediment contamination by polychlorinated biphenyls (PCBs) and some pesticides. This contamination was found to be confined to the urban-industrial areas in the vicinity of Still Creek and the Burnette River (K. Hall, Westwater Research, personal communication). PCB and pesticide residue levels in the sediment in the vicinity of the Iona Island STP outfall are expected to be high (Ken Hall, Westwater Research, personal communication). This belief is supported by two facts: (1) Bawden (1973) has found that tissue samples of Cancer magister collected in the Sturgeon Bank area contained higher PCB levels than control specimens from the Kitimat Arm area. (2) A study known as the Southern California Coastal Research Project, Annual Report (June 30, 1974) indicates that half of the load of PCB discharged to the ocean is attributable to municipal wastewaters.

EPS carried out analyses on residue levels on Sturgeon Bank sediments and found no organic chlorides nor polychlorinated biphenyls above the detection limits (see Table (5)). PCB determinations should also be carried out on sediments in other proposed borrow areas before a conclusion can be drawn on the effects on water quality imposed by a dredging and landfill program.

3.2.7 Sulfides

Sulfides are common substances in muds and in most cases are present as insoluble metallic sulfide forms. However, under anaerobic conditions hydrogen sulfide may be present, particularly if sulfate-rich sludges are deposited on the shore bottom. Hydrogen sulfide is a toxic gas and toxicity arising from sulfide-rich sediments have been reported by Hourston and Herlinveaux (1951) and Servizi et al (1969). In addition, dredging of sulfide-rich sediments could create a temporary odour problem. Odour associated with hydrogen sulfide is already evident near the Iona Island Sewage Treatment outfall.

Sulfides were found in sediments from potential borrow areas (Table 4 &5), but in almost all cases it was concluded that they were present mostly in an insoluble form, probably iron sulfide (Pollutech, 1974). In all cases the total sulfide content was well below the sulfide concentration in polluted sediments analyzed by O'Neal and Sceva (1971) on behalf of the U.S. Environmental Protection Agency. Pollutech (1974) concluded that the sediments from the potential borrow areas were not contaminated with respect to hydrogen sulfide. Dredging of these sediments should not create a significant hydrogen sulfide problem.

Insoluble sulfides can be liberated under reducing (ie. anaerobic) conditions. Observations of dredging programs in the North Arm Sturgeon Bank area indicate that this does not occur.

SECTION 4

BATHYMETRIC ALTERATIONS

A comprehensive report, dealing with the fate of the holes created by dredging activities, has been prepared by the Department of Public Works for the Federal Ministry of Transport, (Isfeld and Wu, 1974) A computer model is presented in the report, illustrating the movement and rate of fill of holes resulting from the use of Phase I, II or III borrow areas, (Fig. 6). Migration and rates of disappearance of holes left by Phase VI, VII and VIII (also North Arm sites) have not, as yet, been computed, however, the "Phase VII and VIII" holes will likely closely parallel the changes predicted for holes I, II, III.

It is pointed out that the hole resulting from utilization of the Phase VI borrow area will divert a large percentage of the flow from the Northern navigation channel through the borrow hole with subsequent shoaling in the navigation channel. It has also been indicated that measures will be taken to alleviate this problem and that if diversion is prevented then the rates of infill and migration for the Phase VI borrow hole will prove negligible.

Background data was insufficient to formulate infill and migration models for borrow holes at Phase IV and V sites, however, the report does offer prediction based on "experience". Specifically, a Phase V borrow hole (middle arm) would show considerably slower rates of infill and migration than that expected of North Arm sites. This is due to previous removal of large quantities of fill upstream of the "Phase V" site.

If the total 34 million cubic yards is removed from the Sturgeon Bank Phase IV site, (which at this time seems very improbable), the Public Works Report indicates that it would take in excess of 100 years to fill and would not likely show any migration. This report also states that this reclamation project is not expected to have any influences on adjacent beaches or coastal processes in this area and, other than the possible diversion of the navigation channel of the North Arm due to excavation at the Phase VI site, no significant disruptions in flow regimens are expected.

With respect to water quality, the creation of sites for tidal pool formation in the borrow holes associated with Phase IV or V sites presents a potential problem. Because of the proposed depth, holes at these sites could act as traps for detritus, resulting in increased bacterial levels and other related changes. The benthic fauna now inhabiting the borrow site areas would not, in all likelihood, re-populate in the borrow holes. Fauna adapted to lower elevations (probably sub-tidal organisms) will colonize the area, these developments, however, will be considered in the fisheries impact study.

SECTION 5

DISCUSSION

5.1 Introduction

Initially, the objective of this study was to review the full range of proposals for expansion of Vancouver International Airport. Over time, and as a result of other ongoing environmental studies, it has become clear that any extension onto Sturgeon Banks would be serious.

We endorse this conclusion. Construction of the larger concepts would entail long periods of dredging. During the months of naturally high silt levels the expected spillway discharge levels are lower than ambient levels at the river mouth, and probably at Sturgeon Banks, but discharge outside that period would increase silt loading and turbidity levels. Lengthening the dredging period would increase the importance of localized effects such as oxygen depletion. Increasing the amount of material dredged would increase proportionally the dangers of redistributing toxic substances capable of biological magnification.

The dredge and fill operations, associated with the construction of Concept One would have an effect on water quality in the Fraser estuary. The magnitude of the effect will depend on the quality of fill material used (ie. which borrow site is chosen) and on the type of dyking measures taken to contain fill material in the landfill site.

Because Sturgeon Bank is an excellent mixing area, it has high value as a biologically productive estuarine region. It is estimated that over 80% of commercially valuable marine species depend on estuarine areas for development at some stage in their life cycle (Ketchum, 1971). The region of concern in this type of project is the area receiving the spoil.

A discussion of water quality parameter levels related to a land reclamation program at Sea Island is made more complex due to both tidal and seasonal fluctuations. It is further complicated by the effect of the effluent from the Iona Island Sewage Treatment plant on water quality.

5.2 Suspended Sediments

The concentration of suspended sediments on Sturgeon Banks is thought to vary seasonally with the flow and turbidity of the Fraser River. During freshet suspended sediment levels at Steveston have been measured at 155-225 ppm. Turbidity measurements are in excess of 180 JTU's during freshet as opposed to 15-30 JTU's from October to February. This compares to the spillway discharge which will probably contain a high percentage of silt with a sediment load of approximately 100 ppm at 48 cfs, assuming a satisfactory berm system.

5.3 Nutrients

Both Sturgeon Bank and North Arm sediments, particularly the former, yielded elutriate tests which were contaminated with respect to phosphates and Nitrogen.

It was also determined that, generally, nutrient levels in the waters of the study area are at a minimum from May through July. It should be noted that nutrient release under anaerobic conditions was not examined, and that the tests may not represent the actual nutrient release under field conditions.

Increases in nutrient concentrations in the area adjacent to the proposed reclamation site will be a result of the proposed dredge and fill procedures if the Sturgeon Bank borrow area is used. However, it is unlikely that increases in nutrient content of the waters, with associated by-products, during the dredge-and-fill procedures, will result in pollution problems, particularly if the Sturgeon Bank borrow area is not utilized as a source of fill material.

5.4 Oxygen Demand

Fraser estuarine waters, in general, display reduced levels of dissolved oxygen due to COD and BOD exerted by material maintained in suspension by tidal action. This is not uncommon in marine estuarine situations.

Localized pockets of lower oxygen concentration occur in the area adjacent to the Iona Island Sewage Treatment Plant outfall, and the Iona Island jetty. These are the result of effluent discharges from the Iona Island Sewage Treatment plant.

Sediments can also contain materials which exert an oxygen demand. During the course of this study it was found that North Arm main channel sediments had a lower oxygen demand than the Sturgeon Bank area sediments. North Arm tidal flat sediments (Borrow site 6) were found to have higher oxygen demand than main channel North Arm sediments, with critical difference limited only to surface (1.0 to 1.5 ft.) samples.

5.5 Metals

Metals are of concern because of their direct or indirect toxicity and their sub-lethal (longer term) effects. It is known that the sediments adjacent to the Iona Island STP outfall are contaminated with respect to most trace metals.

Elutriate tests have indicated that concentrations of trace metals such as iron and mercury will be added to the waters in question during dredge-and-fill proceedings. Colloidal iron complexes are more prevelent in the Sturgeon Banks region than in the North Arm sediments. Iron complexes are not considered toxic and should present no real problem during the VIA expansion. High background levels of zinc and copper do exist and there is some mercury contamination of benthic fauna in the Sturgeon Bank area. Mercury concentrations added to the waters off Sea Island will add to the mercury accumulation of organisms in the area. The inertness of most metal contaminants in coarser materials suggests that a silt content limit could possibly be placed on allowable borrow material to aid in the prevention of further contamination of organisms in the area; however, this relationship has not been clearly shown.

5.6 Chlorinated Hydrocarbons

Most pesticide resides rapidly enter sediments. Sediment contamination with respect to PCBs has been found in the urban-industrial areas in the vicinity of Still Creek and the Burnette River and is suspected to be present in the vicinity of the Iona Island STP outfall. No organic chlorides or polychlorinated biphenyls were found (above the detection limits as per Table 6) in Sturgeon Bank sediments. Chlorinated hydrocarbon levels were not determined for Fraser River sediment samples.

5.7 Sulfides

Sulfides found in sediments from potential borrow areas were found to be present generally in an insoluble form, eg. iron sulfide and at a level determined to be uncontaminated with respect to hydrogen sulfide. A slight H_2S smell was detected in surface samples from Borrow site 6.

5.8 Bathymetry

Potential problems likely manifested in higher detritus levels, as well as other related changes, could result from dredge and fill procedures. Bathymetric considerations are more fully covered by Isfeld and Wu (1975), and the section written by the Fisheries and Marine Service, as part of the overall VIA expansion impact statement.

5.9 Borrow Site Selection

Borrow Site 1 (North Arm Channel)
Sample Site 1 was at the edge of this site, on the bank side. Benedict's Station 2 was in the channel. Although there is high Lead at 10-11.5 ft. and slightly high Zinc at 0-4 ft. and 20-21.5 ft., this site would be acceptable borrow material overall.

Borrow Site 2 (North Arm Channel)
This site is 30% to 83% silt and is not recommended by DPW.

Borrow Site 3 (North Arm Channel)
Although high Lead and Zinc were encountered in some strata of sample site 3 these were not present at sample site 9. This is acceptable borrow material.

Borrow Site 4 (Sturgeon Banks)

We did not chemically analyze cores from this area (its extreme sensitivity for fish and bird habitat excludes it from potential sites). Grain size analysis by depth (Isfeld and Wu, 1974) indicate generally a sandy surface underlain by silty sand; our surface samples of sand showed nutrient levels increased in elutrates, but heavy metals were present in naturally occurring amounts and pesticides were absent. Apparently, the sandy surface is not contaminated by the Iona outfall in the area samples; we cannot determine if the silty sand underneath is contaminated. If this site were selected, further tests of underlying sediments are required. This site is not recommended as borrow material.

Borrow Site 5 (Middle Arm, bank)
This site was identified after the EPS sampling program was completed. In view of its sensitivity for fish we did not institute a new coring program to sample it. Although its low silt content (Isfeld and Wu, 1974) indicate it is probably chemically acceptable, and Benedict's data (Table 6) indicates this, This is not recommended as borrow material.

Borrow Site 6 (North Arm, bank)
Surface samples from this site (Table 3) show variable quality, usually exceeding EPA Guidelines for COD,which is to be expected because of log booming in the area. This site is generally silty sand, and interesting, the general contamination does not extend beyond the surface however, Zinc levels are consistently higher than EPA guidelines and this site is a sensitive fish habitat. This site is not recommended as borrow material.

Borrow Site 7 (North Arm, bank)
This site was identified after the EPS sampling program was completed. In view of its sensitivity for fish, we decided not to institute a new core sampling program. This site is not recommended as borrow material.

Borrow Site 8 (North Arm, channel)
Samples from sediments on this site did not contain contaminants in excess of EPA or OME guidelines. This borrow site would be acceptable as fill for this operation

5.10 Summary

This study has examined possible pollutants discharged by the proposed dredge and fill operation.

Not all potential sites were examined; in view of resource limitations it was decided to concentrate on borrow areas sutable to DPW and not particularly sensitive for fish or birds. Cores and surface samples of sediments from Borrow sites 1, 3, 8 and 6 (because of the large quantity of fill available and its possible pollution through log storage) were studied in some detail. Elutriate tests at Borrow sites 3 and 8 were representative of North Arm channel sites. At Borrow site 4 (Sturgeon Banks) we took four surface samples; we analyzed no samples from Borrow site 2. Borrow site 5 and 7 were identified to us after completion of our sampling programs. We did not re-sample these because these areas were sensitive for fish (although Benedict's (1973) Station 1 is in the vicinity of Borrow Site 5 and appears representative of a non-silty site such as this).

This study has emphasized chemical analysis of the fill material because this is the prime determinant of the pollutants leaving the spillway. As discussed in Section 5.9, Borrow Sites 1, 3 and 8 in the North Arm Channel will be suitable sources of fill.

The initial retaining berm is also important; we believe the berm outlined by DPW (Isfeld and Wu, 1974) is low enough that deposited fill may be washed onto Sturgeon Banks at yearly highest tides; DPW state (H. Wu, pers. comm.) that the berm height can easily be raised with rock fill.

Sturgeon Banks is a very productive area for fish, however, parts of the bank already contaminated by the Iona STP outfall. Potential changes due to the spillway discharge are nutrient enrichment, possible oxygen depletion in a very limited area, increased concentrations of mercury, and addition of other heavy metals to the sediments through silt overflow. Although the level of water pollution added by the spillway discharge would be low if the recommended borrow sites are used, the discharge would better be returned to the Fraser River and away from this sensitive area.

SECTION 6

IMPACT ASSESSMENT FINDINGS

6.1 During the period March through September, the Fraser River has its maximum effect on the estuarine area in terms of sediment load. Dredging operations during this period will have little discernable effect on turbidity because of the already high background suspended sediment values. Suspended sediment levels associated with land reclamation operations will be more pronounced October through February, however, they will still remain relatively low. Settled sediments will contribute to the degradation of intertidal fish and bird habitat if the spillway discharge is discharged to Sturgeon Banks.

6.2 The presence of phosphates and release of ammonia in, and from, dredged material respectively will lead to nutrient enrichment during the time that spillway material is discharged. This may contribute to growth of unsightly algae.

6.3 Oxygen reduction, and increased suspended sediments could present serious, but localized, problems in areas immediately adjacent to the spillway discharge - estuarine water interface. (The latter will physically oscillate with the tidal phase.) If discharged to Sturgeon Banks, dilution over the greater Sturgeon Bank area should serve to minimize any such effects attributatable to the dredge/fill procedure beyond the immediate area. Any dissolved oxygen reduction would be most severe when dredging the initial four feet of borrow sites 7 or 6. A properly designed discharge to the Fraser River would be more satisfactory.

6.4 There is a possibility of disrupting existing contaminated sediments, if the spillway discharge is directed to the Iona Island Sewage Treatment Plant outfall channel. The spillway discharge should be directed away from the channel.

6.5 The sediments dredged from any borrow site (particularly Borrow Site 4) will contain bacteria. Similar dredging activities in the North Arm, Sea Island area, have not been known to cause bathing beach contamination; however, there is a slight possibility of contamination warranting attention during dredging periods to results of the health authorities regular sampling.

6.6 With respect to recommended North Arm borrow sites, liberation of H_2S at the dredging site is not expected to be a problem. Liberation of H_2S in the spillway area could occur when dredging the initial 1.5 feet of sediment if anaerobic conditions were present - this is not expected to occur.

6.7 Standards and Guidelines used by the U.S. Environmental Protection Agency and Ontario Ministry of Environment (OME) are designed for the dredging and open water disposal of sediments, and are not applicable to this landfill operation on a sensitive estuarine bank. However, the acceptable levels stated for the various parameters were the only levels located through our literature search which distinguish contaminated from uncontaminated sediments, and are useful in judging the likelihood of water pollution in the spillway discharge.

6.8 Parsons (1973) found that Fauna from Sturgeon Bank have higher levels of some heavy metals (notably mercury, but also possibly, cadmium, lead, zinc and copper) than animals elsewhere. In certain strata at Borrow sites 1 and 3, zinc and lead concentrations are encountered which are higher than levels set by EPA and OME for the dredging and open water disposal of spoil. Most of these contaminants will be contained in the landfill. Possible increases in lead and zinc loading to this sensitive area could be avoided by direction of the spillway discharge to the Fraser River.

6.9 The nature of the effluent from the Iona Island Sewage Treatment Plant discharged in an area adjacent to the proposed land reclamation site would actually, in most cases, dwarf any water contamination produced as a result of the dredge and fill procedure.

SECTION 7

RECOMMENDATIONS

1. Expansion onto Sturgeon Banks should be limited to the smallest area possible because of expected changes in water quality associated with a landfill operation. On the basis of this report alone, only Concept One would be acceptable, and Concepts Two to Five would be unacceptable; however, on the basis of other reports presented by the Ecological Sub-Committee, we recommend no expansion onto Sturgeon Banks.

2. If fill is required, it should be obtained from Borrow Sites 1, 3 or 8. Clayey silt below 18 feet at borrow site 1 should be avoided.

3. The berm height and spillway location outlined by D.P.W. (Isfeld and Wu, 1974) will lead to increased pollution. If Concept One is approved for construction, the construction techniques should be revised to ensure no tides or waves will overtop the berm. The spillway discharge should be directed to the Fraser River. This environmental design must be subject to Environment Canada approval.

4. A continous monitoring program should be carried out during the dredge and fill procedures to ensure that no gross changes in dissolved oxygen or turbidity or nutrient concentrations or bacteria develop during the project. A monitoring program without adequate background data is similarly limited in scope, however, it would also prove useful in weighing future land reclamation projects.

SECTION 8

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TABLE I

FRASER RIVER SUSPENDED SEDIMENT AND TURBIDITY LEVELS

REPORT	RECORDING STATION	SUSPENDED SEDIMENT OR TURBIDITY READINGS
JOHNSTON (1921)	New Westminster	20 ppm - non freshet 200-250 - freshet
GIOVANDO (1974)	Hope	Minimum 15 ppm - non freshet Maximum 900 ppm - freshet
BENEDICT et al (1973)	North Arm of Fraser River	50-57 (JTU) - August reading
SERVIZI et al (1970)	Hells Gate	180-240 JTU - freshet 15- 30 JTU - non freshet
B.C. RESEARCH (1973a)	South Arm of Fraser near Steveston	11- 19 ppm - non freshet 155-225 ppm - freshet

Table 2

TURBIDITY SETTLING TESTS

A. Settling Characteristics of River Sediments

SALINITY (ppt)		0	1.0	5.0	5.0
Sediment Concentration (% Wet weight)		4	4	4	8
TEMP. °C	TIME (hr.)	TURBIDITY (JTU)			
5	0.5	1250	740	210	215
5	1.0	900	360	160	185
5	3.0	710	185	100	113
5	7.0	465	120	65	70
5	24	400	45	30	35
15	0.5	825	740	177	120
15	1.0	710	470	170	119
15	3.0	790	245	88	50
15	7.0	750	120	50	45
15	24	370	62	21	21

B. Settling Characteristics of North Banks Sediments

SALINITY (ppt)		0	1.0	5.0	5.0
Sediment Concentration (% Wet weight)		4	4	4	8
TEMP. °C	TIME (hr.)	TURBIDITY (JTU)			
5	0.5	2100	1250	225	230
5	1.0	1500	1100	200	186
5	3.0	1500	790	106	125
5	7.0	2300	290	57	60
5	24	980	86	25	30
15	0.5	2500	1500	330	250
15	1.0	1500	900	193	180
15	3.0	1400	560	105	95
15	7.0	1200	300	53	32
15	24	610	98	18	15

NOTE: River sediment is a composite of sample site 3 (bore hole)
North banks sediments is a composite of sample sites 1 and 2 (bore holes)

Table and data are from Pollutech (1974).

WATER QUALITY IN THE VICINITY OF THE IONA ISLAND SEWAGE TREATMENT PLANT

QUALITY PARAMETER	MAXIMUM	MINIMUM	AVERAGE
Dissolved Oxygen (% Saturation)	105	85	93.5
Temperature (°C)	3.0	0.5	0.93
Total Organic Carbon (mg/l)	7	<1	3.7
Phenols (μg/l)	25	<1	6.8
Oil & Grease (mg/l)	6	2	3.3
Total Suspended Solids (mg/l)	22	4	10.7
Total Volatile Solids	8	<1	3.1
Nitrate (mg/l as N)	0.424	0.308	0.350
Ammonia (mg/l as N)	1.8	0.03	0.613
Total Phosphorus (μg/l)	529	147	337
Total Ortho Phosphate (μg/l as P)	352	59	204
pH	8.1	7.4	7.76

NOTE:
- Source of data is B.C. Research (1973)
- Sampling transect is shown in Figure 5 All samples were obtained within this transect.
- All samples were collected on January 9, 1973 at slack high tide.

Table 4

North Arm Fraser River Sediment Analyses - Surface Layer

Borrow Site	1		3			6					7	8	Guidelines	
Sample Site	1	2*	5	9	3	4	6	7	8	2	B*	10	EPA	OME
Volatile Solids (o/o)	4.82	0.42	1.12	0.49	1.43	3.23	4.16	5.28	3.72	2.26		0.62	6.0	
C.O.D. (o/o)	19.9		0.72	0.28	1.68	3.48	5.78	9.48	6.37	2.66		0.66	5.0	
Kjeldahl Nitrogen	530	220	160	920	100	90	660	720	470	270		2330	1000	2000
Total Phosphorus	280	1260	320	2140	190	280	320	580	530	280		880		1000
Sulfides	128.9		<5		8.7	366	44	41	60	57				
Mercury[a]	0.30			<0.1	0.15					0.02	0.052	<0.1	10	0.3
Copper	100	35		11[a]	100					100	21.3[a]	12[a]		
Lead[a]	39	12		11	N.D.					12	8	5	50	
Zinc[a]	80			47	46					69	55	39	50	
Cadmium	N.D.			<1[a]	N.D.					N.D.		<1[a]		
Cobalt	N.D.	20			N.D.					N.D.	12.6[a]			
Chromium	70	200		11[a]	70					50	190[a]	16[a]		
Iron	30000	49000		15800	30000					30000	258[a]	12900		
Manganese	1000	200		1000						2000	354[a]			
Molybdenum	N.D.	<2			N.D.					N.D.				
Nickel	10	100		36[a]	30					30	36[a]	48		

* Sample location fig. 5   a-atomic adsorption   b-emission spectroscopy   N.D. - Not Detectable

Sample locations on fig. 4 and 5. Mercury, Lead and Zinc analyses by atomic adsorption; other metals by semi - quantitative spectral scan except where noted. Results in mg/kg except where noted.

Table 5

North Arm Fraser River Sediment Analyses - Cores

Sample locations on fig. 4. Mercury, Lead and Zinc analyses by atomic absorption; other metals by semi - quantitative spectral scan (Pollutech, 1974) except where noted.

Borrow Site	Sample Site	Depth below sed. sfc. (feet)	Volatile Solids (%)	C.O.D. (%)	Kjeldahl Nitrogen mg/kg	Total Phosphorus mg/kg	Sulfides mg/kg	Mercury mg/kg	Copper mg/kg	Lead mg/kg	Zinc mg/kg	Cadmium mg/kg	Cobalt mg/kg	Chromium mg/kg	Iron mg/kg	Manganese mg/kg	Molybdenum mg/kg	Nickel mg/kg	Silver mg/kg
1	1	0-1.5	4.82	19.90	530	280	128.9			39	80								
		2.5-4	1.49	5.41	390	210	27.2	0.30	100	4	50	N.D.	N.D.	70	30000	1000	N.D.	10	trace
		5 - 6.5	1.96	1.68	300	240	41.1			-	-								
		10 -11.5	1.10	1.35	180	170	<5			113	38								
		15 -16.5	1.76	2.29	260	260	24.2	0.07	70		-	N.D.	N.D.	100	30000	1000	N.D.	30	trace
		20 -21.5	1.87	4.03	350	260	33.5			5	71								
3	3	0 - 1.5	1.43	1.68	100	190	8.7			N.D.	46								
		2.5 - 4	1.01	2.36	20	200	<5	0.15	100	146	46	N.D.	N.D.	70	30000	1000	N.D.	30	trace
		5 -6.5	1.06	1.07	20	190	8.7			-	-								
		10 -11.5	0.77	1.34	90	250	<5			N.D.	39								
		15 -16.5	1.11	1.50	20	210	18.3	0.01	100	-	-	N.D.	N.D.	50	30000	1000	N.D.	30	trace
		20 -21.5	3.05	3.59	40	320	35.6			9	89								
	9	Surface	0.49 [b]	0.28	92	214	-	0.1	11a	11	47	1.0a	-	11a	15800	-	-	36a	-
		5 - 10	0.57 [b]	0.38	98	224	-	0.1	10 [a]	5	35	1.0 [a]	-	9 [a]	12400	-	-	24 [a]	
		15 -16	0.56 [b]	0.28	62	311	-	0.7	11 [a]	10	41	1.0 [a]	-	13 [a]	14400	-	-	33 [a]	
.M.E. Guidelines					2000	1000		0.3											
P A Guidelines			6.0	5.0	1000			10.0		50	50								

a - atomic absorption

b - These are analyses for Total Organic Carbon

Table 5 (continued)

North Arm Fraser River Sediment Analyses - Cores

Sample locations on fig. 4. Mercury, Lead and Zinc analyses by atomic adsorption; other metals by semi - quantitative spectral scan (Pollutech, 1974) except where noted.

Borrow Site	Sample Site	Depth below sed. sfc. (feet)	Volatile Solids (%)	C.O.D. (%)	Kjeldahl Nitrogen mg/kg	Total Phosphorus mg/kg	Sulfides mg/kg	Mercury mg/kg	Copper mg/kg	Lead mg/kg	Zinc mg/kg	Cadmium mg/kg	Cobalt mg/kg	Iron mg/kg	Manganese mg/kg	Molybdenum mg/kg	Nickel mg/kg	Silver mg/kg	Chromium mg/kg
6	2	0 - 1.5	2.26	2.66	270	280	56.8	0.02	100	12	69	N.D.	N.D.	30000	2000	N.D.	30	trace	50
		2.5 -4	1.13	1.28	60	190	42.4			5	51								
		5 - 6.5	0.88	0.90	60	200	<5			-	-								
		10 -11.5	2.11	2.93	300	290	<5	0.16	100	6	68	N.D.	N.D.	30000	1000	N.D.	10	trace	70
		15 -16.5	2.14	4.07	30	410	<5			-	-								
		20 -21.5	2.80	2.98	30	410	200			3	61								
8	9	Surface	0.616[b]	0.664	2330	880	-	<0.1	12[a]	5	39	<1.0[a]	-	12900	-	-	48[a]	-	16[a]
		5 - 10	0.433[b]	0.489	600	810	-	0.2	11[a]	6	41	<1.0[a]	-	15200	-	-	29[a]	-	16[a]
		15 -16	0.554[b]	0.344	1080	1720	-	0.3	10[a]	12	36	<1.0[a]	-	14300	-	-	28[a]	-	14[a]
O.M.B. Guidelines					2000	1000		0.3											
E P A Guidelines			6.0	5.0	1000			10.0		50	50								

a - atomic adsorption

b - These are analyses for Total Organic Carbon

Table 6

Sturgeon Bank and Middle Arm, Fraser River Sediment Analyses - Surface

Borrow Site	4 (Sturgeon Bnk.)		5	Guidelines	
Sample Site	11	13	1	E P A	O.M.E.
Volatile Solids %	-	-	0.21	6.0	
C.O.D. %	6.2	5.1	-	5.0	
Kjeldahl N	-	-	150	1000	2000
Total Phosphorus	-	-	1250		1000
Mercury	N.D.	N.D.	-	10	0.3
Copper	15	15	20		
Lead	<5	<5	5	50	
Zinc	90	65	-	50	
Chromium	45	55	80		
Iron	22000	26000	49000		
Nickel	55	50	100		

Station 13 had 47.8% medium sand, 51.5% fine sand, and 0.7% silt and clay.

No pesticides or PCB's were found at Sample Sites 11 and 13 at the following levels of detection in ppb (parts per billion)

Polychlorinated Biphenyls	20	γ - Chlordane	1.0
Heptachlor	0.8	α - Chlordane	1.0
Aldrin	0.8	p,p' - DDD	2.0
p,p' - DOMU	1.4	p,p' - DDT	2.0
α - Endosulfan	1.4	o,p' - DDT	1.4
β - Endosulfan	1.0	p,p' - DDE	1.4
Lindane	0.6	Dieldrin	1.0
Endrin	1.2	Methoxychlor	4.0

Table 7

Elutriate Test for Sturgeon Bank Sediments

PARAMETER	SEDIMENT		RECEIVING H_2O	ELUTRIATE			
SITE	11	13		11	12	13	14
Ammonia	-		0.04 mg/1	0.33	0.20	0.39	0.26
Nitrite	-	-	<0.005 mg/1	0.11	0.006	0.06	0.005
Nitrate	-	-	0.144 mg/1	0.137	0.92	0.20	0.074
Ortho Phosphate	-	-	<0.005	0.072	0.063	0.079	0.064
Total Phosphates	-	-	0.021 mg/1	0.14	0.93	0.124	0.104
C.O.D.	6.2 mg/kg	5.1 mg/kg	<20 mg/1	32.0	40.0	36	52
Chromium	45 mg/kg	55 mg/kg	<10.0 ug/1	10	10	10	10
Copper	15.0 mg/kg	15.0 mg/kg	<5.0 ug/1	5.	5.0	5.0	5.0
Iron	22,000 mg/kg	26,000 mg/kg	25.0 ug/1	160	205	175	25.
Lead	<5.0 mg/kg	<5.0 mg/kg	<10. ug/1	<10 ug/1	<10 ug/1	<10 ug/1	<10 ug/1
Mercury	N.D.	N.D.	-	-	-	-	-
Nickel	55.0 mg/kg	50.0 mg/kg	<50. ug/1	950 ug/1	<50 ug/1	<50 ug/1	<50 ug/1
Zinc	90.0 mg/kg	65.0 mg/kg	<5.0 ug/1	15 ug/1	15 ug/1	30.0 ug/1	15.0 ug/1

Table 8
Elutrate Test for Borrow Site 3, Sample Site 9

PARAMETER	DEPTH	SEDIMENT	RECEIVING WATER	ELUTRATE
T.O.C.	Surface	0.494%	4.0 mg/l	5 mg/l
	5-10'	0.574%	-	5 "
	15-16'	0.555%	-	5 "
C.O.D.	Surface	0.281%	8.70 mg/l	25.2 mg/l
	5-10'	0.380%	-	10.3 "
	15-16'	0.279%	-	15.2 "
Total Kjeldahl N.	Surface	920 mg/kg	0.420 mg/l	1.82 mg/l
	5-10'	980 "	"	1.12 "
	15-16'	620 "	"	1.68
Total Phosphates	Surface	2,140	0.02 mg/l	0.02 mg/l
	5-10'	2,240	"	0.04 "
	15-16'	3,110	"	0.06 "
Total Cadmium	Surface	<1.0 mg/kg	<1.0 μg/l	<1.0 μg/l
	5-10'	<1.0 "	-	<1.0 "
	15-16'	<1.0 "	-	<1.0 "
Chromium	Surface	11.0 mg/kg	<1.0 μg/l	<3.0 μg/l
	5-10'	9.0 "	-	<3.0 "
	15-16'	13.0 "	-	<3.0 "
Copper	Surface	11.0 mg/kg	<1.0 μg/l	3.0 μg/l
	5-10'	10.0 "	-	1.0 "
	15-16'	11.0 "	-	1.0 "
Iron	Surface	15,800 mg/kg	<50.0 μg/l	50.0 μg/l
	5-10'	12,400	-	<50.0 "
	15-16'	14,400	-	<50.0
Lead	Surface	11.0 mg/kg	<1.0 μg/l	<1.0 μg/l
	5-10'	5.0 "	-	<1.0 "
	15-16'	10.0 "	-	<1.0 "
Mercury	Surface	<0.1 mg/kg	0.12 μg/l	0.18 μg/l
	5-10'	-	-	0.14 "
	15-16'	<0.1	-	0.24
Nickel	Surface	36 mg/kg	<1.0 μg/l	3.0 μg/l
	5-10'	24 "	-	<1.0 "
	15-16'	33 "	-	<1.0 "
Zinc	Surface	47 mg/kg	1.0 μg/l	12 μg/l
	5-10'	35	-	1 "
	15-16'	41	-	1 "

Table 9

Elutrate Test for Borrow Site 8, Sample Site 10

		SEDIMENT	RECEIVING WATER	ELUTRATE
T.O.C.	Surface	0.616%	4.0 (mg/1)	5.00 (mg/1)
	5-10'	0.433%	"	6.00 "
	15-16'	0.554%	"	5.00 "
C.O.D.	Surface	0.664%	8.7 (mg/1)	18.10 (mg/1)
	5-10'	0.487%	"	16.00 "
	15-16'	0.344%		10.80 "
Total Kjeldahl N.	Surface	2.330 mg/kg	0.420 (mg/1)	2.10 (mg/1)
	5-10'	600 "	"	2.24 "
	15-16'	1080	"	1.86
Total Phosphates	Surface	880 mg/kg	0.02 (mg/1)	0.50 (mg/1)
	5-10'	810 "	"	0.07 "
	15-16'	1720 "	"	0.06 "
Total Cadmium	Surface	<1.0 mg/kg	<1.0 (μg/1)	<1.0 (μg/1)
	5-10'	<1.0 "	"	"
	15-16'	<1.0 "	"	"
Chromium	Surface	16.0 mg/kg	<1.0 (μg/1)	<3.0 (μg/1)
	5-10'	16.0 "	"	<3.0 "
	15-16'	16.0 "	"	<3.0 "
Copper	Surface	12.0 mg/kg	<1.0 (μg/1)	3.0 (μg/1)
	5-10'	11.0 "	"	2.0 "
	15-16'	10.0 "	"	2.0 "
Iron	Surface	12,900 mg/kg	< 50. (μg/1)	50. (μg/1)
	5-10'	15,200 "	"	< 50.
	15-16'	14,300 "	"	50.
Lead	Surface	5.0 mg/kg	< 1.0 (μg/1)	<1.0 (μg/1)
	5-10'	6.0 "	"	<1.0 "
	15-16	12.0 "	"	<1.0 "
Mercury	Surface	0.1 mg/kg	0.12 (μg/1)	0.28 (μg/1)
	5-10'	0.2 "	"	0.32 "
	15-16'	0.3 "	"	0.18 "
Nickel	Surface	48.0 mg/kg	< 1.0 (μg/1)	< 1.0 (μg/1)
	5-10'	29.0 "	"	<1.0 "
	15-16'	28.0 "	"	<1.0 "
Zinc	Surface	39.0 mg/kg	1.0 (μg/1)	4.0 (μg/1)
	5-10'	41.0 "	"	7.0 "
	15-16'	36.0 "	"	2.0 "

TABLE 10 SUMMARY OF WATER QUALITY IN THE LOWER FRASER SYSTEM PRIOR TO 1972 (From Benedict et al., 1973)

Fraser River Quality for North Arm / Middle Arm Reaches.

Quality Parameter \ Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
TEMP. (°C)	0.0-6.0	2.0-6.0	3.5-8.0	6.0-10.0	7.0-12.0	11.0-15.0	13.0-19.0	15.0-20.0	12.0-21.5	6.5-13.0	2.5-9.0	0.5-5.0
DO (mg/ℓ)	8.6-14.4	9.7-13.7	10.2-14.5	9.8-12.4	9.7-12.1	9.0-11.6	7.2-11.3	8.2-10.0	2.4-11.0	9.7-11.7	8.0-12.6	10.1-12.3
BOD (mg/ℓ)	2 - 3		<1 - 2	3 - 4	<4	<1 - 2	<1 - 3	<1 - 3	<1 - 4	1 - 3	2 - 4	2 - 3
COD (mg/ℓ)			6 - 9					3 - 7				
TOC (mg/ℓ)									1 - 16			
PHENOLS (μg/ℓ)									0.9 - 7.2			
OILS/GREASE (mg/ℓ)									0.5 - 3.0			
DETERGENTS (mg/ℓ)												
TAN/LIG (mg/ℓ)			0.30 - 0.45					0.15-0.35	0.3-6.9			
COLOUR UNITS												
P.B.I. (mg/ℓ)			N.D.-3.2					1.4-4.8				
TOT. COLIF./100mℓ	<30-150000	90-110000	<30-93000	<30-150000	<30-110000	40-150000	<30-230000	40-430000	40-230000	40-93000	40-230000	<30-93000
TURBIDITY UNITS								21 - 28	2 - 25			
TOT. SOLIDS (mg/ℓ)			96-23,143					77-117				
TOT. VOL. SOLIDS (mg/ℓ)			13-3,848					22 - 31				
SUSP. SOLIDS (mg/ℓ)			5 - 22					47 - 71	21 - 129			
DISS. SOLIDS (mg/ℓ)								70-286	46-3006		66 - 244	
CONDUCTANCE (μmho)	91-25 280		109-27,800	116-379	93-99	77-92	79-86	92-404	64-3230		56-340	
KJELDAHL-N (mg/ℓ)									0.10-0.43			
NITRATE-N (mg/ℓ)			0.20-0.24	0.08-0.18		0.05-0.14		0.04-0.07	0.04-0.06		0.11-0.19	
NITRITE-N (mg/ℓ)	ND-0.01								0.003-0.004			
ORTHO-P (μg/ℓ)					3 - 30		5 - 10	<4	<4 - 40		<4	
TOTAL-P (μg/ℓ)									1 - 24			
ORGANOCHLORIDE (μg/ℓ)												
ORGANOPHOSPH. (μg/ℓ)												
TOTAL HARDNESS 1)			71-97					46-49	37-605			
TOT. ALKALINITY 1)	27-76		48-91	45-53	36-40	32-37	38	32-47	28-49		21 - 31	
pH	7.0-7.4		7.4-7.8	7.5-7.7	7.4-7.8	7.4-7.7	7.7-7.8	7.4-8.2	6.7-7.9		7.2-7.5	
FREE CO_2 (mg/ℓ)	1.2-12.5		4.6-4.9	3.5-4.9	2.2-5.0	2.4-6.8	2.5-3.5	2.0-4.4	0.7-9.6		3.4-6.8	
BICARB. (mg/ℓ)												
CARBONATE (mg/ℓ)												
Ca (mg/ℓ)	11.4-176		23.8-36.0	14.5-16.8	14.3-16.8	9.9-14.9	11.9-13.9	14.9-16.9	8.3-39.2		7.1-11.7	
Mg (mg/ℓ)	1.7-775		25.9-32.0	4.0-8.3	1.8-2.1	2.7-3.2	3.8	3.4-8.6	2.1-102.0		1.7-6.8	
Na (mg/ℓ)	2.2-4850		1.9-597	4.0-44	1.4-2.2	1.0-1.8	1.7-1.9	1.1-43.3	1.1-790		0.4-21.5	
K (mg/ℓ)	ND-206		11.1-21.7	1.2-2.0	0.9-1.6	0.5-1.4	1.2-1.9	1.4-3.8	0.6-125		0.5-4.8	
Cl (mg/ℓ)	2.4-9350		ND-11,600	1.2-81.1	<1.0-2.9	<1.0-1.6	≤1	1.0-80.0	1.0-1120			
F (mg/ℓ)											3.9-16.7	
I (mg/ℓ)												
SO_4 (mg/ℓ)	3.5-1136		38.3-42.6	23.6-44.0	2.3-9.4	5.3-10.4	3.6-4.6	5.5-18.7	7.8-45.0		0.1-69.1	
CN (mg/ℓ)												
Al (mg/ℓ)												
Cd (mg/ℓ)												
Cu (mg/ℓ)			ND					ND	0.002-0.052			
Hg (mg/ℓ)												
Fe (mg/ℓ)									0.45-0.85			
Pb (mg/ℓ)									0.001-0.034			
Mn (mg/ℓ)												
Ni (mg/ℓ)												
Ag (mg/ℓ)												
Zn (mg/ℓ)									0.0005-0.007			
As (mg/ℓ)												
SILICA (mg/ℓ) 2)			4.6	4.2-4.6		4.0-5.7		4.1-4.8	3.6-4.8			
FLOW (cfs)												

1) mg/ℓ as $CaCO_3$

2) mg/ℓ as SiO_2

ND = not detectable

Table 11

Sediment Quality From Previous Studies

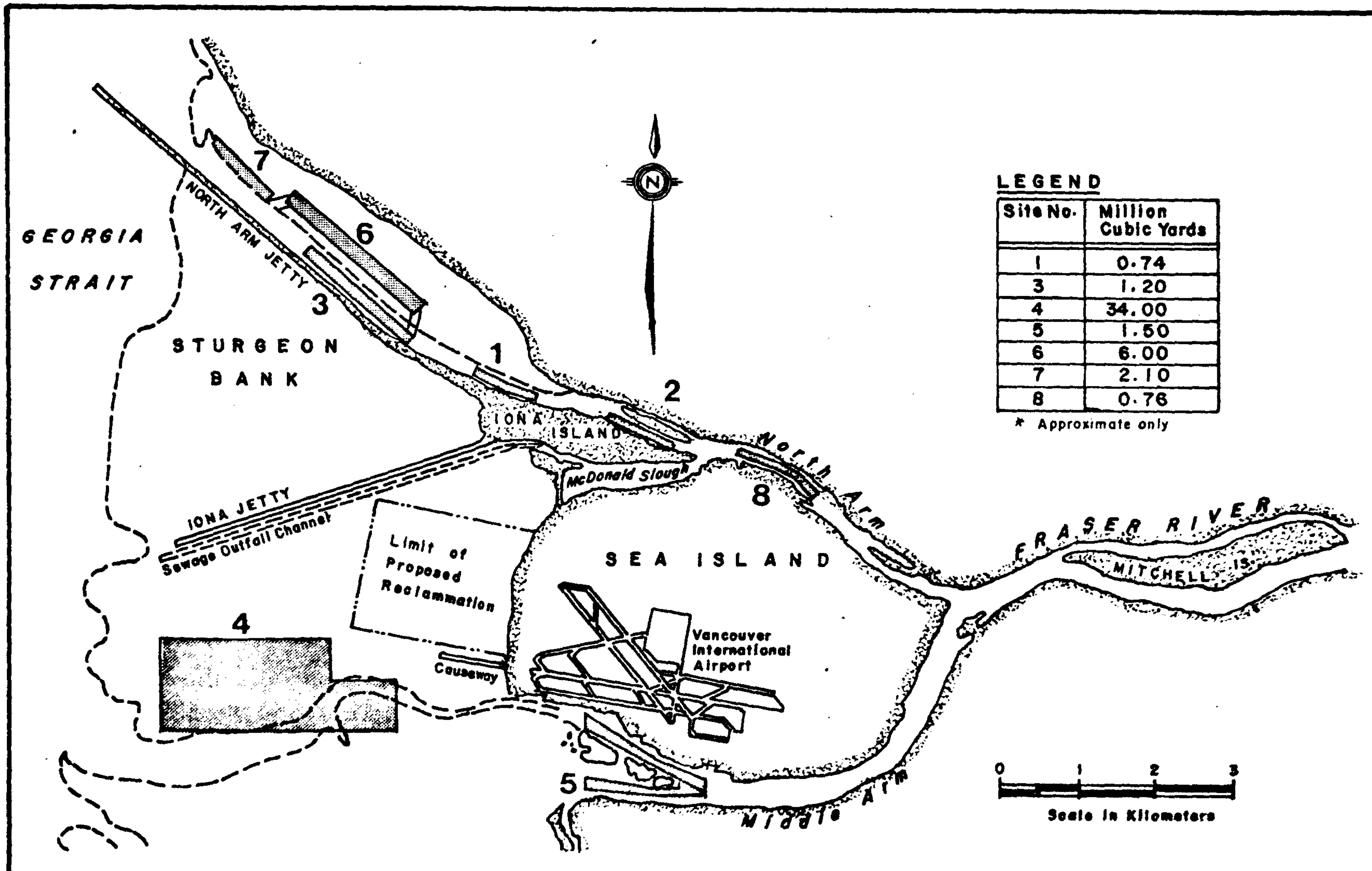
SEDIMENT QUALITY DETERMINED IN PREVIOUS STUDIES

Quality Parameter (in mg/kg)	Westwater Research (Benedict *et al* 1973) (1)			Westwater Research (Hall, unpublished) (2)		B.C. Research (1973) Iona Island Study (from study transect) (2)		
	Station 1	Station 2	Station 3	Station A	Station B	Maximum	Minimum	Average Background
Volatile Content	0.21	0.42	0.25	-	-	-	-	-
Kjeldahl Nitrogen	150	220	210	-	-	3360	58	101
Total Phosphorus	1250	1260	1140	-	-	926	386	390
TOC	-	-	-	-	-	327	0.23	0.17
Cadmium	-	-	-	2.7	-	5.8	0.5	0.61
Cobalt	20	20	20	14.3	12.6	34	13	15.3
Chromium	80	200	125	233	190	102	22	22.8
Copper	200	35	10	127	21.3	168	15	15.4
Iron	49	70	56	303	258	32	15.2	17.8
Mercury	-	-	-	0.50	0.052	-	-	-
Manganese	200	500	200	415	354	514	151	273
Molybdenum	<2	<2	<2	-	-	-	-	-
Nickel	100	60	60	59.2	36	65	32	34
Lead	5	5	5	102	8.02	189	7	5.7
Zinc	-	-	-	142	55.4	-	-	-

(1) Metals measured by emission spectroscopy.

(2) Metals removed with perchloric/nitric acid and measured with atomic absorption.

- Background in B.C. Research report = north of Iona Island Jetty.
- Sample locations given on Figure 5.



LEGEND

Site No.	Million Cubic Yards
1	0.74
3	1.20
4	34.00
5	1.50
6	6.00
7	2.10
8	0.76

* Approximate only

FIGURE 1 LOCATION OF PROPOSED BORROW SITES.

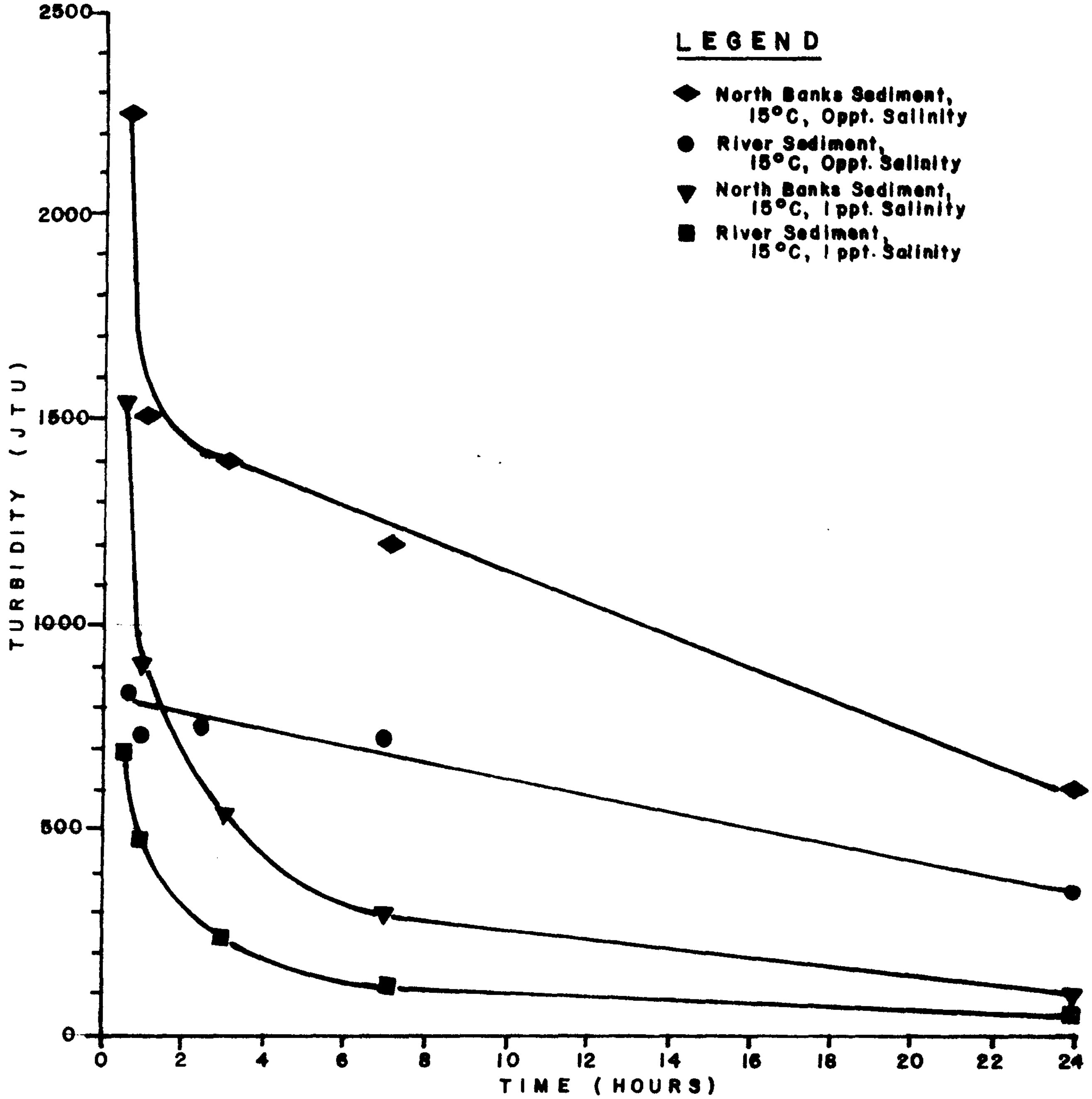


FIGURE 2 PLOTS OF RESIDUAL TURBIDITY IN SUSPENSION DURING SEDIMENT SAMPLING TESTS

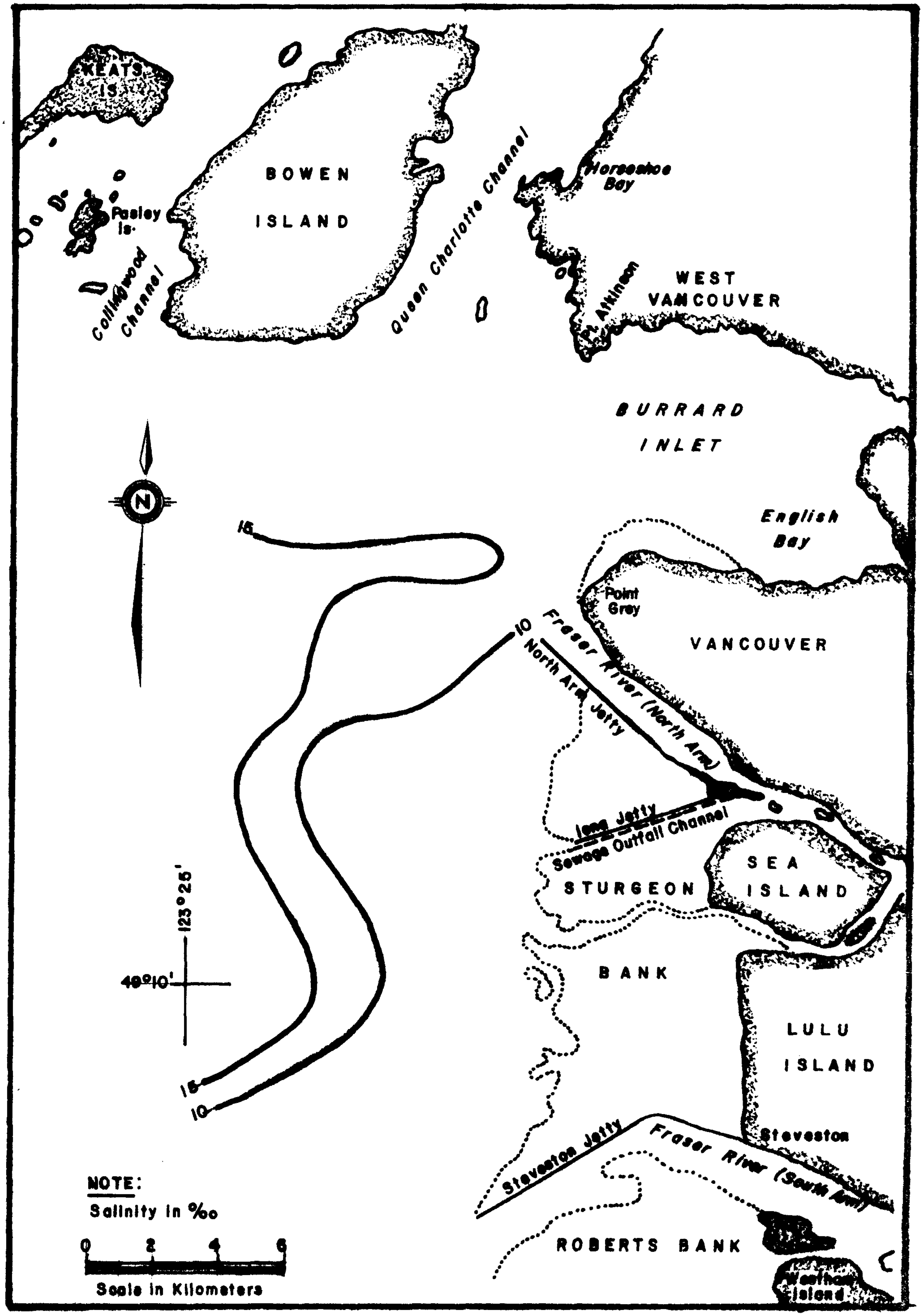


FIGURE 3 SURFACE DISTRIBUTION OF SALINITY AT THE FRASER RIVER ESTUARY (May 29 - June 1, 1950)
(From Hoos and Packman, 1974)

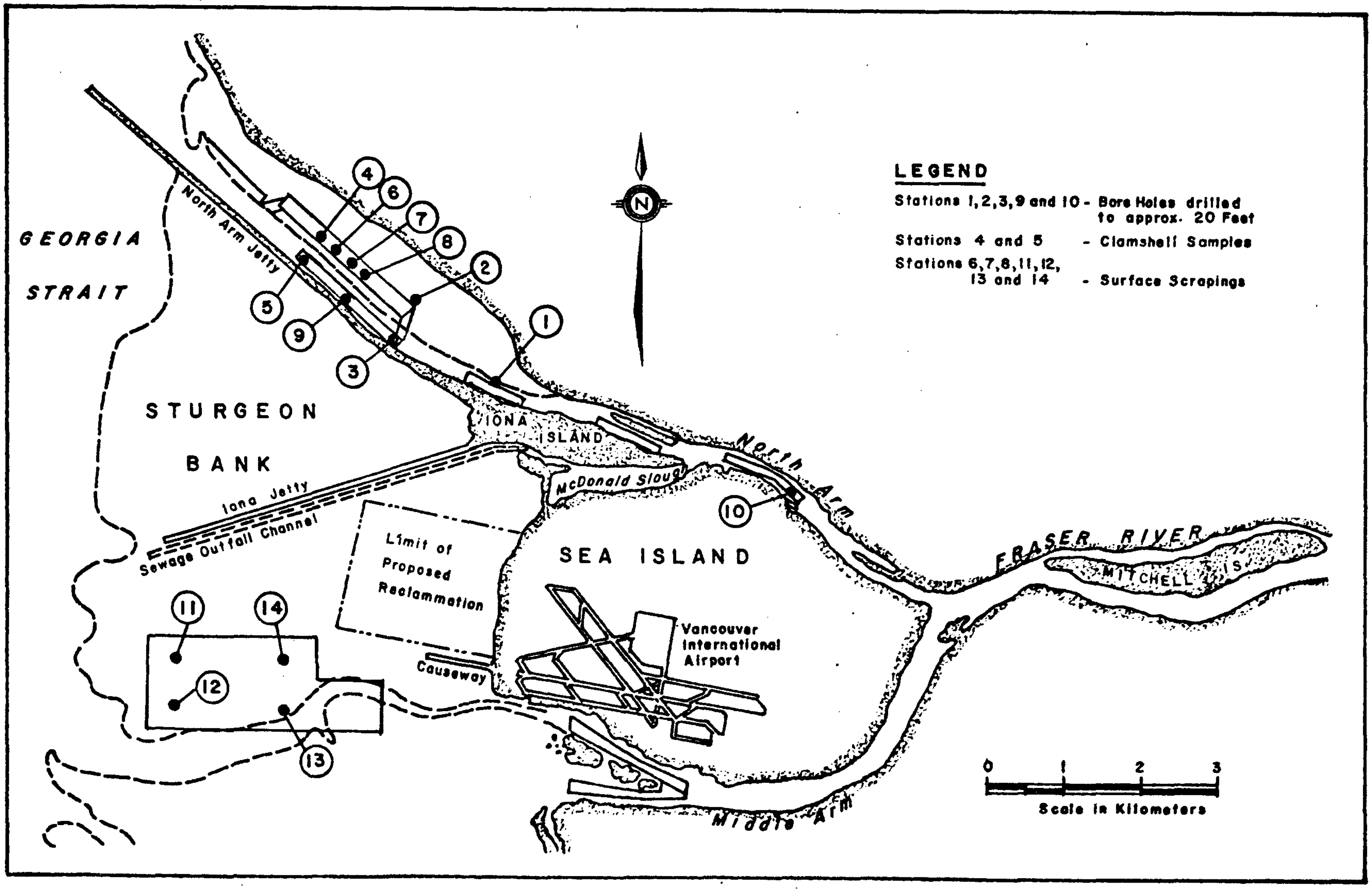


FIGURE 4 LOCATION OF SEDIMENT SAMPLING STATIONS

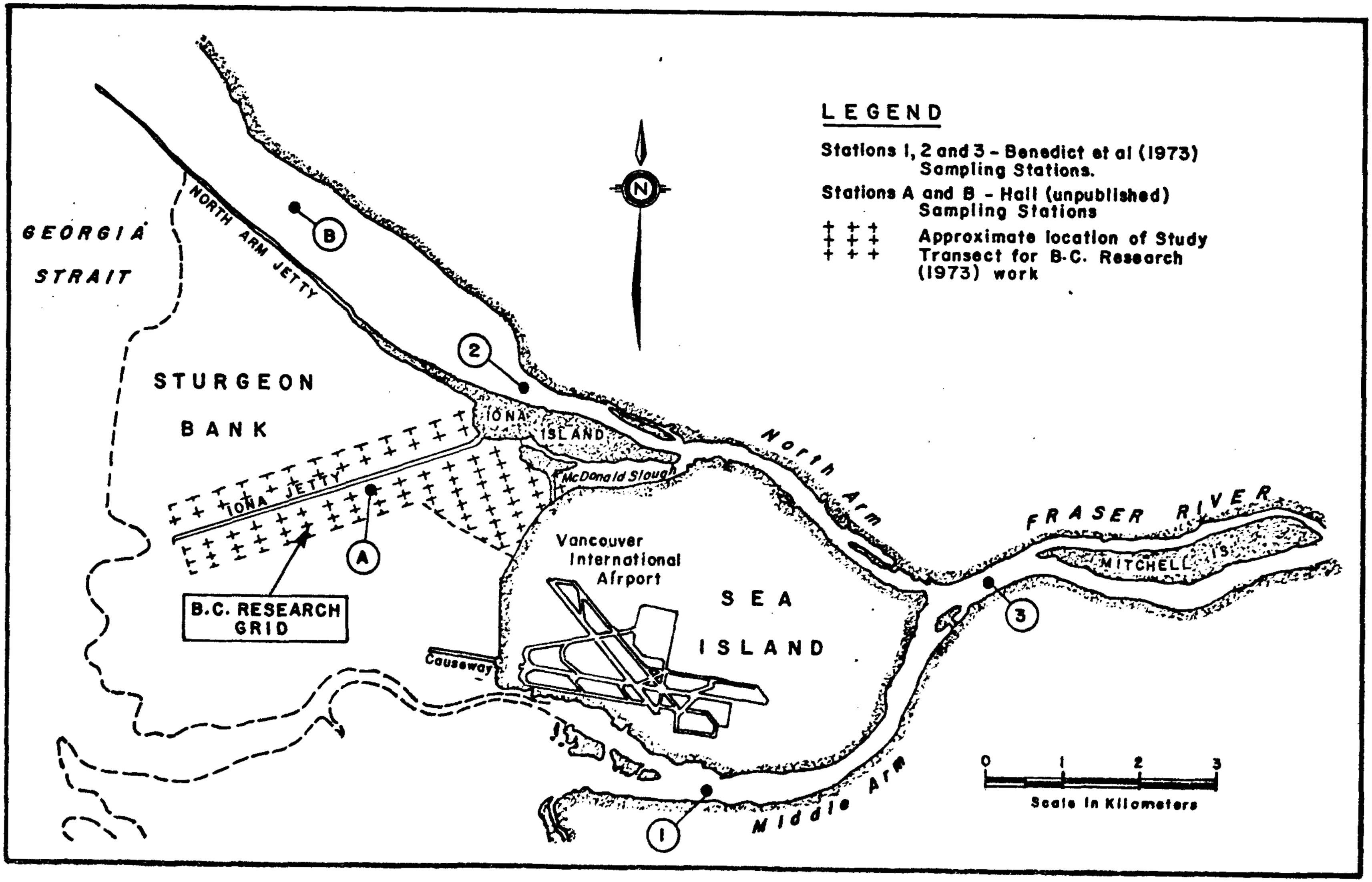
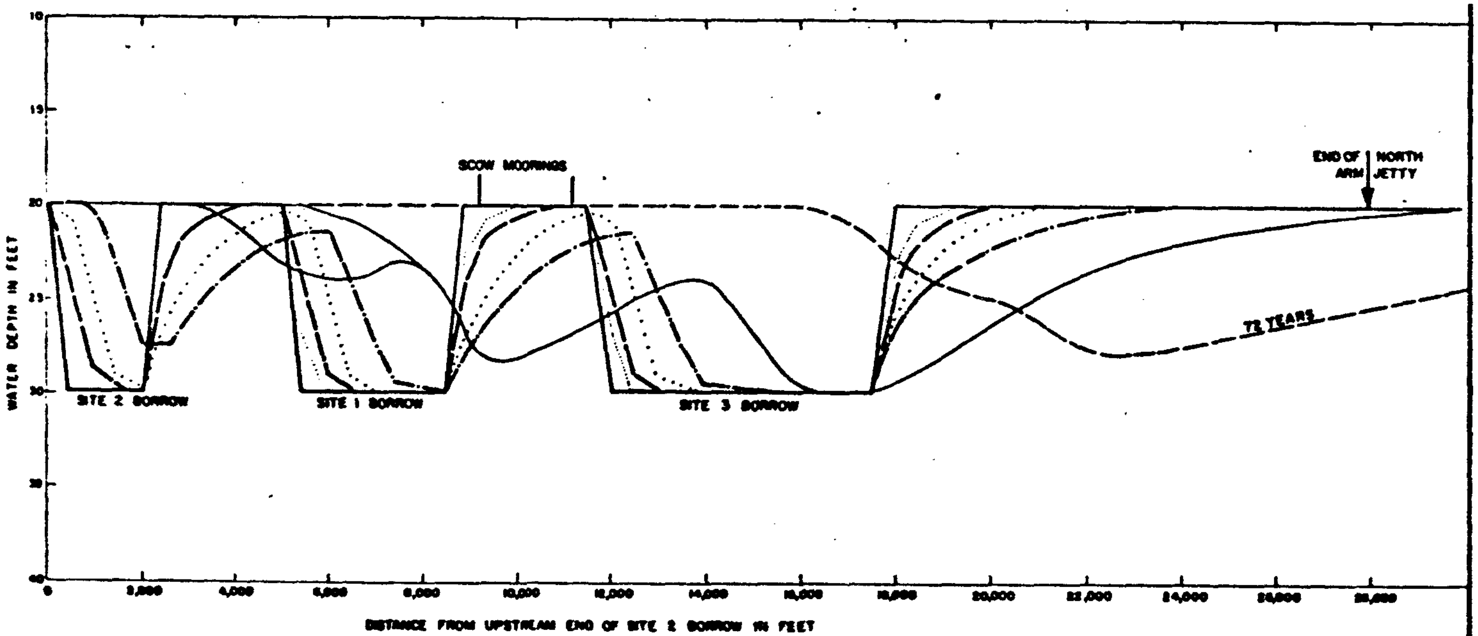


Figure 5 - Location of other sampling stations referred to in the text.



NOTE

BED ELEVATIONS AFTER 1,2,4,8,20 AND 72 YEARS ARE SHOWN DUE TO BED LOAD ONLY
A CONSERVATIVE ESTIMATE OF BED LOAD, DUE TO COMBINATION OF BED AND SUSPENDED
LOAD WILL BE TO HALF THE TIMES INDICATED ON FIGURE; ie, THE BED AFTER 0.5,1,2,4,10
AND 36 YEARS ARE INDICATED.

FIGURE 6 - Infill and Migration of Borrow Holes in North Form of North Arm

APPENDIX I

SAMPLING AND ANALYTICAL PROCEDURES FOR SEDIMENT ANALYSIS

As a supplement to the initial water quality "impact study" (Pollutech, 1974), surface samples collected from Sturgeon Bank (in the proposed Phase IV borrow region) and core samples from two locations in the North Arm of the Fraser River (Figure 2) were analysed.

The Sturgeon Bank sediments were collected in plastic bottles, kept on ice until delivery to the lab and stored at 4° C prior to testing. The core samples were collected in the same manner as outlined in the Pollutech report. Water samples for both Sturgeon Bank and North Arm sediment elutriate tests were collected from surface waters above Sturgeon Bank approximately 1/2 mile west of the proposed reclamation site. Water samples were also stored at 4° C. The Sturgeon Bank samples were analysed in the EPS laboratory. The procedures that were used are outlined in the Fisheries Service - Environmental Protection Service Laboratory Manual. Metal concentrations were determined using atomic absorption via direct aspiration. The North Arm core samples were snalysed by Pollutech, Pollution Advisory Service. They were preserved as outlined in the Pollutech (1974) report and sediment analysis procedures were carried out according to the Environmental Protection Agency Manual entitled, "Chemistry Laboratory Manual on Bottom Sediments" (1969). All the chemical sediment results were calculated on a dry weight basis. Elutriate samples from these cores were analysed according to Standard Methods for the Examination of Water and Wastewater" (1971), published by the American Public Health Association. The Metal analysis of the North Arm samples were carried out using atomic absorption via extraction with APDC and MIBK except for iron which was analysed using direct aspiration and mercury which was analysed using a flameless atomic absorption method.

The elutriate test procedures, as followed by both the EPS and Pollutech laboratories are described in a recent paper published by the U. S. Army Engineer Waterways Experiment Station (office of Dredged Material

Research - March, 1974). Briefly, the sediment samples are mixed with the receiving water in a volumetric 1:4 ratio of dredged material - receiving water. This is done by volumetric displacement. Three hundred ml. of unfiltered receiving water is placed in a 2/1 graduated cylinder and the sediment added until the mixture reaches a total volume of 600 ml. The flask is then filled to 1500 ml. with unfiltered receiving water giving a final volume ratio of 1.4 dredged material - disposal site water. The mixture is shaken for 1/2 hour on a mechanical rotating mixer and the suspension is then decanted, filtered and finally analysed.

APPENDIX II

GAPS IN KNOWLEDGE

1. The complex nature of the estuarine ecosystem prohibits the development of a simulation model accurate enough to predict quantitative changes in turbidity and sediment load due to dredging activities. A study, several years in duration, would be required to develop a model with sophistication sufficient to make quantitative projections. As a consequence, this study has leaned toward qualitative rather than quantitative projections.

2. Background data on existing turbidity and suspended sediment levels in the Fraser River estuary are sparse. Those data that have been used in this report pertain to the Fraser River itself. These values have proven useful in determining gross seasonal fluctuations in background turbidity and suspended sediment content.

3. The aggregated effects of wind surface currents, upwellings, varying tidal currents and Fraser River discharge rates make the accurate calculation of spillway discharge dilution rates impossible. Spillway discharge onto Sturgeon Banks may result in localized effects on water quality. Spillway discharge onto the Fraser River is recommended.

4. Existing guidelines pertaining to dredging materials are incomplete (O'Neal and Sceva, 1971). These standards include only seven parameters, based on dredging procedures carried out in Washington State and, as such are limited in scope. EPS conducted elutriate tests on proposed borrow materials which provided additional information on which to judge dredging material quality.

5. Baseline data on the water quality for Sturgeon Bank have been infrequently recorded. Water quality on the Bank is affected tidally, seasonally, and by the effluent from the Iona Island Sewage Treatment Plant. A complete knowledge of baseline values would require systematic water quality monitoring for a number of years. Because baseline data is scare, the assessment of dredging impact on chemical water quality is restricted. How-

ever, use of the data that were available and the examination of results from elutrate testing procedures permitted a qualitative assessment of expected water quality changes attributable to dredging operations.

6. Deep (to 15 feet) core samples of sediments from the Sturgeon Bank borrow area have not been analyzed. This would be necessary if this borrow site is further considered.

7. EPS elutrate testing did not include sulfides, a parameter which could be significant in waters deficient in oxygen. This would only constitute a problem if spillway discharge were directed toward the environmentally degraded area adjacent to the Iona Island Sewage Treatment Plant, an area of known low oxygen concentration. This report recommends direction of spillway discharge away from this area.

8. Synergistic effects have been noted in investigations of toxicity of metals in solution while sub-lethal effects of metals on fish are not fully understood. The determination of acceptable metal concentration levels is, therefore, difficult. Since there may be a correlation between the amount of metals released to solution and particle size, recommendations for the choice of borrow materials with the least amounts of silt and clay have been made.

9. The detection of pesticide levels in waters and sediments is limited by the lack of significantly sensitive testing procedures. Most pesticide residues are known to rapidly enter sediments. In view of this phenomenon, EPS carried out analyses on residue levels of Sturgeon Bank sediments using the method now available. P.C.B. and pesticide levels were not determined for the Fraser River sediments in this study, but are presented in an addendum (S.G. Pond, in prep.)

APPENDIX III

ENVIRONMENTAL EFFECTS OF DREDGING OPERATIONS: A LITERATURE REVIEW

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For:

Environemntal Protection Service
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January, 1975

LITERATURE REVIEW ON THE EFFECTS OF DREDGING

INTRODUCTION:

This report has been prepared as one segment of Environmental Protection Service input into assessment studies for the proposed Vancouver International Airport (V.I.A.) expansion. The information in this report has been divided into various categories. Hydraulic dredging techniques, the landfill method associated with plans for V.I.A. expansion, have been reviewed in a separate category.

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.

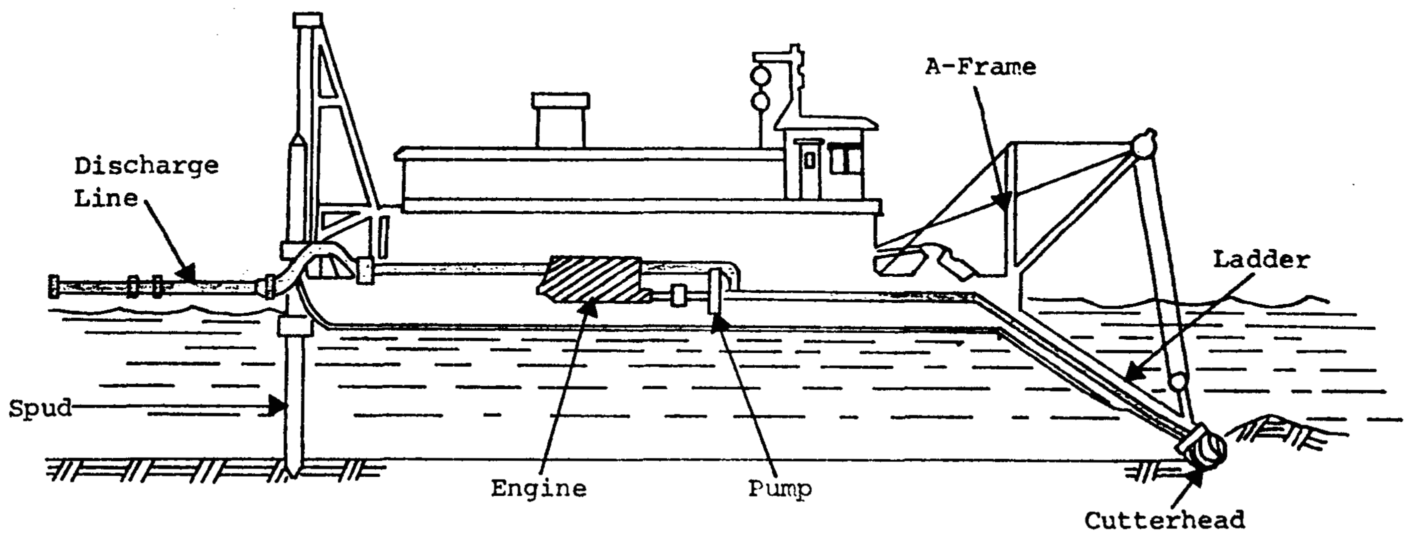

FIGURE 1 SKETCH OF HYDRAULIC PIPELINE DREDGE

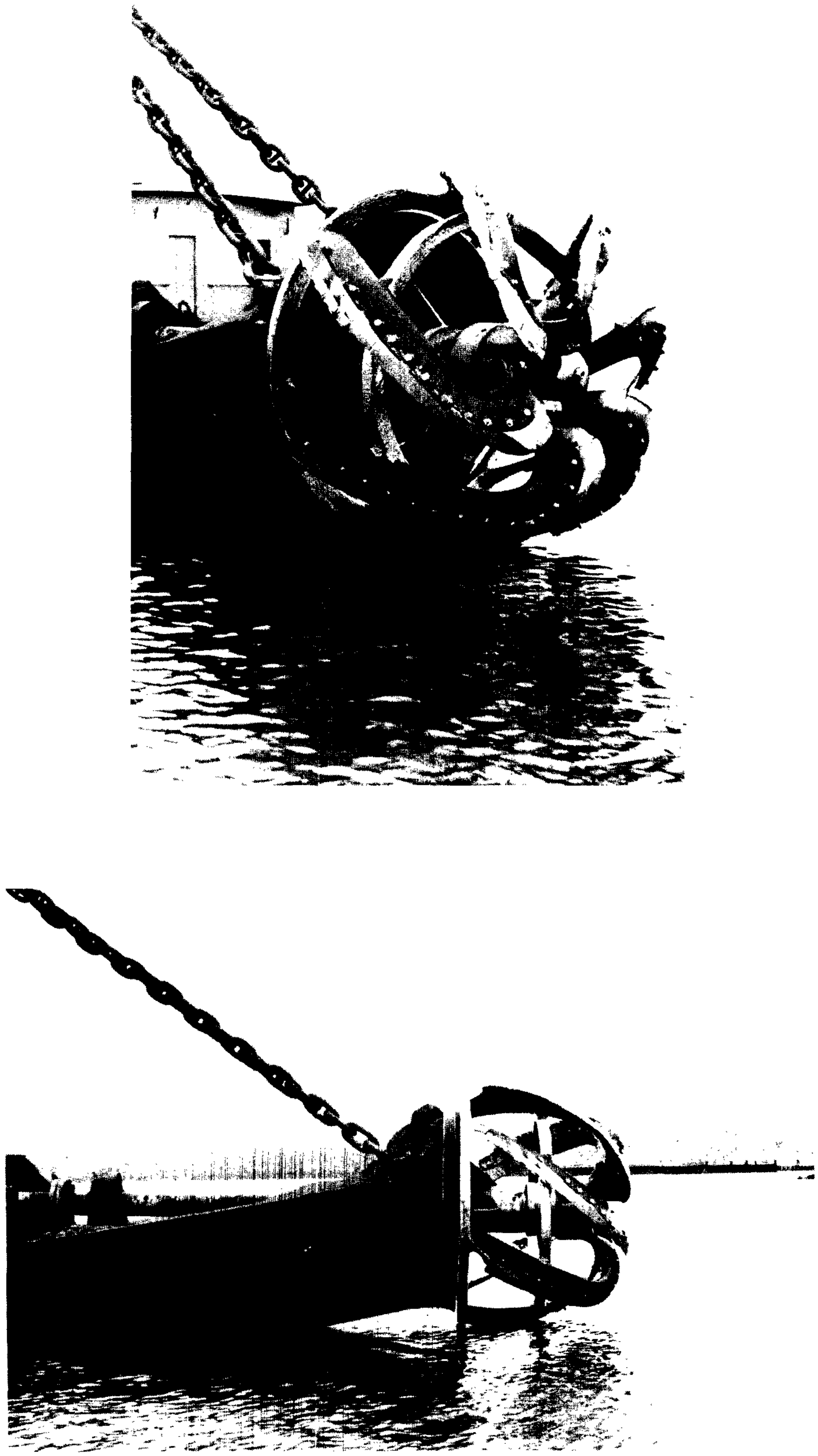

FIGURE 2 PHOTOGRAPHS OF PIPELINE DREDGE CUTTERHEADS

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.

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 tug-boats. 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 suspendded 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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