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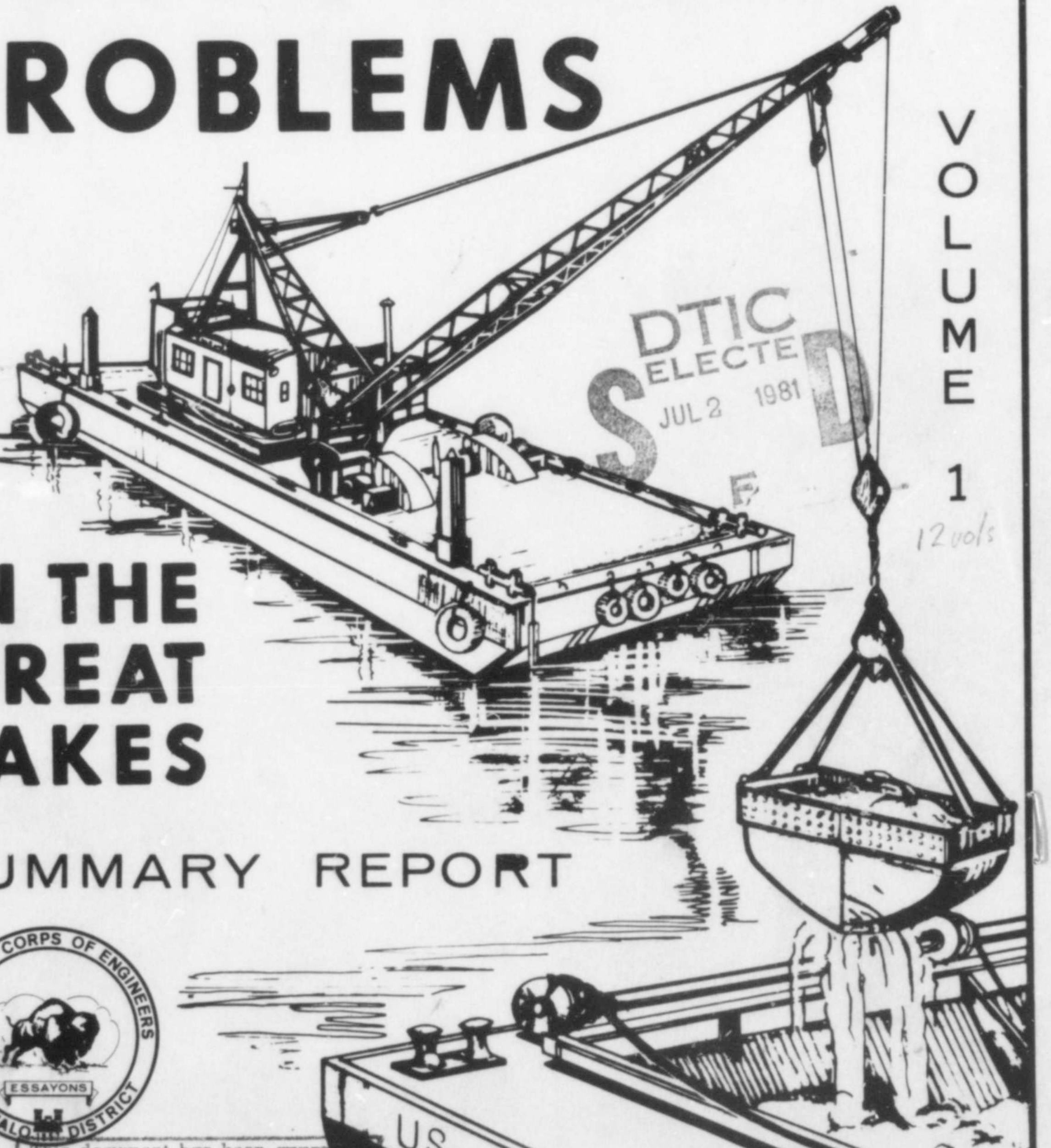
DREDGING and WATER QUALITY PROBLEMS IN THE GREAT LAKES



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U.S. ARMY CORPS OF ENGINEERS
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The present report presents the results of a study conducted by the Corps of Engineers with cooperation of the Federal Water Pollution Control Administration to evaluate the effects of water quality of current dredging practices including the disposal of dredged material in unconfined open water areas of the Great Lakes, as well as to develop the most practical methods for management of pollution problems that may be identified as resulting from dredging operations on the Lakes. The investigations conducted during the study included contruction and operation of diked areas, treatment

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SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)* of the dredged material, modifications to dredge equipment and in dredging operations, functional studies of the effects on lake ecology of open-lake disposal, surveys of possible alterate disposal areas at 37 Great Lakes harbors and connecting channels, and an economic evaluation of benefits which might accrue from improved Great Lakes water quality.

DREDGING AND WATER QUALITY PROBLEMS
IN THE GREAT LAKES

June 1969

DEPARTMENT OF THE ARMY
BUFFALO DISTRICT, CORPS OF ENGINEERS
1776 NIAGARA STREET
BUFFALO, NEW YORK 14207

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DEPARTMENT OF THE ARMY
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Dredging and Water Quality Problems in the Great Lakes

(The "Pilot Program")

SYLLABUS

BACKGROUND

For more than a hundred years, the U. S. Army's Corps of Engineers has been building and maintaining the harbors and channels through which flow the commerce of the Great Lakes, vital to America's strength and prosperity.

As a result of soil erosion and wastes discharges, heavy sediment loads wash into those channels. Year by year this material has to be removed to maintain the previously established navigation depth. About 10.8 million cubic yards of material are dredged each year from Great Lakes harbors; 6.7 million cubic yards from Lake Erie harbors alone. Some harbors have to be dredged out every year; others less often. In all, 115 harbors must be dredged more or less frequently.

Up to now, the Corps has been depositing most of the dredged material in the Lakes--specifically, in about a hundred selected disposal areas located near enough to the harbors to minimize hauling costs, yet far enough away to avoid interference with water intakes, beaches, or other facilities.

As population and industrial development have increased along the Lakes, the sediments that must be dredged from the harbors and channels have become increasingly polluted. As a result, most, but not all, of the sediments dredged at the commercially more important harbors have become contaminated by pollutants from municipal, industrial, and agricultural sources.

THE "PILOT" STUDY

Early in 1966, the Corps began investigating the feasibility of an alternate disposal program for several harbors on the Great Lakes. It was estimated that, if the program were adopted, the construction costs would exceed $95 million and the annual dredging costs would be increased by $3 million. Before requesting the taxpayers to accept such a financial responsibility, the Bureau of the Budget indicated that the Corps should conduct a pilot investigation with the cooperation of the Federal Water Pollution Control Administration.

To assist them in the pilot investigation, the Corps engaged the services of an independent Board of Consultants. The Board's task was to advise the Corps and other agencies on the development of the pilot program, study new approaches to the problems involved, and evaluate the results and findings. Their many suggestions resulted in a substantial broadening and intensification of many aspects of the study.

The investigations conducted during the study included sampling surveys of dredging and disposal activities, construction and operation of diked areas, treatment of the dredged sediments, modifications to dredge equipment and in dredging procedures, functional studies of the effects on lake ecology of open lake disposal, surveys of possible alternate disposal areas at 37 Great Lakes harbors and channels, and an economic evaluation of benefits which might accrue from improved Great Lakes water quality as a result of cessation of open lake disposal of polluted dredgings.

FINDINGS

1. Each harbor is unique. No single solution to dredgings disposal problems can be laid down for any one lake, let alone all the Lakes together. The amount and kind of pollutants found in dredgings; the sources of the pollutants, and the practicality of controlling such sources; the environmental effects of open-lake disposal; the availability and cost of sites for diked disposal areas; the characteristics of the hinterland of each harbor, and of the sediments which wash down into the lake -- all these vary widely from harbor to harbor. Hence

conditions observed at one harbor should not be generalized as applying everywhere throughout the Lakes; nor should remedial policies and practices.

2. The removal of dredged material is not harmful as a rule to water quality or the natural environment within the harbors where the dredging takes place. In some places, it may be beneficial to the sedimentary environment. The pilot study found that, in general, disturbing the sediments does not cause major changes, only temporary ones, which are much the same in effect as those caused by the passage of a large vessel. On the other hand, the removal of wastes and pollutants can be beneficial to the harbor environment, particularly if the influx of more pollutants can be reduced.

3. The effects of dredgings disposal in open lake disposal areas remain open to question. Any harmful effects on water quality could not be identified as resulting exclusively from dredgings disposal. In some cases, the lake area was found already so degraded that additional pollution from dredgings disposal could not be detected. However, bio-assays showed that polluted sediments were toxic to small forms of animal life. The Board of Consultants concluded that "in-lake disposal of heavily polluted dredgings must be considered presumptively undesirable" pending further study.

4. Maintenance dredging performs a waste management function presently in that it removes culturally produced sediments generated by various social institutions located within the Great Lakes Basin. Should alternate disposal be required for future maintenance dredgings, the Corps would be performing a waste management function to an even greater degree than at present.

5. Alternate Disposal in diked areas would be very costly. At the 35 harbors where most dredging takes place, dredging and disposal costs would be multiplied some 3½ times. But the impact is not uniform. For example,

Indiana Harbor costs would be increased less than 50 percent, whereas for Detroit River, Huron Harbor, and Oswego Harbor, they would go up about tenfold. The design, composition, and location of diked areas; techniques of handling the deposited material; the advisability of supplementary treatment or other measures; the relationship of diking to other land-use planning - - such factors may vary widely from one locality to another. But, in general, diking is less costly than any other means of handling the dredgings short of lake disposal.

6. Treatment of dredged material may be effective, but would also be very costly. Treatment of dredgings was investigated: (1) at existing waste treatment plants; (2) at separate treatment plants; and (3) on board dredges. Even the least costly treatment process was many times the cost of open lake disposal. At Cleveland, Ohio, where open lake disposal costs $0.78 per cubic yard, the least expensive treatment process would cost $5.11 per yard. At Ashtabula, Ohio, the corresponding figures are $0.35 against $9.08 per yard (a 26-fold increase). In general, the Corps concludes that treatment would add about $4 per yard to the disposal costs at large harbors and $8 at moderate-sized ones.

7. The benefits of halting open-lake disposal are largely intangible. Improvements in lake water quality would probably be difficult to isolate from other changes taking place in the Great Lakes environment. (By and large, in their present condition, all the Great Lakes, even Lake Erie, still are excellent sources of municipal raw water.) Hence benefits in reduced costs to municipal and industrial water-intake systems were shown to be negligible. Further study is needed to disclose additional ways of using filled and made land. At present, any benefits from halting open lake disposal are mainly intangible and not susceptible to objective evaluation, the value placed on intangible benefits

depends largely on the value orientation and perspective of the evaluator.

8. Dredgings represent only a small part of the sediments reaching the Lakes. Only eight percent of the sediment and dissolved solids reaching Lake Erie, and a smaller portion in the other Lakes, makes any part of its journey in a dredge. Even if no dredging were done, the sediments would eventually make their way to the open lake by physical processes. If all dredgings were put into diked areas, the volume of overall sediments and dissolved solids reaching the Lakes would be reduced by about eight percent, and of pollutants by the same general magnitude.

9. Control of pollutants at the source will take time. No one can say how long it may take pollution abatement measures now underway to reduce materially the volume of pollutants that get into, and must be dredged from, the harbors and channels. For pilot-study purposes, it was assumed that appreciable relief might be felt after about ten years. By far the largest volume of sediments making its way to the Lakes originates as soil erosion in the countryside. It is unlikely that there would be a substantial reduction in the amount of these sediments after the assumed ten-year period. Thus, the ten-year period may not be adequate for any program of alternate disposal. However, it was used as a reasonable assumption for purposes of cost estimating and feasibility planning.

CONCLUSIONS

1. Studies should continue. Both the Corps and the Board of Consultants identified a number of areas where further research is needed. Some of the more prominent areas concern: (1) the effect of dredgings disposal on the environment of the open lake, (2) aeration of harbor sediments in advance of dredging, and (3) the need for more detailed and systematic samplings at many harbors.

2. A ten year program to deposit polluted dredgings in diked areas may be desirable. The report presents feasible ten-year diking programs at 35 harbors where polluted sediments exist. This program, if fully implemented, is estimated to cost up to $110 million for initial construction costs and ten years of increased annual operation and maintenance costs. Once approved, it will take 2 or 3 years to construct the dikes after programs are approved and funds provided. The report also presents two other feasible programs of less than full implementation of the total program as possible alternatives.

3. Extra costs for the ten year program should not be charged to navigation. Since the purposes of eliminating open lake disposal are not navigation purposes, and the benefits sought are not navigation benefits, the extra costs involved in alternative means of disposal should not be allocated to the navigation functions of the project concerned, but rather to functions such as wastes disposal or pollution abatement. One method of allocation of costs of alternate disposal as a pollution abatement program would be to local authorities with such assistance from Federal sources as is presently available or becomes available under the Federal Water Pollution Control Act and other Federal assistance programs.

4. A two-year expedient program of diking could be started immediately with Federal funds at a few of the worst problem areas. This would permit progress to be made in those areas while the pilot study is being discussed and reviewed, considered decisions on the ten-year program are being made, and procedures set up.

5. Open-lake disposal of non-polluted dredgings can be safely continued. Also, considering the relatively high costs of diking at small harbors, the small volume of dredgings involved, and limited uncertain benefits that would

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be derived from alternate disposal, open-lake disposal probably should be continued at some of the smaller harbors, even though their sediments may be somewhat polluted.

DECISIONS

Ultimately Congress will have to decide whether it is warranted to make the extra expenditures required for a ten-year program of dredgings disposal in the interest of pollution abatement. If so, it must decide the magnitude of the program and the formula for proportionate cost-sharing between federal and non-federal interests.

DEPARTMENT OF THE ARMY
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IN REPLY REFER TO

13 June 1969

SUBJECT: Dredging and Water Quality Problems in the Great Lakes

Division Engineer, North Central

Section 1

INTRODUCTION

1.1 The Problem

The Great Lakes and connecting waters constitute the largest concentration of fresh water in the world and one of our most valuable resources. Together with the St. Lawrence River, these waters provide a major transportation network, sources of water supply, resources for recreational and business activities, and a wildlife habitat. The abundance of natural resources and the availability of an economical transportation network provided by the Great Lakes have been instrumental in the development of a highly industrialized and densely populated region. In effect, the harbor and channel developments on the Lakes have become economic lifelines to America's growth and industrial prosperity.

Through River and Harbor Acts, Congress has delegated to the Corps of Engineers the responsibility for improving and maintaining harbors and waterways on the Great Lakes. Harbor and channel improvements are accomplished by new work dredging. Navigation depths are maintained by periodical maintenance dredging. At present, the Corps is maintaining navigation depths for 115 harbor and channel projects throughout the Great Lakes.

The need for maintenance dredging arises primarily because the harbors of the Great Lakes are located predominantly at the mouths of rivers flowing into the Lakes. As a result of soil erosion and waste discharges, heavy sediment loads are carried into the harbors by the rivers. In addition, the littoral drift of bottom material and storm-generated currents redistribute the deposited sediments into previously dredged areas in the form of shoals. Periodical maintenance dredging is required to remove sediments from all sources in order to maintain the previously established navigation depth. The amounts of material dredged each year vary for each harbor depending on the extent of deposition that has accumulated from all sources since the last dredging. In a typical year, the amount of material dredged and disposed of through maintenance work is approximately ten million cubic yards. At present, about fifty harbors on the Great Lakes require annual maintenance dredging, while the remainder require dredging every two to five years.

The Great Lakes region has experienced a tremendous growth in population and industrialization over the years. Along with that growth, the waters flowing through the harbors and into the Lakes have received increasing pollutional loads. In the past, these pollutional loads received various degrees of partial treatment or no treatment at all. As a result, most, but not all, of the materials dredged at the commercially more important harbors have become contaminated by pollutants from municipal, industrial, and agricultural sources.

In general, although not entirely, for more than a century the material dredged from Federal projects has been placed in disposal sites which were in the deep water areas of the Lakes. The methods used in dredging the harbors and channels, including disposal of the dredged material, have been developed to accomplish the required dredging work with the minimum expenditure of public funds.

Early in 1966, the Corps began investigating the feasibility of using alternate disposal areas at a number of harbors on the Lakes. These early investigations contemplated a four-year program for construction of diked disposal areas for the 15 most critically polluted harbors on the Great Lakes. It was estimated that, if the program were adopted, the construction costs would be $95,566,000 and the additional annual dredging costs would be approximately $3,000,000.

Before requesting the taxpayers to shoulder the burden of additional costs above the existing expenditures for harbor maintenance, the Bureau of the Budget indicated that there should be further study of alternatives and an evaluation made of the public benefits to be derived from using the proposed alternate disposal practices. Accordingly, the Bureau requested that the Corps of Engineers conduct a pilot investigation with the cooperation of the Federal Water Pollution Control Administration to obtain acceptable solutions to the dredgings disposal problem.

1.2 Scope

The present report presents the results of a study conducted by the Corps of Engineers with cooperation of the Federal Water Pollution Control Administration to evaluate the effects of water quality of current dredging practices, including the disposal of dredged material in unconfined open-water areas of the Great Lakes, as well as to develop the most practicable methods for management of pollution problems that may be identified as resulting from dredging operations on the Lakes.

The investigations conducted during the study included construction and operation of diked areas, treatment of the dredged material, modifications to dredge equipment and in dredging operations, functional studies of the effects on lake ecology of open-lake disposal, surveys of possible alternate disposal areas at 37 Great Lakes harbors and connecting channels, and an economic evaluation of benefits which might accrue from improved Great Lakes water quality. A complete inventory of the surveys and investigations undertaken during the study is included in the appendices to the present report.

In addition to reporting on the investigations conducted during the study, the present report also contains the views of a Board of Consultants selected to assist in the study. The composition and function of the Board of Consultants is described in Section 9. The final section presents the views of the reporting officer, namely the District Engineer, Buffalo District, Corps of Engineers.

1.3 Authorization

The present study was authorized by the Chief of Engineers on 22 November 1966 to comply with Executive Order No. 11288 issued in furtherance of the purpose and policy of the Federal Water Pollution Control Act, as amended (33 USC 466). The Executive Order required the heads of the departments, agencies, and establishments of the Executive Branch of the Government to provide leadership in the nationwide effort to improve water quality through prevention, control, and abatement of water pollution from Federal Government activities in the United States.

1.4 Prior Studies

In the past few years there have been a number of studies undertaken and reports written on the general subject of pollution in the Great Lakes. However, prior to 1967, there were no comprehensive reports that considered the specific effects on the water quality of the Lakes from disposal of dredged materials in open-lake disposal areas.

A report was submitted by the U. S. Public Health Service entitled "Special Studies of Lower Detroit River Pollution Resulting from Operations of the U. S. Hopper Dredge SAVANNAH," June-August 1948. The purpose of this report was to investigate the pollutional effect in the Detroit River from maintenance dredging operations in the Rouge River.

In July, 1959, the Comptroller General of the United States submitted to Congress a report on spoil disposal activities of the Corps. A major part of the report discussed the value and uses of spoil and contained suggestions for future Congressional policy in terms of: (1) the adequacy of Government participation in benefits from land enhancement resulting from deposits of spoil on land, and (2) any requirements for local interests to make a cash contribution for any land enhancement which may stem from deposits of spoil from navigation projects authorized by Congress.

In 1963, the Bureau of Commercial Fisheries made an extensive study of the organic content and oxygen demand of bottom sediments in Lake Erie. A detailed discussion of the results of that study is included in Section 2 of the present report.

A special study entitled "Cleveland Bottom Mud Deposits," 3-4 September 1964, was prepared by the Department of Health, Education, and Welfare. The study analyzed water and bottom mud samples from a Lake Erie disposal area which had been abandoned in 1957. Further comment on this study is made in Section 6.4.3.

Another report by HEW entitled "Report on Pollution of the Detroit River, Michigan Waters of Lake Erie, and Their Tributaries" was included in the, "Proceedings of the Second Session, June 15-18, 1965, of the Conference in the matter of Pollution of the Navigable Waters of the Detroit River and Lake Erie and Their Tributaries in the State of Michigan." The report was a comprehensive pollution study of the Detroit River, including one of its tributaries, Rouge River.

A feasibility study entitled "Provision of Alternate Disposal Areas for 15 Lake Erie Harbors," February 1966, was submitted by the Buffalo District, Corps of Engineers. This report was essentially a cost study of alternate diked disposal of material dredged from the specific Lake Erie harbors. Similar reports have since been submitted by the Corps of Engineers covering one or more harbors in each of the other Great Lakes.

Wayne State University was engaged to make a bibliographical search of prior technical literature related to chemical, biological and economic aspects of dredging and disposal of spoil material. The search, completed 1 October 1968, is attached as Appendix C11.

Section 2

THE GREAT LAKES: BASIC DATA

2.1 Geography

The Great Lakes Basin, shown in Fig. 1, is defined by the drainage area of Lakes Superior, Michigan, Huron, Erie, and Ontario. The Basin includes a land and water area of about 295,000 square miles, of which approximately 95,000 square miles represent the area of the five Great Lakes.

Figure 1 Great Lakes Basin

At average water levels, the Lakes hold a volume of 5,460 cubic miles, discharging approximately 238,000 cubic feet per second through the St. Lawrence estuary into the North Atlantic Ocean. The principal data on the Great Lakes are given in Table 1.

Lake Superior, the largest area of fresh water in the world, is at an average surface elevation of 600.4 feet above sea level (Fig. 2). The outflow from Lake Superior is regulated at St. Mary's Falls, by a complex of hydroelectric power plants, control gates and navigation locks. At St. Mary's Falls, which lies between the twin cities of Sault Ste. Marie, Michigan, and Sault Ste. Marie, Ontario, the water surface elevation drops 22 feet before continuing to flow via the St. Mary's River to Lake Huron.

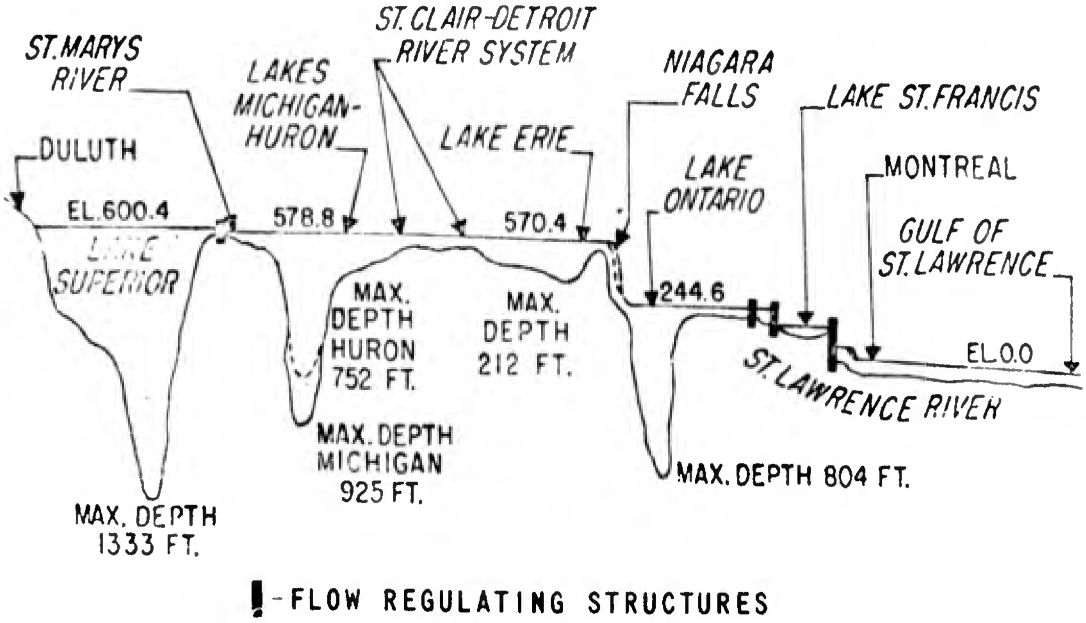


Figure 2 Great Lakes Profile

Lakes Huron and Michigan, connected by the wide Straits of Mackinac, are at the same surface elevation, 578.8 feet above sea level. Depending on the barometric pressure and wind direction, the direction of flow through the straits alternates from east to west, but the net flow is eastward. The entire discharge of the Lake Michigan basin goes into Lake Huron, with the exception of a small amount of water diverted at Chicago. Effective 1 March 1970, the quantity diverted cannot exceed 3200 cubic feet per second averaged on a biennial basis.

The outflow from Lake Huron goes down the St. Clair River to Lake St. Clair, and then down the Detroit River to Lake Erie. Except for some improvements by dredging, the 55-mile Lake Huron-to-Lake Erie waterway is essentially a natural channel.

Table 1

Principal Data of the Great Lakes

Lake	Length (mi.)	Breadth (mi.)	Length of Coastline Including Islands (mi.)	Water Surface Area (sq. mi.)	Drainage Basin Land Area (sq. mi.)	Max. Depth (ft.)	Aver. Depth (ft.)	Volume (cu. mi.)
Superior	350	160	2,980	31,800	48,200	1,333	487	2,935
Michigan	307	118	1,660	22,400	45,500	925	276	1,170
Huron	206	183	3,180	23,000	49,600	752	195	849
Erie	241	57	856	9,900	22,700	212	58	110
Ontario	193	53	726	7,600	27,200	804	283	393

Lake Erie is at a surface elevation of 570.4 feet above sea level because of the Niagara escarpment. The Niagara River, with an average discharge of 202,000 cubic feet per second, descends 60 feet from Lake Erie to the brink of Niagara Falls, drops 167 feet at the Falls, and then descends nearly another 100 feet through the Niagara gorge. Emerging from the gorge, the river enters Lake Ontario at an elevation of 244.6 feet.

Lake Ontario, the smallest of the five Great Lakes in area, discharges into the St. Lawrence River. The outflow is completely regulated by control structures in the river. The St. Lawrence River flows 640 miles from Lake Ontario to Anticosti Island in the Gulf of St. Lawrence.

2.2 Hydrology

The average net total supply of water available to a given lake represents contributions from precipitation on the lake's surface, runoff from the land area, ground water, inflow from upstream lakes, diversions, and evaporation from the lake's surface. All of the contributions are additive, with the exception of the evaporation from the lake's surface, which reduces the supply, and diversions, which may either increase or decrease the supply.

Three diversions, the Chicago and the two Canadian, are of particular significance to the net supply of water available to the Great Lakes Basin because they divert water completely out of the basin, as in the case of the Chicago diversion, or into the basin from outside drainage areas, as in the case of the two Canadian diversions. The other diversions, such as the Welland Canal, simply divert water to another area within the basin.

Diversion of water out of the Lake Michigan Basin into the Mississippi River drainage basin began at Chicago in 1848 with the completion of the Illinois and Michigan Canal. The Canal was constructed from the Chicago River across a low land divide to the Illinois River at a point just below LaSalle, Illinois, thus permitting through navigation. In 1900, the Metropolitan Sanitary District completed a drainage canal from the Chicago River to the Des Plaines River at Joliet, Illinois. The canal reversed the flow of the Chicago River and diverted Lake Michigan water to the Illinois River system. The total quantity diverted was limited to an average of 8,500 cubic feet per second in 1925. Following a period of unusually low levels of the Great Lakes, legal action resulted in a Supreme Court decision in 1929 to restrain the Chicago authorities from diverting any water at all. After further consideration of the issue, a Federal permit was issued in 1930 for the diversion of an average quantity of 1,500 cfs, exclusive of pumpage for municipal water supply. In 1938, the discharge was increased to an average rate of 3,100 cfs. A 1967 Supreme Court decree, effective 1 March 1970, established a limit of 3,200 cfs, including pumpage, as averaged on a biennial basis.

The original diversion of water from the Hudson Bay drainage basin into Lake Superior, called Long Lake Project, began in 1937. A second Canadian diversion, known as the Ogoki Project, commenced in 1943. Together, the two diversions have discharged water into Lake Superior at an average rate of about 5,000 cubic feet per second since 1945.

The mean rate of discharge from each of the Great Lakes is indicated in the following tabulation. The rates are adjusted to reflect the conditions that would have occurred if the present diversions had been in effect throughout the period of record. They also include the effects on supplies to the lakes downstream of Lake Superior resulting from regulations of the outflow of that lake.

Table 2

Mean Rate of Discharge for Each of the Great Lakes

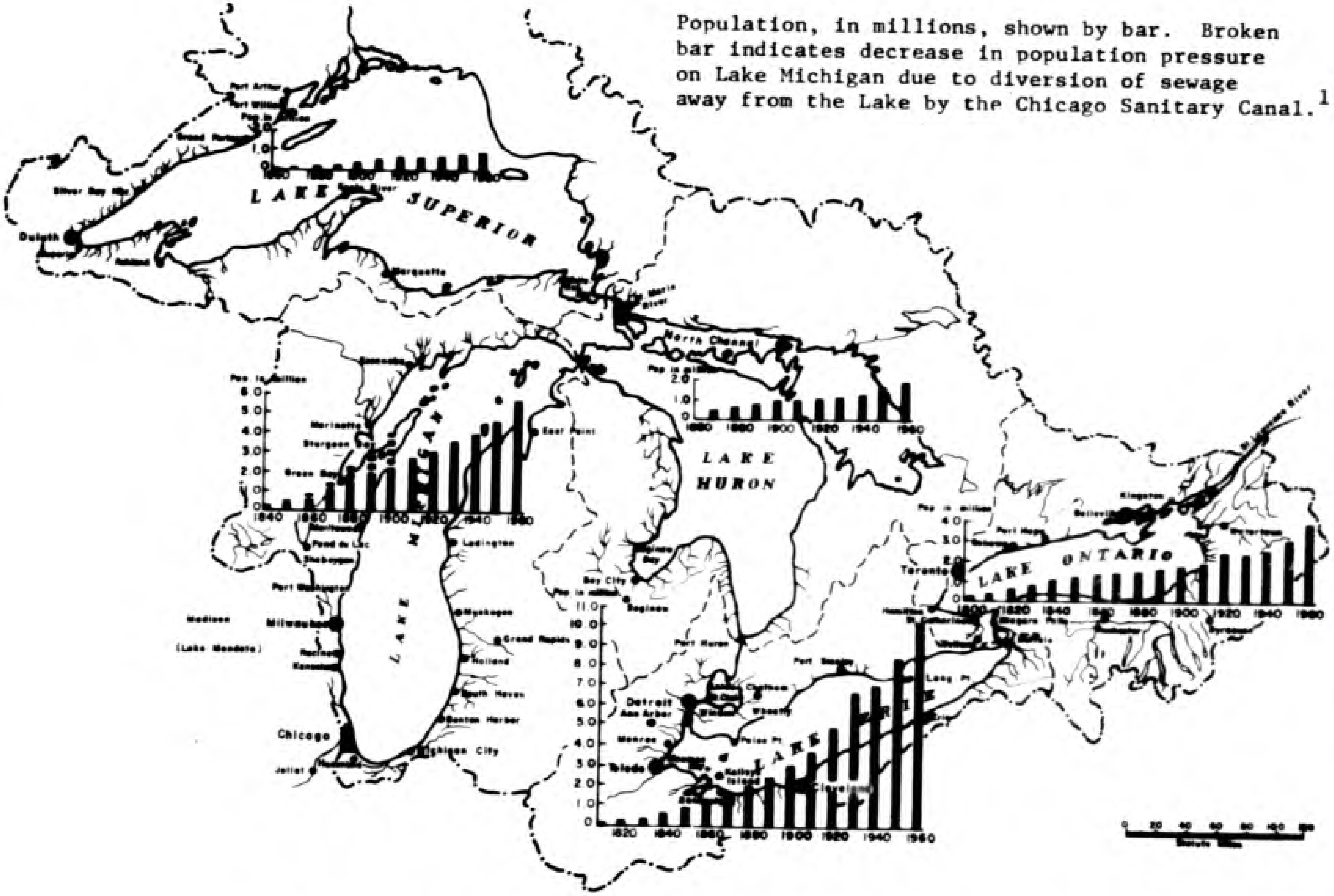
Lake	Mean Discharge (cfs)
Superior	76,900
Michigan	a
Huron	183,100
Erie	203,900
Ontario	238,000

a Not available

2.3 Watershed Characteristics

2.3.1 Population

The Great Lakes region covers only about 4 percent of the total United States land area, yet, in 1968, the population of the region was estimated to be 30 million persons or about 15 percent of the total for the nation. Of the 30 million, it is estimated that the effluent from approximately 26 million persons is being discharged directly or indirectly into the Great Lakes (See Fig. 3). Within less than fifty years, the population of the Great Lakes area is expected to exceed 50 million people, and it is anticipated that some day a megalopolis will extend from Chicago and Milwaukee to Montreal, Canada.



Population, in millions, shown by bar. Broken bar indicates decrease in population pressure on Lake Michigan due to diversion of sewage away from the Lake by the Chicago Sanitary Canal.[1]

Figure 3 Population Growth in the Great Lakes Basin

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[1] A. M. Beeton, Changes in the Enviornment and Biota of the Great Lakes. International Eutrophication Symposium, National Academy of Science.

2.3.2 Industry

As the result of a combined rail-water transportation network, the port cities of the Great Lakes became centers of industry and shipping. Port industries developed because of easy access to the resources of a vast hinterland and an economical, readily available means to transport commerce to national and international markets.

Today, the industries of the Great Lakes region produce about 36 percent of the output value of the United States manufacturing industries, over 30 percent of the nation's export of manufactured products, and about 23 percent of the nation's farm products sold. About one-half of the nation's steel capacity is located at Great Lakes ports, and, with the addition of nearby steel centers, such as Pittsburgh, approximately two-thirds of the nation's steel capacity is served by Great Lakes ports.

2.3.3 Land Use

The tributary drainage area of the Great Lakes in the United States is about 129,000 square miles, or 82.3 million acres. The soil in the tributary land generally is composed of glacial and post-glacial deposits. Much of the ground is flat or slightly undulating, accented by drumlins, eskers, dunes, and lakes; it is well adapted to agricultural uses. The United States Department of Agriculture, Soil Conservation Service, estimates that about 71.1 million acres of the Great Lakes tributary drainage area is agricultural land.

The largest use of the land is for forests and woodlands, with main concentrations being in northern Minnesota, Michigan, Wisconsin, and New York. Farm land use, of which approximately 33 percent is cropland and 6 percent pasture, is located primarily in eastern Wisconsin, northern Indiana and Ohio, and southern Michigan. The 11.2 million acres of non-agricultural land either has been used for urban and industrial development or left undeveloped because the land was too rugged or the soil was too poor.

Since a large percentage of the drainage area of the Great Lakes is in agricultural use, soil erosion, augmented by runoff from construction projects in urban and suburban areas, introduces millions of tons of silt into the tributaries of the Great Lakes region each year. For example, the loss of soil in the Maumee Basin alone, which drains into Lake Erie, is over 2,000,000 tons annually. As soil washes from the land, the chemicals intended to nourish plants and control insects are carried into the streams and subsequently into the Lakes themselves.

2.4 Beneficial Uses

2.4.1 Water Supply

The Great Lakes constitute the largest concentration of fresh water in the world. Billions of gallons of water are withdrawn daily from the Great Lakes and their tributaries, but only a small percentage of this water is consumed. The majority of the water is returned, after use, to regional tributaries and eventually enters back into the Lakes. Municipalities and industries, especially those engaged in power generation, are large users of water, but nearly all of the water is returned after use. However, much of the water used for municipal and industrial purposes suffers varying degrees of deterioration depending on the amount of treatment that it is given. While irrigation usage consumes a large percentage of the quantity withdrawn for that purpose, the total amount of water withdrawn from the Great Lakes Basir for irrigation use is relatively small in comparison to that withdrawn for other uses.

2.4.2 Wastewater Disposal

Every body of water has a natural capacity to assimilate certain quantities of pollutants, with larger quantities requiring larger bodies of water. Dilution of stable pollutants diminishes their effects on water quality, while unstable pollutants are broken down by chemical, biological, or physical processes indigenous to a particular body of water. The Great Lakes provide readily available receiving bodies for the disposal of wastes from municipalities and industries around the Lakes. The volume of pollutants that any body of water can assimilate is not unlimited, however, and there are signs, such as accelerated eutrophication, that the volume of wastes put into the Great Lakes in recent years may be exceeding the natural assimilation capacity of Lakes Erie, Michigan and Ontario.

2.4.3 Navigation

Historically, navigation has played a major role in the growth of the Great Lakes Basin. With the completion of the St. Lawrence Seaway in 1959, a 27-foot deep draft channel extended from the Atlantic Ocean to the west end of Lake Superior and the south end of Lake Michigan. The opening of the Seaway stimulated international trade through the ports of the Great Lakes. The overseas general cargo traffic for all U. S. Great Lakes ports increased from an average of 500,000 tons for the period 1952-58 to 1,800,000 tons in 1959. The average annual tonnage increased to 3,800,000 tons in 1964, and is projected to increase to 5,600,000 tons by 1975.[1]

In addition to overseas general cargo traffic, large tonnages of commerce are transported inter-lake and intra-lake between U. S. Great Lakes harbors and Canadian ports on the Lakes. In recent years, inter-lake and intra-lake traffic has exceeded 300 million tons, including 50 million tons of Canadian imports and exports.

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[1] Great Lakes - Overseas General Cargo Traffic Analysis, Department of the Army, Corps of Engineers, North Central Division, March 1967.

2.4.4 Recreation

In comparison to coastal regions, there is little actual recreational usage of the open-water expanses of the Great Lakes. With the discontinuation of the Georgian Bay Line and Canadian Pacific steamships, excursion travel on the Lakes has all but disappeared. On the other hand, competition for use of the Great Lakes shores and adjacent lands is intensifying rapidly every year.

In the United States and Canada, over 9,700 miles of shoreline exist along the Great Lakes. Water-based recreation is concentrated in various favorable areas which are protected from the sea and weather. Pleasure boating, water sport activities, and sport fishing are usually confined to open water in or near bays, harbors, river mouths and island areas. On the other hand, swimming, picnicking, camping, hiking, sight-seeing and other shore-bound activities utilize a wide expanse of shoreline.

Since licenses to fish in the Great Lakes are not required by most of the bordering states, there is little quantitative information about the use of the Lakes for sport fishing. However, it is generally recognized that the planting of coho salmon in Lakes Superior and Michigan during the past two years has increased the sport fishing potential, especially in Lake Michigan where the planting was highly successful. Plantings of lake-run brook trout (coasters), rainbow trout (steelheads), and chinook salmon also offer promising sport fishing potentialities. In addition to the aforementioned fisheries, pier, breakwater and small-boat fishing for perch, walleye, bass, carp, freshwater drum and bullheads, combined with smelt dipping in the spring and ice fishing in the winter in certain areas, offer a wide spectrum of angling in the Great Lakes region.

2.4.5 Commercial Fishing

Commercial fishing has played an important role in the settlement and development of the Great Lakes region. In recent years, though, the commercial fishing industry on the Lakes has been plagued with many problems which have culminated in a steady decline of the commercially more valuable species. However, the total commercial landings have remained essentially unchanged (near 100 million pounds) since 1885.

Lake Erie is the most productive fishery of all the Great Lakes. The high yield (7.3 lb. fish/ acre/year) in Lake Erie is probably the result of warm temperatures, a shallow basin, and an abundant nutrient supply. Lakes Michigan, Huron, Superior and Ontario follow in order of productivity, but their combined total only about equals the yield from Lake Erie.

After the sea lamprey invasion into the Great Lakes, lake trout and whitefish in Lakes Superior, Huron, and Michigan declined rapidly. Along with the decline of those predatory fish, the alewife and smelt populations increased tremendously. However, recent lamprey control measures, such as chemical treatment of the lamprey spawning areas, and the recent stockings of lake trout and coho salmon have proved quite successful. The present state of commercial fishing in the Great Lakes is characterized by restoration of the higher priced species, such as trout and whitefish, and increased utilization of the lower priced species, such as smelt and alewives.

2.5 Water and Bottom Sediment Characteristics

A knowledge of the physiochemical and biological characteristics of the Great Lakes is fundamental to a discussion of water quality of the Lakes. Some of the oldest data on record are concerned with water level fluctuations. Levels of the Lakes are high in summer and low in winter because of seasonal variations in precipitation and runoff. Annually, the fluctuations vary from slightly more than one foot on the upper Great Lakes to almost two feet on Lake Ontario. Long term changes are caused by long term variations in precipitation. Short term fluctuations are due to differences in barometric pressures, winds and subsequent periodic surface seiches resulting from these two factors. Winds, which commonly blow parallel to the longitudinal axis of Lake Erie, sometimes produce a difference in water level between Buffalo, New York, and Toledo, Ohio, as great as 13.5 feet.

Circulation of water in the Great Lakes, involving both surface and subsurface current patterns, greatly influences the effects on water quality of nutrients and pollutants discharged into the Lakes. Even though surface current patterns have been recorded for more than 150 years, information on subsurface current patterns has been obtained only recently. While surface currents are generated primarily by winds, subsurface movements are caused, for the most part, by internal waves originating during periods of thermal stratification.

Water quality of the Lakes is influenced significantly by thermal stratifications, which result in two masses of water differing in temperature and density. The upper mass, or epilimnion, is lighter in weight and has a higher temperature than the hypolimnion, the lower mass. The thermal gradient between the two masses is referred to as the thermocline. After becoming stratified, the density difference effectively prevents mixing of the waters in the epilimnion with those in the hypolimnion. The stratification becomes stronger as the difference in density between the epilimnion and hypolimnion becomes greater. The summer thermocline begins to form in late spring at a depth of a few feet, but it may be found at depths of 200 feet in Lake Michigan by early fall. The thermal regime is similar in all the Great Lakes, with the thermocline usually located at depths of 45 to 60 feet. Shallow areas, such as western Lake Erie, exhibit only temporary stratification during hot, calm periods of the summer.

Transparency differs considerably in the Great Lakes. Penetration and spectral distribution of light with depth is a function of the quantities and qualities of substances dissolved and suspended in the water. Water selectively absorbs light of long wavelenghts (red end of the spectrum). Light of short wavelengths (blue end of the spectrum) is reflected easily, and will penetrate deepest into water with little suspended matter. Conversely, light of long wavelengths will penetrate deeper in turbid waters than light of short wavelengths. Blue-green light penetrates to the greatest depth in Lakes Huron and Superior, green light in Lake Michigan and yellow-orange light in Lakes Erie and Ontario, indicating the relatively smaller amounts of suspended matter in the upper Lakes in comparison with the lower Lakes.

The chemical composition of Great Lakes waters is influenced to a high degree by the geochemistry of the terrain and the form of the basin with respect to inflows and outflows. In addition to gaseous components, such as oxygen and carbon dioxide, varying quantities of carbonates, chlorides, sulfates, phosphates, and nitrates are found. These anions occur in combination with metallic cations, such as calcium, sodium, potassium, magnesium, and iron, to form ionizable salts. The total dissolved solids and the specific conductance (reciprocal of the resistance measured between two electrodes and usually expressed as micromhos) are useful parameters for measuring the total chemical content of the water. The total dissolved solids concentrations are shown in Table 3.

Table 3

Dissolved Solids in the Great Lakes[a]

Lake	Total Dissolved Solids (mg/l)
Ontario	185
Erie	180
Michigan	150
Huron	110
Superior	60

a - See Figure 7

Conductivities in Lakes Ontario, Erie and Michigan are greater than 200 micromhos (at 18°C), while in Lake Huron it is less than 200 micromhos, and in Lake Superior it is 79 micromhos.

Other parameters are also important in describing the chemical composition of Great Lakes waters. Total alkalinity ranges from 46 mg/l (as $CaCO_3$) in Lake Superior to 113 mg/l in Lake Michigan. The pH ranges from 8.0 to 8.5 in the Lakes except for Lake Superior, where pH averages 7.5. In general, chemical concentrations are in the same relative proportions in all the Lakes, with the greatest concentration being in Lakes Erie and Ontario. Potassium averages around 1 mg/l in all the Lakes. Concentrations of total phosphorus are low in the open waters of the upper Lakes, especially in Lake Superior (<5 mg/kl). The phosphorus content of the offshore water of Lake Erie is about six times that of the other Lakes, and is much higher inshore, especially near the inflow of large rivers.

The role of the bottom sediments is of great significance to the water chemistry of Lake Erie. In the deep basins of all of the Great Lakes, except Lake Erie, sediments consist mostly of glacial clay. The shallow, gently sloping bottom of Lake Erie is predominantly organic mud. In 1963, the Bureau of Commercial Fisheries made a study of the organic content and oxygen demand of Lake Erie sediments. The distribution of organic material suggested that sediments deposited or originating in the western basin were probably resuspended and redeposited in the deeper portions of the central and eastern basins (Figure 4). Two types of measurement were made of oxygen uptake, mixed sediment BOD[1] and two hour core uptake[2]. The two methods were designed to measure the maximum and minimum oxygen uptake that could be exerted by the sediments.

Contours of sediments BOD values in Lake Erie are plotted in Figure 5. The areas of high oxygen uptake are located from between Kelleys Island and Pelee Island to Vermilion, between Lorain and Cleveland and between Point Pelee and Erieau, Ontario. The areas of high oxygen uptake appear to be areas of permanent deposition. It also should be noted that a tongue of low values exists southwest of the Pelee passage, which probably reflects the main flow of the Detroit River.

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[1] Mixed sediment BOD was measured by introducing sediment to a tube containing water saturated with oxygen. The contents were mixed by a magnetic stirrer and the tube stoppered by an oxygen electrode. The remaining dissolved oxygen was measured after 5 minutes. The sediment was filtered, dried, and weighed. The results are expressed in micrograms of oxygen consumed per gram of sediment per 5 minutes.

[2] Core uptake was measured by placing sediment into 50 milliliter centrifuge tubes, washing the sides, centrifuging, decanting the supernatent, refilling with water saturated with oxygen, stoppering and incubating at 20°C for 2, 4, and 6 hours. After incubation water was siphoned into 5 milliliter glass-stoppered bottles which were used as micro-D.O. bottles. Two milliliters were titrated with 0.0025 N sodium thiosulfate. The results of the 2-hour incubations were included and expressed as micrograms of oxygen consumer per square centimeter of sediment per hour.

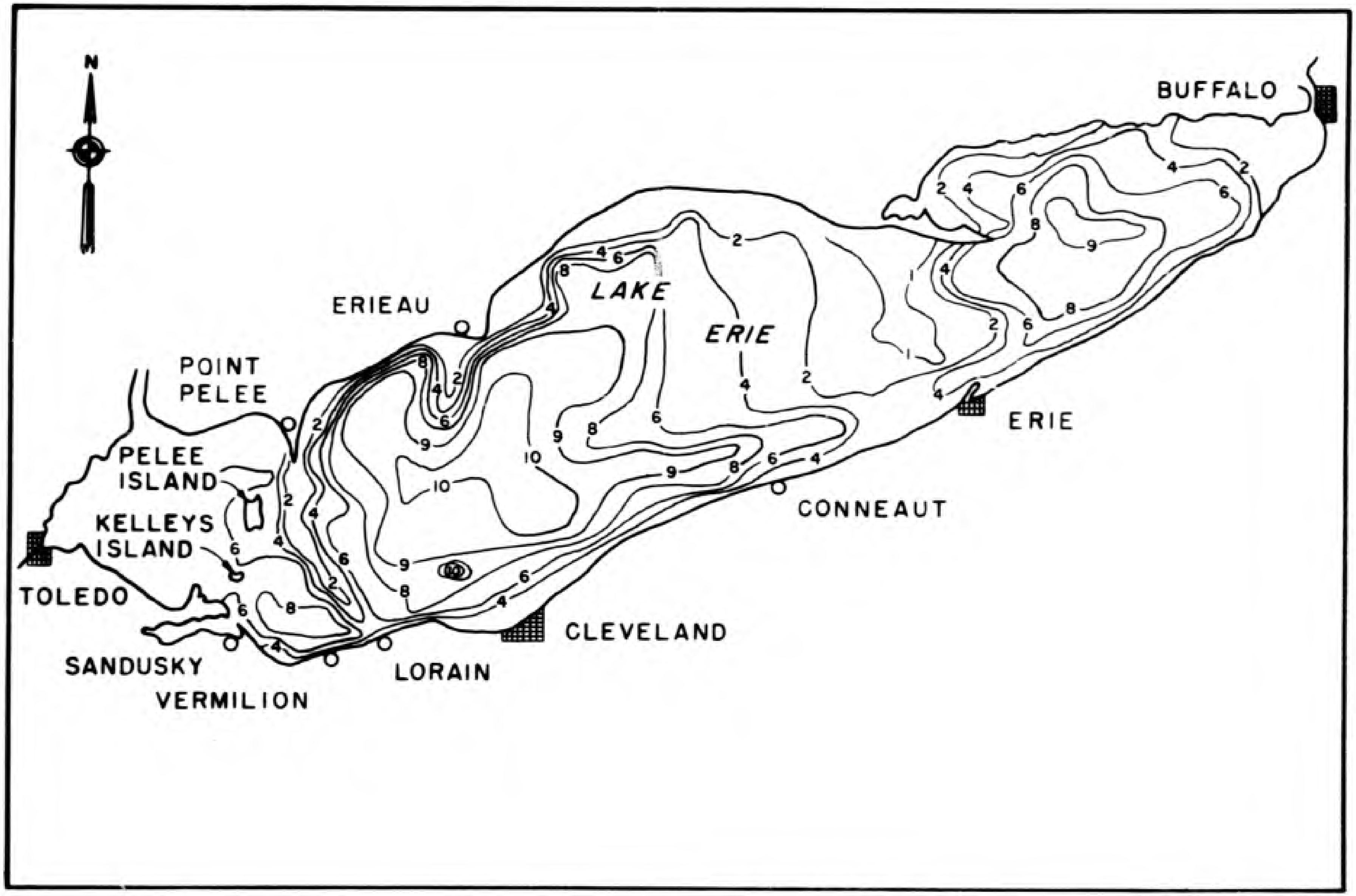


Figure 4. Percent Organic Matter, Lake Erie, 1963

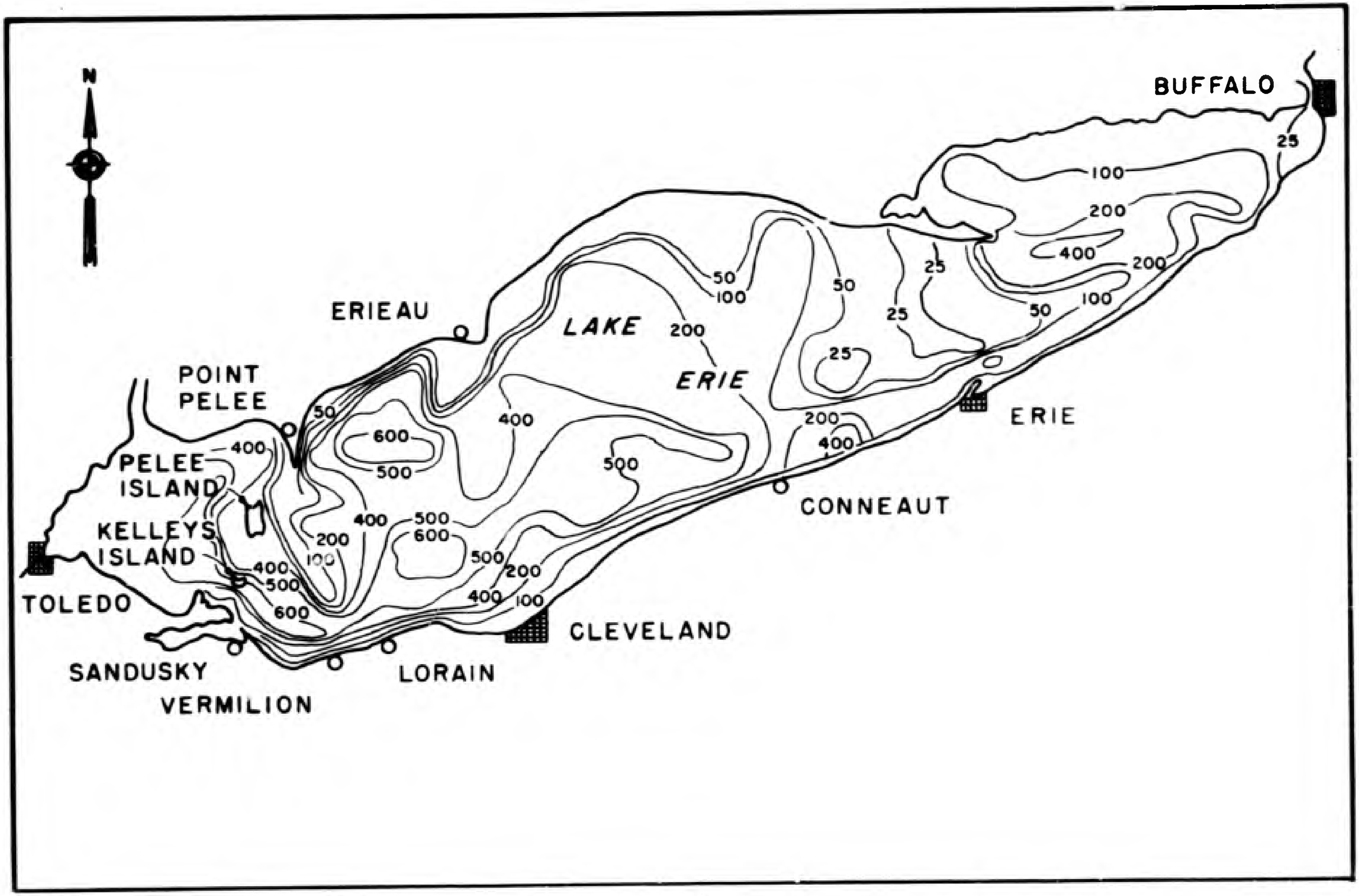
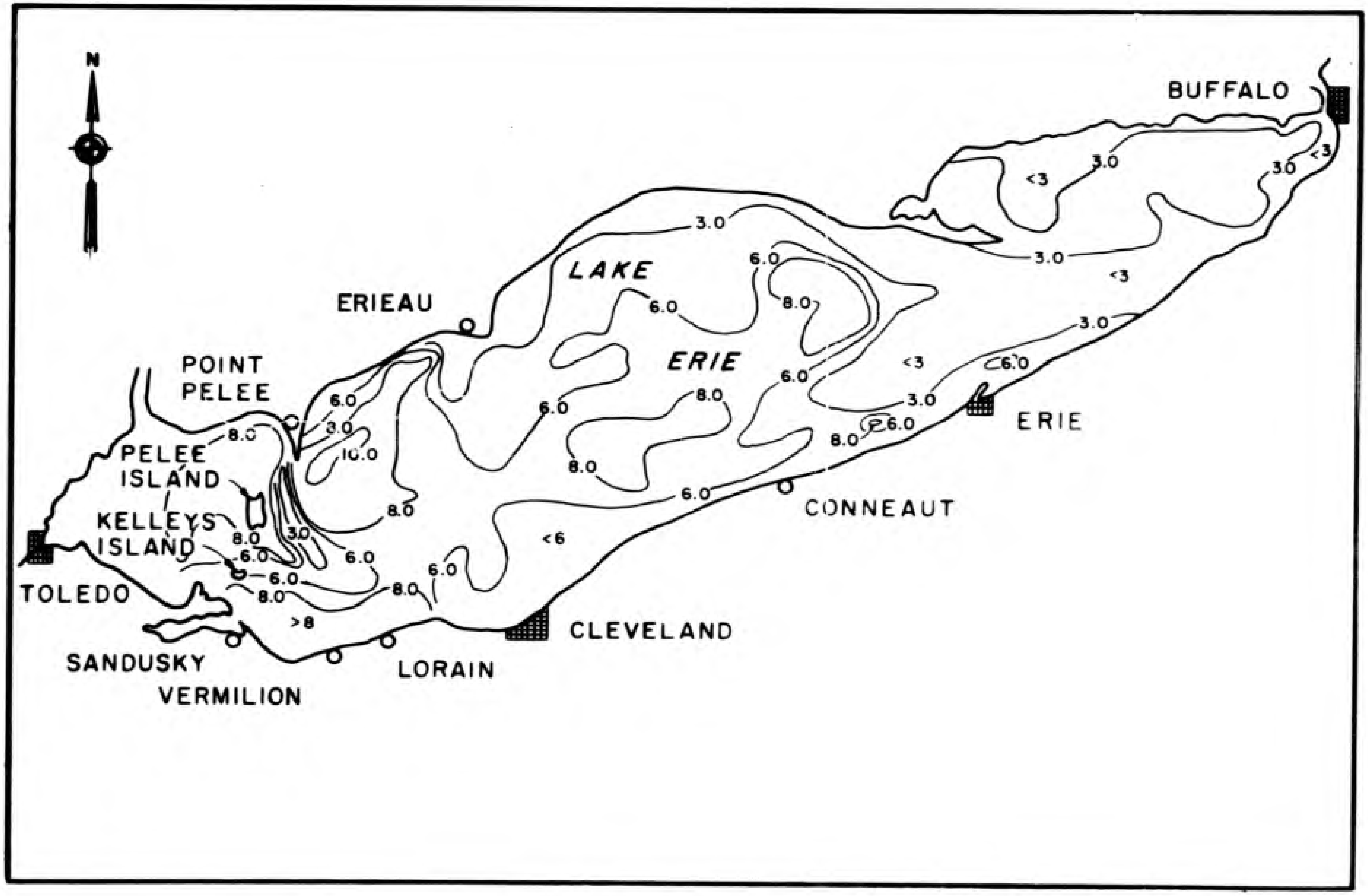


Figure 5. Mixed Sediment BOD ($\mu g O_2$ consumed/g sediment), Lake Erie, 1963

Figure 6 shows contours of two-hour core oxygen uptake values for Lake Erie. The chart of data from the core samples is much less straightforward with less differentiation between various areas in the lake. However, the low area north of Pelee Island and the higher areas north and south of the low area are easily seen. The values in the eastern basin are quite low.

It is interesting to note that although the percentages of organic matter are comparable in the central and eastern basins of Lake Erie, the oxygen uptake of the sediments in the western basin is higher. The Bureau of Commercial Fisheries suggests that the higher uptakes occur because the organic matter in the western basin is probably of very recent origin, while that in the eastern basin may be older and more nearly oxidized. It can also be noted that values of oxygen uptake in U. S. waters are higher than those in the Canadian waters, possibly due to differences in the source of organic materials. The Canadian organic material may originate largely from agricultural sources, while the U. S. material may reflect municipal and industrial wastes to a greater extent.

In the summer, vertical mixing in most of Lake Erie is limited by thermal stratification. The hypolimnion, isolated from atmospheric replenishment, eventually becomes depleted of dissolved oxygen because of the high oxygen demand of the bottom sediments. Depletion of dissolved oxygen leads directly to anaerobic conditions, resulting in an accelerated exchange of some chemicals between sediments and water because of the greater solubility of the chemicals in a reduced state. The reduced forms of iron, manganese, and sulphur, along with phosphorus, ammonia, and carbon dioxide may be leached from the sediments to the overlying waters. The effect is a nutritional stimulus to plankton growth. The death and sedimentation of these plankters renew the organic matter. In turn, the organic matter is again bacteriologically degraded in a succeeding stratification contributing to another hypolimnetic deoxygenation and nutritional enrichment. Thus, in



Two-Hour Core Uptake ($\mu g O_2$ consumed/cm^2/hour), Lake Erie, 1963 spite of elimination of all waste inputs, it is possible for bottom sediments to reach a state of enrichment whereby the above cycle would be perpetuated indefinitely. The cycle is more complex, however, because nutrients are continuously introduced into Lake Erie and there is a large flow through the lake.

The biota of the Great Lakes is composed of species usually associated with nutrient-poor, or oligotrophic conditions. Species associated with nutrient-rich, or eutrophic conditions are important in Lake Erie, Green Bay and similar environments. Diatoms are by far the most important constituents of the phytoplankton, although blue-green and green algae are especially abundant at times in Lake Erie. Even in Lake Erie, though, diatoms usually comprise 75 percent of total phytoplanktons. The more abundant genera are Asterionella, Cyclotella, Fragilaria, Stephanediscus, Tabellaria, and Melosira. Diaptomid copepods dominate the biomass of zooplankton in the Great Lakes, although protozoans and rotifers may be greater in numbers. Cladocerans are abundant in summer.

One major period of plankton abundance occurs in summer in the open waters of the upper Lakes. In the more productive areas, such as Green Bay, Lake Erie and the southern end of Lake Michigan, two major phytoplankton pulses occur, one in spring and the other in fall. In Lake Erie, the spring pulse consists almost entirely of diatoms. Populations of blue-green algae, such as Microcystis and Aphanizomenon, contribute, along with diatoms, to the fall pulse. In Lake Erie, large zooplankters are abundant in summer, and smaller ones in spring and fall. Most zooplankters in Lake Michigan reach only one population peak a year.

Two large crustaceans, Mysis relicta and Pontoporeia affinis, are the dominant deep water fauna of the Great Lakes. Midge larvae (Tendipedidae), oligochaete worms (Lumbriculidae and Tubificidae) and sphaeriid clams are also numerous. The shallow water areas have a greater variety of species, many of which are common to smaller lakes. Midge larvae, oligochaetes (Naididae, Tubificidae, and Lumbriculidae), leeches, snails (Lymnea, Valvata, Amnicola, and Goniobasis), caddisfly and mayfly (Hexagenia) nymphs are among the dominant groups.

In summary, Lakes Huron and Superior are oligotrophic based upon their physical, chemical, and bioligical characteristics. The nature of the biota and the high dissolved oxygen in Lake Michigan indicate oligotrophy, but high conductivity and total dissolved solids indicate a trend toward mesotrophy, an intermediate condition between oligotrophy and eutrophy. Lake Ontario has the chemical characteristics of an eutrophic lake, but, it also has the biota and morphometry of an oligotrophic lake, and might be best termed mesotrophic. All indications show the central and especially the western basin of Lake Erie to be highly eutrophic. The eastern basin still contains oligotrophic or mesotrophic biota, because of its deeper water.

Section 3

THE GREAT LAKES: Pollution

3.1 Deterioration of Quality

3.1.1 Eutrophication

At the time of the recession of the last ice sheet of the glacial period, the Great Lakes as they are known today were probably nutrient-poor or oligotrophic. Throughout the natural developmental history of the Lakes, there has been a gradual increase of sediments, mineral matter, and nutrients in the basin, primarily due to runoff from the watershed. The increased fertility of the Lakes themselves has paralleled closely the development of its drainage basin. The increase in nutrients, called eutrophication, has resulted in chemical and biological changes in the Great Lakes. However, those changes have been too rapid to be attributed solely to a natural aging process.

There is evidence that man's activities are greatly accelerating eutrophication in Lakes Erie, Ontario, and Michigan. Concentrations of population in these watersheds are causing undesirable changes in the water quality and biota of these lakes. Huge quantities of nutrients are being added to these lakes by municipal, industrial, and agricultural wastes. Lake Huron, even with a small population bordering it, also is showing signs of accelerated eutrophication, probably due to the flowthrough waters from Lake Michigan. Lake Superior, except for a slight increase in phosphorus in the south shore waters, is the only one of the Great Lakes in which chemical composition has remained practically constant during recorded history.

Changes in concentration of certain chemical ions, along with changes in species composition and abundance of the biota, can be used to detect and measure the degree, rate, and sometimes the source of accelerated eutrophication. For example, total dissolved solids have increased by about 12 mg/l in Lake Huron, 20 mg/l in Lake Michigan, and 50 mg/l in Lakes Erie and Ontario in the past 70 years.

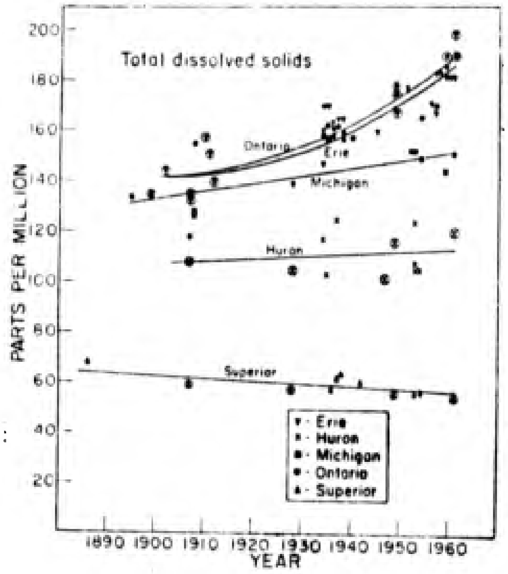


Figure 7 Concentration of Total Dissolved Solids in the Great Lakes. (BEETON 1965) Circled points are averages of 12 or more samples.

In addition, calcium, chloride, sodium-plus-potassium, and sulfate, all increased significantly in Lake Erie during the past 50 years. The rate of increase in total dissolved solids in Lake Ontario has been the same as that in Lake Erie (BEETON 1965). On the average, the chemistry of Lake Ontario waters is similar to Lake Erie because Lake Erie flows into Lake Ontario, and also because of the influence of urban areas such as Toronto, Hamilton, and Rochester.

Since there are little reliable data on past conditions, increases in nitrogen and phosphorus are evident only in a few areas. Along the south shore of Lake Superior, where an east-west littoral current carries the outflows from a number of tributaries and several urbanized areas, phosphorous concentrations are somewhat higher than in the open Lake. Phosphate concentrations are higher in Green Bay and southern Lake Michigan than those in the open waters of Lake Michigan. Total nitrogen probably has increased threefold and total phosphorous has doubled in Lake Erie in the last 35 years. The Detroit River alone supplies 107,500 tons per year of total nitrogen and 29,700 tons per year of total phosphates to Lake Erie.[1] Free ammonia concentration doubled at the Toronto, Ontario, intake in Lake Ontario between 1923 and 1954.

Other chemical contaminants in the waters, generally associated with the centers of industrial activity and commercial shipping, are in the form of oil, phenolic compounds, or other persistent organic chemicals, ammonia, and highly acidic or alkaline materials. These substances have both immediate effects in the vicinity of the discharge point and a progressive buildup in the concentrations of certain persistent chemicals in the Lakes as a whole.

The small quantity of oxygen normally dissolved in water is perhaps the most important single ingredient necessary for a healthy, balanced, aquatic environment. Dissolved oxygen is consumed by living organisms through respiration, but it is replenished from the atmosphere and through the life processes of aquatic plants. When organic pollution enters the environment, oxygen consumption may be greater than replenishment. The resulting oxygen deficiency may be great enough to produce critically low oxygen levels for fish and other desirable organisms and to convert the stream or lake into an odor-producing nuisance because of anaerobic conditions.

A decrease in dissolved oxygen has been recorded in the bottom waters of southern Green Bay since 1938 and in Lake Erie since 1929; however, the area and extent of depletion probably have been increasing rapidly in recent years. In the central basin of Lake Erie, oxygen depletion now occurs for a continuous period of a month or more in late summer.

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[1] Major Sources of Nutrients for Algal Growth in W. Lake Erie, Proceedings of 9th Conference University of Michigan, Pub. No. 15, pgs. 389-394, 1965.

Another indication of deteriorated water quality is the presence of coliform bacteria. Coliform organisms are significant because they occur in the fecal matter of all warm-blooded animals, including man. Consequently, the presence of these bacteria in a body of water is usually evidence of fecal contamination. Since such contamination is an avenue for transmission of certain waterborne diseases, the presence of coliforms is an indication of a possible health hazard from pathogenic bacteria and viruses.

In general, the severe problems of bacterial contamination in the Great Lakes Basin occur in the waters near population centers. For example, between 1913 and 1948, the bacterial load at the outlet of the Detroit River increased threefold (BEETON 1961). At present, the most severely contaminated nearshore areas exist at Detroit, Michigan; Cleveland, Ohio; and Buffalo, New York; where coliform counts are in the hundreds of thousands per 100 milliliter sample.

Changes in species composition and abundance of plankton, benthic fauna, and fish populations reflect changing environments in the Great Lakes. For instance, phytoplankton has tripled in Lake Erie between 1919 and 1963. Populations of algae have attained "bloom" concentrations in western Lake Erie and they are causing problems at water intakes in southern Lake Michigan. Growths of Cladophora, an attached alga, are a problem in many areas. This alga is scoured off lake bottoms by storms and drifts inshore, where wave action piles it up onto the beaches, causing unsightly conditions. The subsequent decay of the alga produces putrid odors.

Certain species of benthic fauna are intolerant to polluted waters and have disappeared from harbors, river mouths and large areas of Lake Erie and Green Bay. The intolerant species have been replaced by pollution-tolerant species of oligochaete worms and tendipedid midges, which are able to withstand periods of deficiency or absence of dissolved oxygen.

3.1.2 Effects on Beneficial Uses

3.1.2.1 General

Pollution has a significant effect on many beneficial uses of the Great Lakes. Only a few water uses, such as navigation and hydroelectric power, are not noticeably affected. Although it is difficult to evaluate the specific effects of pollution, many trends and ecologic changes, that can be traced either directly or indirectly to pollutants, have occurred over the years. The effects of pollution on the beneficial uses of the Great Lakes are discussed in the following sections.

3.1.2.2. Water Supply

The effects of pollution on Great Lakes raw water quality for public supplies is difficult, if not impossible, to evaluate in light of existing data. Appendix C9 indicates that for the most part correlations do not exist between chemical costs of treatment and the incoming raw water quality. In general, chemical dosages are applied according to a set of operating rules which are influenced by the wind direction, season of the year, water current and direction, and temperature combined with informed operator judgment.

Presumably, if the operating rules were changed strictly because of a significant permanent change in raw water quality, it might be possible to show trends in pollutional effects on Great Lakes water used for public supplies. The present condition of the Lakes for water supply purposes is such that even Lake Erie, the most eutrophic of the Great Lakes, "still is an excellent source of municipal raw water."[1] However, the concentrations of dissolved solids for instance, are increasing, and their subsequent effect on raw water quality and the treatment thereof, should be closely monitored.

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[1] FWPCA, Lake Erie Surveillance Data Summary 1967 - 1968, May 1968, p. 1

3.1.2.3. Wastewater Disposal

As stated in Section 2.4.2, wastewater disposal is a beneficial use of the Great Lakes up to the limit of the natural assimilation capacity of the Lakes. It was also stated that there are signs that such capacity may have been reached and exceeded for Lakes Erie, Michigan and Ontario. Thus, their use for wastewater disposal, in effect, has become a major cause of pollution in those lakes. As a result, Federal and state regulatory agencies have required more effective treatment in order to reduce the amount of pollutants discharged directly or indirectly to those lakes and to all of the Great Lakes as well.

3.1.2.4 Recreation

Swimming is by far the most popular form of water-oriented recreational activity in the Great Lakes today. Expanding populations and additional leisure time have produced an ever increasing demand for adequate beaches and swimming areas. In recent years, numerous beaches throughout the Great Lakes have been closed, either intermittently or permanently, because of water pollution problems. A 1967 survey of 51 Lake Erie beaches revealed that only three were unquestionably safe for swimming, while 11 were considered unsafe. The remaining 37 beaches were subject to occasional or frequent pollution problems.

Beaches near the large metropolitan centers often remain closed because of the health hazard from waterborne bacteria from partially treated sewage discharges and combined sewer overflows. In addition to bacterial contamination, undesirable swimming conditions have been created by masses of algae drifting in swimming areas. Further, decaying algae which accumulate on the beaches are often so putrid that recreational activities in the area are impossible.

The effects of pollution on sport fishing in the Great Lakes are quite clear. The more desirable species, such as lake trout, walleye, and whitefish, are being replaced by the less desirable species, such as carp, catfish, alewives, and smelt. Attempts have been made to reverse the trend with varying degrees of success. The most encouraging experiment is the introduction of the coho salmon into Lake Michigan. The coho is an anadromous fish of the west coast, and is an effective predator that could reduce the alewife population. About four and one-half months after the 1966 planting of the young coho smolts, about 10,000 adults were harvested as they returned to the stream to spawn. In 1967, over 265,000 cohos were harvested, some of which weighed over 20 pounds. In the spring of 1967, almost 2.2 million coho fingerlings were stocked in streams tributary to Lakes Michigan and Superior. Lakes Erie and Ontario were also stocked with lesser quantities. Considering the results achieved from 850,000 cohos planted the year before, expectations for future harvests are optimistic, especially if natural reproduction occurs.

3.1.2.5 Commercial Fishing

The commercial fishing industry on the Great Lakes has been faced with the same basic problem discussed in the previous section, that of the more desirable species being replaced by less desirable ones. Commercial fishing produced over 40 million pounds of alewives in 1967, a 20-fold increase since 1960. Even though they are easy to catch, alewives are only profitable under certain market conditions when prices are adequate. The instability of commercial fishing in all of the Great Lakes has led to an economically archaic industry with old boats, old equipment, few younger men entering the industry, and little emphasis on new methods.

3.1.3 State and Federal Water Quality Standards

Water pollution is defined as the addition of any soluble or solid particulate matter which changes the quality or characteristics of a body of water in a manner which interferes with, lessens, or destroys a desired use. It is recognized that culturally produced sediments are solid particulate matter and when deposited in harbors and channels they do interfere with the navigational use of the water by restricting vessel draft. In this sense, maintenance dredging could be considered a pollution abatement measure in removing culturally produced sediments from navigable waters. Sections 9.5.2, 9.7.2, and 10.6 provide further comment on the consideration that the Corps is performing a wastes management function through its present maintenance dredging.

The term water quality is relative, taking on one of several meanings, depending upon the intended use of the water. Water of high quality for industrial use may be of poor quality for the swimmer. Nevertheless, water quality criteria must be established in order to improve and maintain the nation's water supply in a useable condition.

The Federal Water Quality Act of 1965 (Public Law 89-234) was established to improve and maintain water quality for continued technological and cultural growth of the United States. The law requires the individual states to adopt water quality standards applicable to interstate waters or portions thereof within their state, together with a plan for upgrading and maintaining the water quality. In establishing such standards, the states shall take into consideration the use and value of water for public water supplies, propagation of fish and wildlife, recreational purposes, agricultural, industrial, and other legitimate uses.

Under provisions of the Federal Act, the Great Lakes states have adopted water quality standards for all of their interstate waters including the Great

Lakes. While each state in the Great Lakes region has its own set of standards and classification systems, they do have basic similarities. As a representative example, the Class "A" standards for New York's interstate waters, including Lake Ontario, are as follows:

Class A

Best usage of waters: Source of water supply for drinking, culinary of food processing purposes and any other usages.

Conditions related to best usage: The waters, if subjected to approved treatment equal to coagulation, sedimentation, filtration, and disinfection, with additional treatment if necessary to reduce naturally present impurities, meet or will meet U. S. Public Health Service Drinking Water Standards and are or will be considered safe and satisfactory for drinking water purposes.

Quality Standards for Class A Waters

Items	Specifications
1. "Floating solids; settleable solids; sludge deposits.	None which are readily visible and attributable to sewage, industrial wastes or other wastes or which deleteriously increase the amounts of these constituents in receiving waters after opportunity for reasonable dilution and mixture with the wastes discharged thereto.
2. Sewage or waste effluents.	None which are not effectively disinfected.
3. Odor producing substances contained in sewage, industrial wastes or other wastes.	The waters after opportunity for reasonable dilution and mixture with the wastes discharged thereto shall not have an increased threshold odor number greater than 8, due to such added wastes.
4. Phenolic compounds.	Not greater than 5 parts per billion (Phenol).
5. pH	Range between 6.5 and 8.5.

6. Dissolved oxygen	For trout waters, not less than 5.0 parts per million; for non-trout waters, not less than 4.0 parts per million.
7. Toxic wastes, oil, deleterious substances, colored or other wastes or heated liquids.	None alone or in combination with other substances or wastes in sufficient amounts or at such temperatures as to be injurious to fish life, make the waters unsafe or unsuitable as a source of water supply for drinking, culinary or food processing purposes or impair the waters for any other best usage as determined for the specific waters which are assigned to this class."

Open waters of each of the Great Lakes meet, or for the most part, are of better quality than Class "A" waters. When considering the many uses of water, it is obvious that some waters in the Great Lakes cannot and need not be Class "A". Each state has classified limited areas, such as harbors, to correspond to the areas' most applicable usage. Again, New York's system serves as an example.

Class B

Best usage of waters: Bathing and any other usages except as a source of water supply for drinking, culinary or food processing purposes.

Quality Standards for Class B Waters

Items	Specifications
1. "Floating solids; settleable solids; sludge deposits.	None which are readily visible, and attributable to sewage, industrial wastes or other wastes or which deleteriously increase the amounts of these constituents in receiving waters after opportunity for reasonable dilution and mixture with the wastes discharged thereto.
2. Sewage or waste effluents.	None which are not effectively disinfected.
3. pH	Range between 6.5 and 8.5.
4. Dissolved oxygen	For trout waters, not less than 5.0

	parts per million; for non-trout waters, not less than 4.0 parts per million.
5. Toxic wastes, oil, deleterious substances, colored or other wastes or heated liquids.	None alone or in combination with other substances or wastes in sufficient amounts or at such temperatures as to be injurious to fish life, make the waters unsafe or unsuitable for bathing or impair the waters for any other best usage as determined for the specific waters which are assigned to this class."

Class C

Best usage of waters: Fishing and any other usages except for bathing or a source of water supply for drinking, culinary or food processing purposes.

Quality Standards for Class C Waters

Items	Specifications
1. "Floating solids; settleable solids; sludge deposits.	None which are readily visible and attributable to sewage, industrial wastes or other wastes or which deleteriously increase the amounts of these constituents in receiving waters after opportunity for reasonable dilution and mixture with the wastes discharged thereto.
2. pH	Range between 6.5 and 8.5.
3. Dissolved oxygen	For trout waters, not less than 5.0 parts per million; for non-trout waters, not less than 4.0 parts per million.
4. Toxic wastes, oil, deleterious substances, colored or other wastes or heated liquids.	None alone or in combination with other substances or wastes in sufficient amounts or at such temperatures as to be injurious to fish life or impair the waters for any other usage as determined for the specific waters assigned to this class."

New York has chosen dissolved oxygen; suspended, colloidal and settleable materials; debris, materials, and oil of unnatural origin; toxic and deleterious substances; total dissolved solids; taste and odor producing substances; and acidity and basicity of water (pH) as their parameters for determining water quality. Some states have included a few more parameters that they regard as useful in their areas, but all states have set specific limits on coliform bacteria counts for their interstate waters. Michigan and Illinois have included limits on nutrients (nitrogen and phosphorus). Increased concern over heated effluent and radioactivity from existing and proposed power plants and other industrial facilities on the Great Lakes has prompted Michigan, Illinois, Indiana, and Ohio to include temperature and radioactive materials in their water quality parameters. Each parameter, applied to a particular area, has been designed to protect maximal usage of that water resource.

3.2 Natural and Cultural Pollution

It is useful to think of pollution as occurring (1) naturally, as in the case of soil erosion which also leaches out nutrients not derived from man's activitites, and (2) culturally, as in the case of waste discharges resulting from man's activities. Such a distinction, especially if the two forms are inventoried and quantified, is helpful in locating those areas where control areas are most urgently needed and where funds could be allocated to achieve the most beneficial results.

Indeed, it was hoped that during this study, sufficient data could be assembled to show how much polluted matter of all types reach each lake annually from all sources, then to determine how much of this annual inflow is moved from one place in the waters of the lake - within harbors - to the open lake disposal areas by dredging. The quantities would be measured in terms of the parameters discussed later in Section 6.2.2. This would enable one to quantify the possible relative improvement to the Lakes through removal of dredge spoil by impoundment. Perhaps it would be discovered that some fraction of all the pollutants reaching the Lakes could thus be removed. The comparative worth of removing those pollutants by impoundment of dredgings or by removing them at their source through expanded treatment facilities could be intelligently judged then. However, only limited information is available at the present time because of variations in loadings between high and low runoff periods, seasonal and economic conditions influencing the production of waste products, and variations in the assimilation capacities of the rivers transporting pollutants. A much greater amount of data would be needed to establish a reasonably reliable source breakdown and constituent balance of the pollutants reaching the Lakes. To acquire such data would take a period of years and would require a large field force to monitor, sample, and analyse every single inflow continuously the year round.

Based upon work done by both Federal and State agencies, as well as several universities, the FWPCA program offices on the Great Lakes have compiled some data on the pollutional loadings to each of the Lakes, except for Lake Superior. These data are presented in tables 4 through 15. The implications and conditions to be drawn from this limited information are discussed later in Section 10.

Table 4

Pollutants Contributed to Lake Michigan

From Major Tributaries[a]

Input	Total Soluble Phosphorus-P[b]	Total Nitrogen	Toxic Metals[c]	Suspended Solids	Dissolved Solids
DIRECT TO LAKE MICHIGAN					
Manistique River	11	332	100	7,574	141,255
Manitowoc River	17	64	14	2,373	21,170
Sheboygan River	17	172	44	3,376	40,332
Milwaukee River	37	406	39	4,508	68,620
Burns Ditch	87	338	15	3,103	65,700
St. Joseph River	159	2,143	284	42,523	627,800
Kalamazoo River	77	1,420	112	22,448	403,325
Grand River	318	2,712	412	44,895	653,350
Muskegon River	33	852	239	16,973	399,675
Pere Marquette River	5	202	112	6,169	120,633
GREEN BAY TRIBUTARIES					
Fox River	397	8,870	477	108,770	1,178,950
Oconto River	43	2,530	55	10,950	204,400
Peshtigo River	23	516	193	13,140	246,375
Menominee River	115	2,014	NS	41,610	492,750
Ford River	4	189	40	2,354	67,343
Escanaba River	20	422	150	16,005	166,075
Rapid River	41	119	NS	1,416	18,798
Whitefish River	13	80	NS	1,117	43,800
TRAVERSE BAY TRIBUTARY					
Boardman River	16	NS	NS	NS	55,789

a Tons/year
b Total Phosphorus -P not analyzed
c Includes Copper, Cadmium, Nickel, Zinc and Chromium

NS Not Sampled
Not sampled: Oil & Greases, Volatile Solids, COD, Phenols, BOD

Table 5

Pollutants Dumped in Lake Michigan Spoil Areas

Dredged From Lake Michigan Harbors[a]

Harbor	Oils & Greases	Total Phosphorus	Total Nitrogen	Volatile Solids	COD	Toxic Metals[b]	Phenols	BOD	Suspended Solids	Dissolved Solids
Waukegan, Illinois	109	11	19	-	1,680	163	.016	-	-	-
Calumet River, Ill.	1,185	97	86	-	11,250	5,660	.010	-	-	-
Indiana Canal, Illinois	1,640	61	104	-	16,250	4,430	.065	-	-	-
Green Bay, Wisc.	200	1	198	-	7,280	458	.039	-	-	-
Kenosha, Wisconsin	54	1	16	-	1,720	196	.018	-	-	-
Milwaukee, Wisconsin	100	11	15	-	3,680	344	.073	-	-	-
Manitowoc, Wisconsin	44	7	66	-	2,350	241	.060	-	-	-
Two Rivers, Wisconsin	41	10	120	-	8,100	2,120	.087	-	-	-
Manistee Harbor, Michigan	10	3	3	600	300	-	c	2	-	-
Muskegon Harbor, Michigan	6	3	1	500	40	-	c	3	-	-

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[a] Tons/year
[b] Includes Total Iron, Copper, Cadmium, Nickel, Zinc, Lead, & Chromium
[c] Not significant

Table 6

Loadings To Lake Huron[a]

Parameter	Inflow from Lake Superior	Inflow from Lake Michigan	U. S. Tributaries	Outflow from Lake Huron
Chlorides (Cl)	78,000	280,000	950,000	1,000,000
Total Solids	3,900,000	6,400,000	5,200,000	22,000,000
Suspended Solids	78,000	95,000	290,000	1,600,000
Volatile Susp. Solids	78,000	95,000	90,000	520,000
Total Iron (Fe)	36,000	13,000	6,000	35,000
Total Phosphate (PO_4)	2,900	5,700	5,000	15,000
Soluble Phosphate (PO_4)	1,400	2,800	3,300	12,000
Nitrate-Nitrogen (N)	10,000	9,500	5,200	31,000
Ammonia-Nitrogen (N)	5,700	9,000	4,900	19,000
Organic-Nitrogen (N)	5,700	7,600	2,800	19,000
Calcium (Ca)	930,000	1,400,000	810,000	4,700,000
Magnesium (Mg)	210,000	520,000	230,000	1,600,000
Sodium (Na)	140,000	190,000	400,000	700,000
Potassium (K)	72,000	94,000	74,000	170,000
Sulfate (SO_4)	210,000	900,000	470,000	3,000,000
Alkalinity ($CaCO_3$)	3,000,000	4,400,000	1,800,000	14,000,00
Hardness ($CaCO_3$)	3,200,000	5,200,000	2,700,000	16,000,00
Phenol	140	95	68	520
COD	430,000	240,000	260,000	1,200,000
BOD	72,000	94,000	39,000	170,000
DO	720,000	530,000	110,000	1,900,000
Flow (in cfs)	72,600	48,000	11,000	176,900

---

[a] Tons/year

Table 7

Pollution Loadings to Lake Huron[a]

Parameter	From all Sources	From Dredging of Saginaw Harbor, Mich[b]	From Dredging of Harbor Beach, Mich.[c]
Oil and Grease		1,000	20
Total Phosphorus (P)	2,300	130	20
Total Nitrogen (N)	30,000	100	-
COD	700,000	10,000	2,000
Phenols	100	0.2	d
BOD	80,000	1,000	-
Suspended Solids	700,000	-	-
Dissolved Solids	9,000,000	-	-
Volatile Solids	-	20,000	2,000

a Tons/year
b Based on 500,000 c.y. of dredging
c Based on 35,000 c.y. of dredging
d Not significant

Table 8

Constituent Balance for the Rouge River[a]

Parameters	Estimated Total Quantities that reach the Rouge River, from Industrial Sources	Estimated Total Quantities Removed from Rouge River by Dredging[b]
Oil and Grease		11,000
Total Phosphorus (P)	0.3	650
Total Nitrogen (N)	-	100
Volatile Solids	-	40,000
COD	-	60,000
Phenols	150	0.6
BOD	30,000	5,000
Suspended Solids	20,000	-

[a] Tons/year

[b] Based on 450,000 c.y. of dredging

Table 9

Waste Loads to Lake Erie Basin Waters-1966[a]

Source	BOD	Chlorides	Total Phosphorus	Suspended Solids[b]	Dissolved Solids
Industrial	480,000	10,980,000	5,900		
Municipal	900,000	1,830,000	86,400		
Ruran Runoff		3,120,000	18,220		
Urban Runoff			8,760		
Lake Huron Outflow	950,000	6,500,000	<20,000	3,800,000	116,000,000
U.S. Undifferentiated				73,000,000	84,000,000
Canada Undifferentiated	100,000 est.	2,900,000	18,000	57,100,000	
Total	2,430,000	25,330,000	157,280	133,900,000	200,000,000

---

a FWPCA Lake Erie Report, August 1968 Table 4-9, all values in pounds per day

b Over two-thirds of this comes from shore erosion. Exclusive of solids (9*million tons annually) deposited in the lake in dredging operations.

* U.S. dredgings deposited in Lake Erie by both the Corps of Engineers and permitees amounted to about 5 1/2 million tons of solids in 1966 and 4 million tons in 1967.

Table 10

Summary of Tributary Loadings to Lake Erie[a]
1967
(Sampling Location plus downstream data)

Tributary	Total Solids		Total Chlorides		Tot. Phosphorus	
	lbs/Day	Tons/Year	lbs/Day	Tons/Year	lbs/Day	Tons/Year
Maumee River	12,118,639	2,211,887	532,706	97,137	16,336	2,996
Portage River	795,905	142,202	48,839	8,896	921	168
Sandusky River	3,097,688	565,173	111,434	20,324	3,241	591
Huron River	782,429	142,776	29,055	5,297	868	158
Vermilion River	617,502	112,580	30,100	5,491	383	70
Black River	910,128	166,267	65,240	11,900	1,044	190
Rocky River	941,970	172,095	81,993	14,915	1,571	287
Cuyahoga River	4,089,506	746,308	514,052	93,968	8,640	1,570
Chagrin River	1,624,320	296,380	61,340	11,206	811	148
Grand River	7,980,336	1,456,409	4,095,644	765,533	647	118
Ashtabula River	644,078	121,180	327,797	59,812	74	14
Cattaraugus Creek	1,845,504	336,895	44,928	8,213	552	101
Total	35,721,657	6,516,462	5,977,542	1,108,971	35,284	6,447

[a] FWPCA, Lake Erie South Shore Tributary Data Summary, 1967, Table 6

Table 11

Cleveland Harbor Annual Waste Load Balance Estimate[a]

	Load to River				Load Removal				
	Cultural	Natural	Unaccounted	Total	River Flow	Rv. Dredging[b]	Hbr. Dredging[c]	Unaccounted	Total
Oil and Grease	20,350	150		20,500	100	18,000	2,400		20,500
Phosphorus	4,450	100		4,550	240	2,000	450	1,860	4,550
Nitrogen	13,500	1,500		15,000	4,600	2,500	480	7,420	15,000
Volatile Solids	Unknown	Unknown		174,000	90,000	64,000	20,000		174,000
COD	72,000	Unknown	112,000	184,000	35,000	120,000	29,000		184,000
BOD		Unknown		13,000	3,900	7,600	1,500		13,000
Phenols	100				20				
Total Iron	20,000	60,000		80,000	1,300	56,000	14,000	8,700	80,000
Silica	6,000	490,000		496,000		280,500	216,000		496,000
Suspended Solids	150,000	200,000	508,000	858,000	48,000	510,000	300,000		858,000
Dissolved Solids	490,000	170,000		660,000	470,000	290	180	189,530	660,000

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a Tons/year
b Based upon 845,000 c.y. dredging in river
c Based upon 500,000 c.y. dredging in harbor

Table 12

Fairport Harbor Annual Waste Load Balance Estimate[a]

	Load to River				Load Removal				
	Cultural	Natural	Unaccounted	Total	River Flow	Rv. Dredging[b]	Hbr. Dredging[c]	Unaccounted	Total
Oil and Grease	240	80		320	4	96	220		316
Phosphorus	---120---		570	690	30	370	290		690
Nitrogen						420	320		
Volatile Solids						16,000	16,000		
COD						11,000	9,400		
Total Iron						4,400	3,300		
Suspended Solids	20,000	190,000		210,000	18,000	90,000	102,000		210,000
Dissolved Solids	1,170,000	130,000		1,300,000	1,300,000	260	300		1,300,000

a Tons/year
b Based upon 190,000 c.y. removed from river
c Based upon 215,000 c.y. removed from river

Table 13

Conneaut Harbor Annual Waste Load Balance Estimate[a]

	Load to River				Load Removal				
	Cultural	Natural	Unaccounted	Total	River Flow	Rv. Dredging[b]	Hbr. Dredging[c]	Unaccounted	Total
Oil and Grease	54	30		84		34	50		84
Phosphorus	25	11	15	51	6	16	29		51
Nitrogen						54[d]	60[d]		
Volatile Solids						2,300	2,900		
COD						3,000	3,000		
Total Iron						860	2,000		
Suspended Solids	50					27,000	56,000		
Dissolved Solids	50	46,000			46,000	5	8		

a Tons/year
b Based upon 35,000 c.y. removed from river
c Based upon 65,000 c.y. removed from harbor
d Kjeldahl Nitrogen

Table 14

Buffalo Harbor Annual Waste Load Balance Estimate[a]

	Load to River and Harbor				Load Removed from Harbors					
	Cultural	Natural	Unaccounted	Total	River Flow	Rv. Dredging[b]	Outer Harbor[c]	Tonawanda & Black Rock[d]	Permit Dr.	Total
Oil and Grease	2,500	120				920	1,300	480		
Phosphorus	600	75				77	140	73		
Nitrogen	4,500	500				180	410	160		
Volatile Solids						6,400	18,000	6,600		
COD						9,900	21,000	9,000		
BOD	30,000									
Total Iron						4,100	15,000	2,900		
Suspended Solids						67,200	185,000	65,000		

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[a] Tons/year
[b] Based upon 125,000 c.y. dredging in river
[c] Based upon 400,000 c.y. dredging in Buffalo Outer Harbor
[d] Based upon 100,000 c.y. dredging Black Rock Channel and Tonawanda Harbor

Table 15

Estimated Quantities of Pollutants from all Sources that Reach the Waters of Lake Ontario Annually[a]

Inputs	Point Sources	Niagara R.	Other Major Tributaries	Totals	Great Sodus[b]	Rochester[c]	Oswego[d]	Totals
Total Phosphates	2,880	22,400	4,250	29,530	.5	100	33	134
Total Nitrogen	2,400	87,300	19,000	108,700	.8	20	.1	20.4
Volatile Solids	-	-	-	-	7.3	2,500	-	2,510
COD	Not available	1,660,000	339,000	1,999,000	-	3,500	85	3,585
BOD	23,900	471,000	64,200	559,100	1	31	2.6	35
Suspended Solids	471,000	4,750,000	795,000	5,591,800	120	18,000	1,300	19,420
Dissolved Solids	64,200	32,300,000	4,640,000	37,010,300	-	-	-	-

[a] Tons/year
[b] 30,000 c.y.
[c] 360,000 c.y.
[d] 80,000 c.y.

Section 4

DREDGING OPERATIONS: EXPERIENCE TO DATE

4.1 Dredging Operations

4.1.1 Historical

Dredging of harbors on the Great Lakes dates back to the early 19th century. Improvement to harbors at that time consisted of measures to combat formation of bars at river mouths caused by littoral drift of material along the lake shore and deposition of suspended matter carried down the rivers. The projects, in general, provided for removal of the bars by dredging or the construction of parallel piers extending into the lake. The piers were intended to increase velocities during periods of high flow so as to scour out the channel between the piers sufficiently to accommodate the vessels then in use. As vessels increased in size, it was necessary to perform dredging operations to maintain navigable depths. Quantities of dredging increased gradually with growth in vessel dimensions.

A new phase of harbor development was initiated at the turn of the century. Large harbors along the lake fronts were formed by construction of breakwaters out into the Lakes. These large areas were at first of sufficient depth for navigation, but they also served as excellent settling basins for material brought down from upstream areas, and it became necessary to dredge them periodically to maintain navigable depths. Volumes of dredging continued to increase as vessels became ever larger. Projects were undertaken periodically to deepen harbors to keep up with vessel draft requirements.

Present projects call for depths of 27 to 30 feet in outer harbors and connecting channels between the Lakes and somewhat lesser depths in inner harbors and channels.

4.1.2 Quantities moved

Dredging operations can be classed in two general categories: maintenance; and new work dredging. Maintenance dredging comprises the removal of soft and easily excavated sediments deposited since the last dredging. It is generally required annually in the commercially more important harbors and less frequently in harbors for light-draft recreational craft.

New work dredging is employed to improve a harbor area or channel by widening or deepening. This type of dredging removes materials, ranging from limestone to compacted clays, which were deposited in older geologic times. In performing new work dredging some small amounts of very recently deposited material is also removed. New work dredging is performed only when authorized and funded by Congress after a need for and justification of the improvement has been shown.

Past dredging records in the Corps offices are in sufficient detail to compile a good history of dredging operations from 1933 to the present, but earlier records are incomplete. Figures 8 through 12 are bar graphs showing the yearly volumes of dredging in each of the Great Lakes and connecting channels. These data include only dredging by the Corps. In addition, local industries have dredged the area between the Federal channels and the unloading piers and in private slips and channels. Data on such dredging were not readily available, but the volume is estimated to be less than 10 percent of that dredged by the Corps.

At present, it is unlikely that further deepening of harbors and connecting channels by new work dredging will occur in the near future. Almost all major harbors are now improved to accommodate the size of vessel which can pass through the ship locks on the St. Lawrence River, the Welland Canal or the St. Mary's River. The new Poe Lock, completed in 1968 at Sault Ste. Marie, Michigan, can pass vessels larger than any now navigating the Great Lakes. Under study at the present time are proposals to construct additional locks on the St. Lawrence River

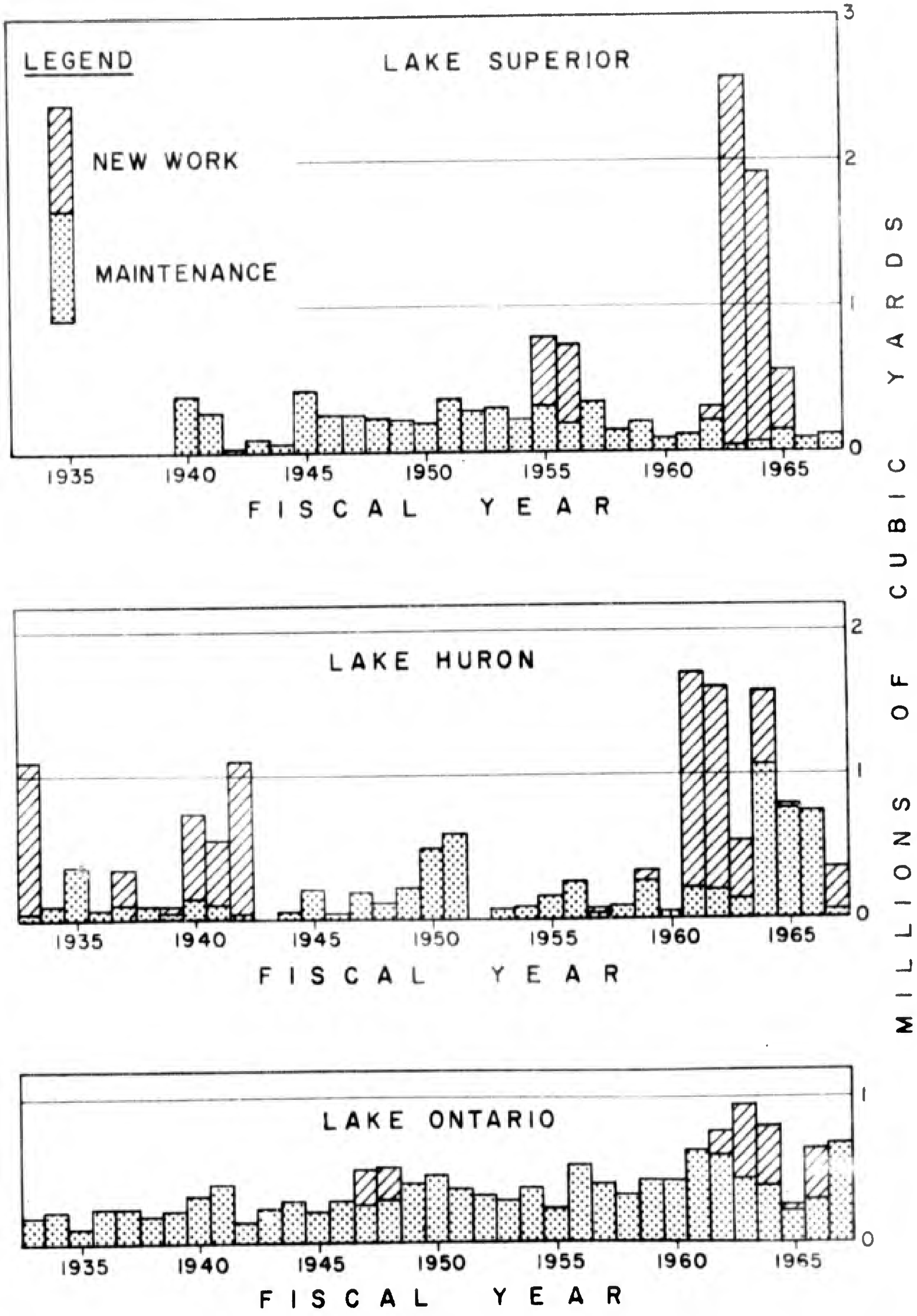

Figure 8. Dredging In Lakes Superior, Huron And Ontario By Corps Of Engineers

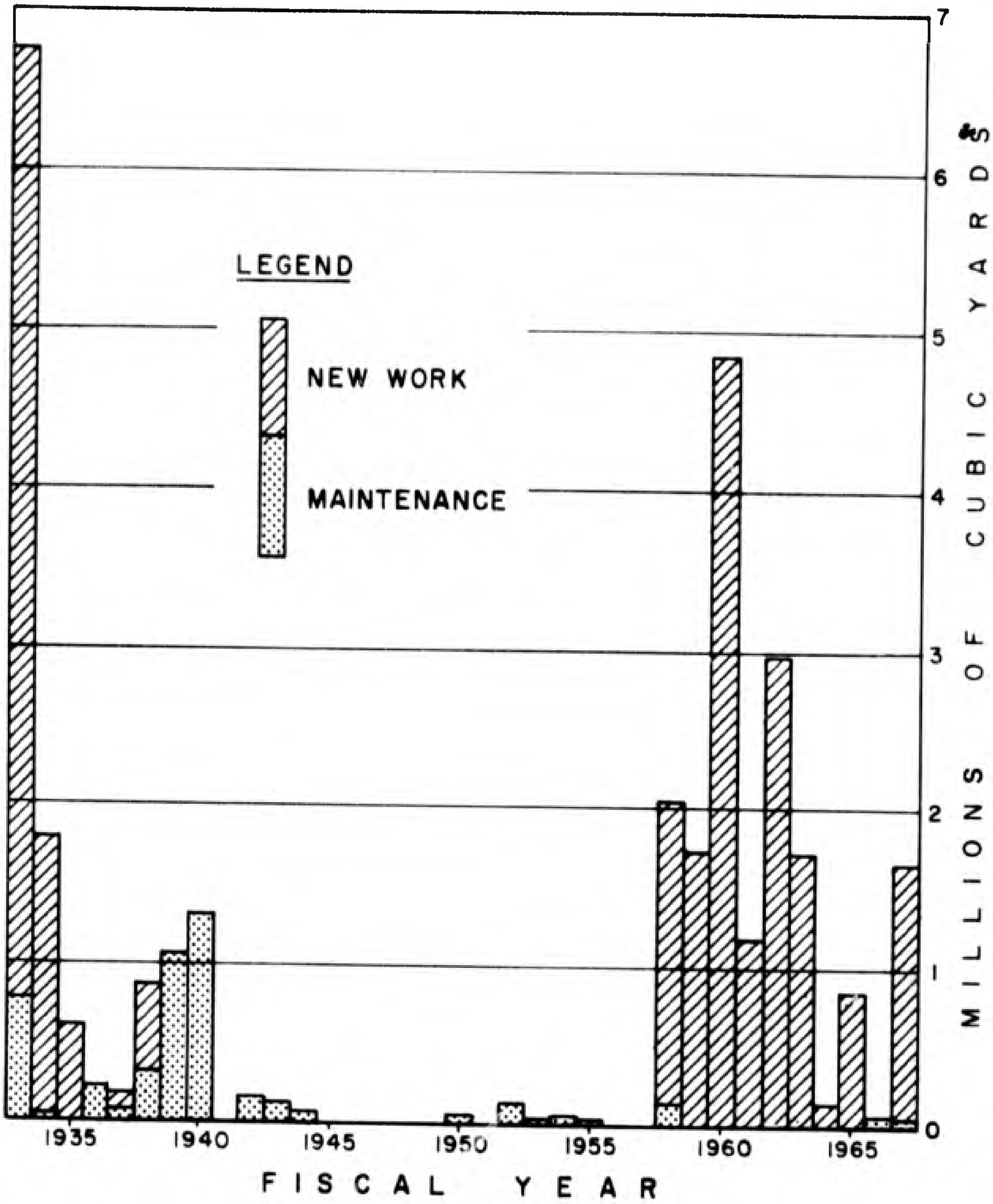

Figure 9. Dredging in St. Mary's River By Corps Of Engineers

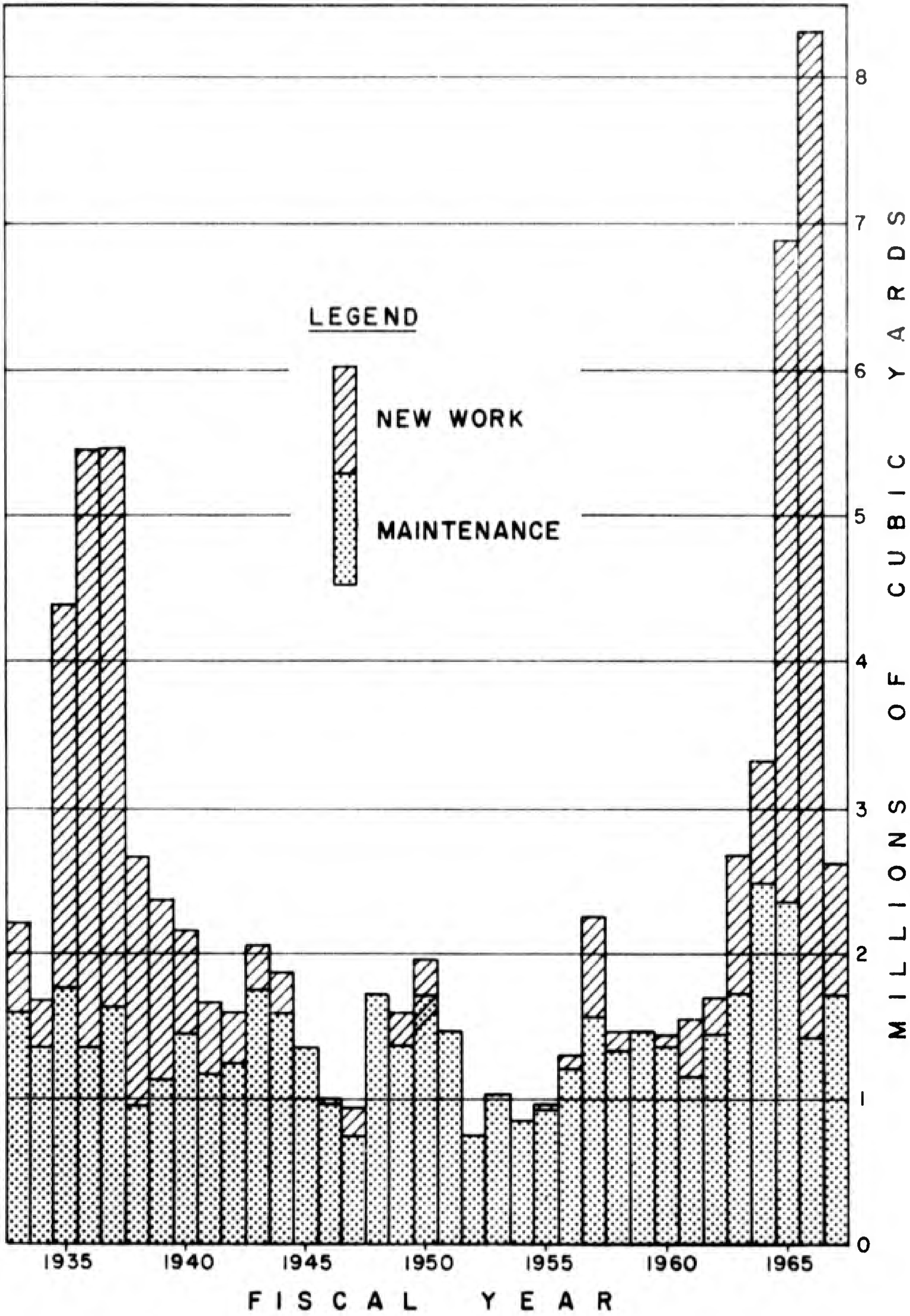

Figure 10. Dredging In Lake Michigan By Corps Of Engineers

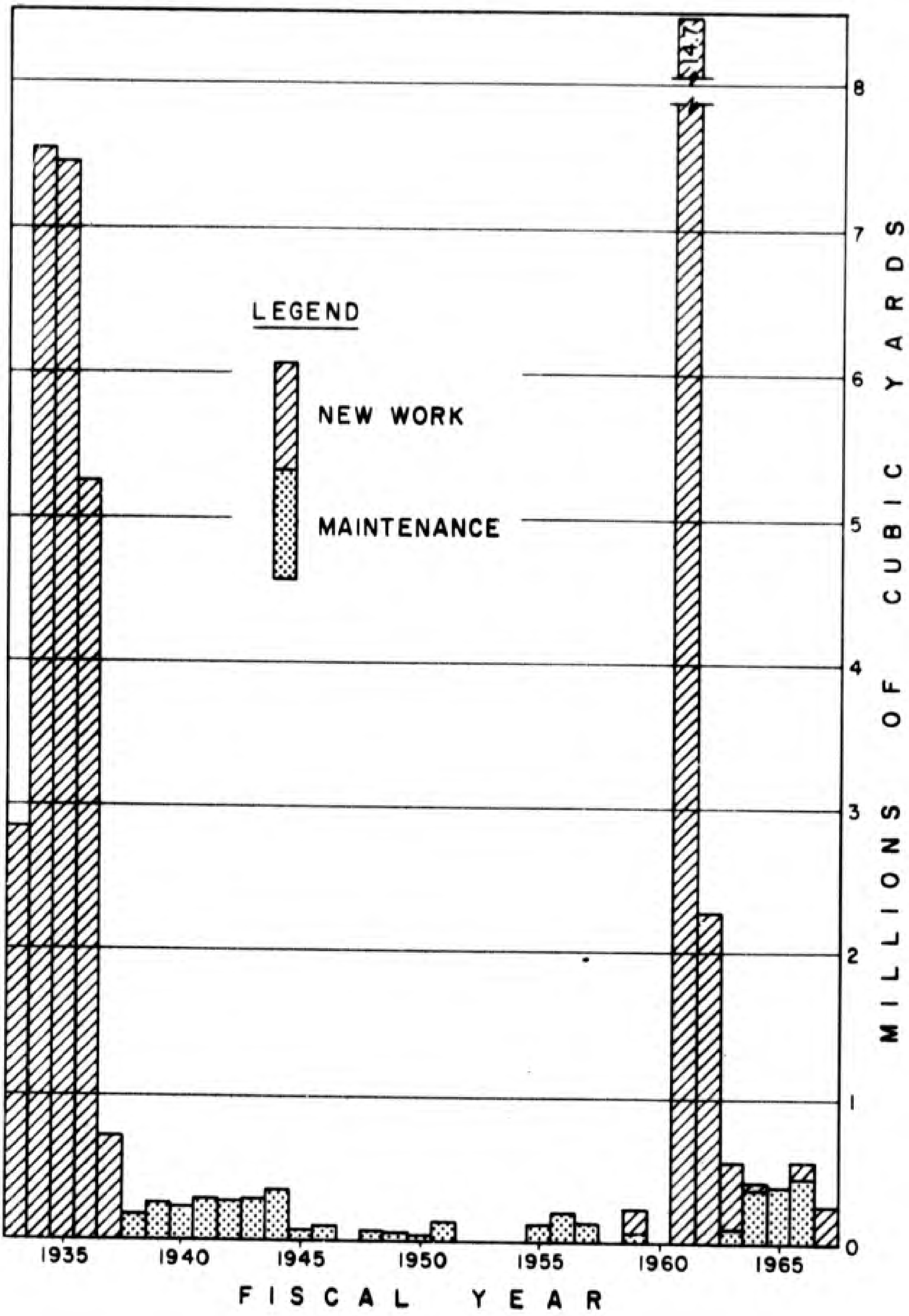

Figure II. Dredging in Lake St. Clair and St. Clair River by Corps of Engineers

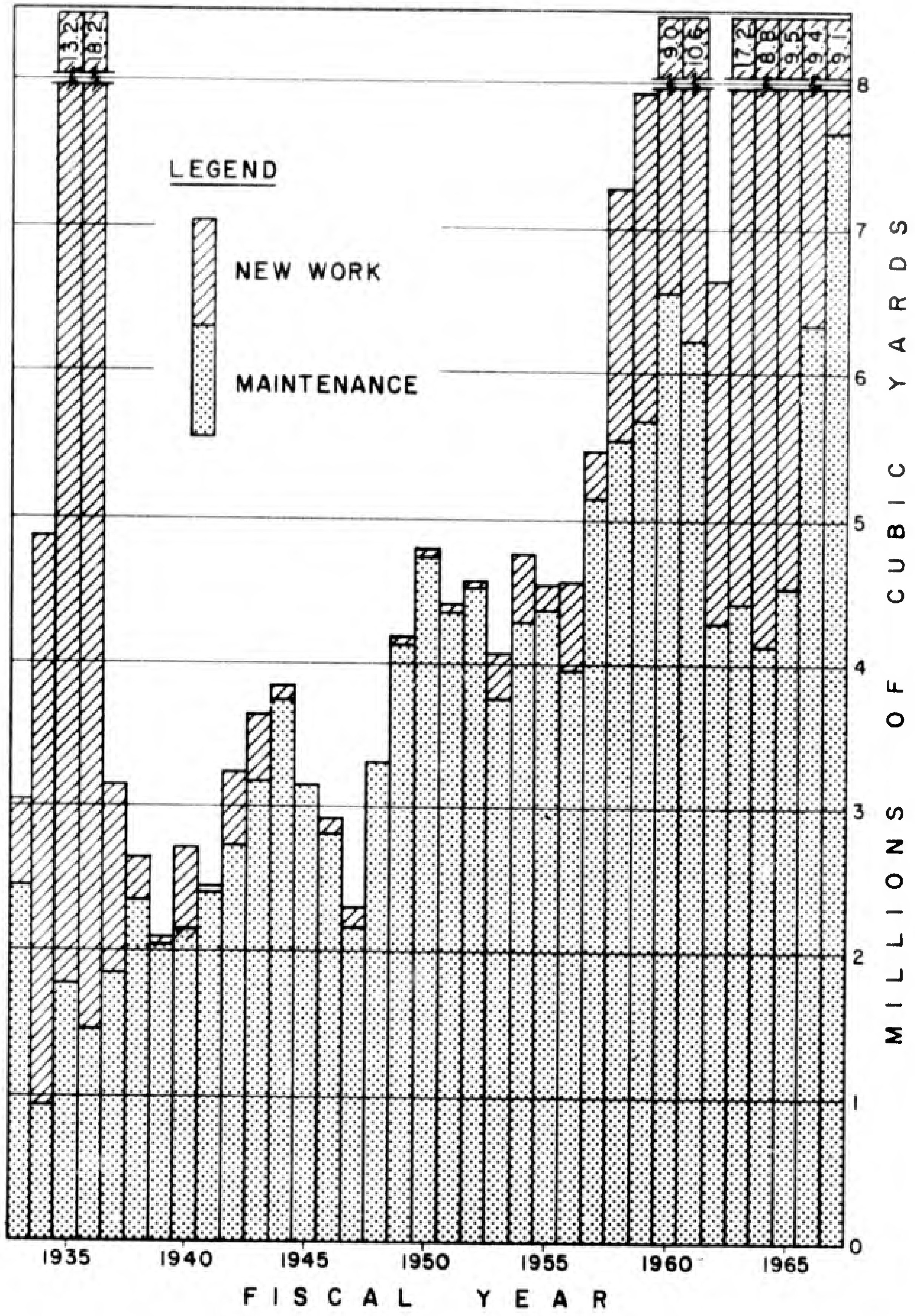

Figure 12. Dredging In Lake Erie And Lower Detroit River Including Rouge River By Corps Of Engineers

and new canals linking Lakes Ontario and Erie to relieve congestion and provide capacity for additional shipping. These projects, if authorized and constructed, are likely to include ship locks of larger size than those now available. Vessels larger than those now in use are being planned, and there will be a growing demand for deeper and larger harbors. However, costs for further improvement by new work dredging would be of such magnitude that it is difficult to speculate that such improvements could be justified.

Estimates of future annual maintenance dredging requirements are difficult to make because of the variations in the present quantities dredged. Also, it is expected that current efforts by regulatory agencies may result in a reduction in the volume of waste discharges which now end up as harbor sediments. While the volume of such discharges is large, it is generally only a small fraction of the dredging volume. Increased soil conservation practices may reduce the amount of sediment originating from soil erosion, but, up to the present, such practices have been implemented only at small watersheds. Table 16 shows the estimates for future annual maintenance dredging for the various harbors currently maintained by the Corps. The tabulated values do not reflect any reductions which may result from the aforementioned control measures.

Table 16

Estimated Quantities of Future Annual Maintenance Dredging

Lake or Connecting Channel	Name of Harbor or River Project	Future Annual Maintenance Dredging in 1,000 Cu. Yds.
Lake Ontario	Great Sodus Bay Harbor	40
	Oswego Harbor	80
	Rochester Harbor	360
	Other small projects	nil
		480
Lake Erie, Niagara and Detroit Rivers	Ashtabula Harbor	220
	Black Rock Channel & Tonawanda Harbor	100
	Buffalo Harbor	525
	Cleveland Harbor	1,220
	Conneaut Harbor	100
	Detroit River	800
	Dunkirk Harbor	20
	Erie Harbor	300
	Fairport Harbor	400
	Huron Harbor	200
	Lorain Harbor	300
	Monroe Harbor	240
	Rouge River	300
	Sandusky Harbor	600
	Toledo Harbor	1,400
	Other small projects	35
		6,760
Lake Huron, St. Mary's River	Au Sable Harbor	40
	Harbor Beach	30
	Saginaw River	600
	St. Mary's River	250
	Other small projects	100
		1,020
Lake Michigan	Calumet Harbor and River	200
	Chicago Harbor and River	108
	Charlevoix Harbor	30
	Frankfort Harbor	32
	Grand Haven Harbor and River	100
	Green Bay Harbor	137
	Holland Harbor	105
	Indiana Harbor	151
	Kenosha Harbor	29
	Kewaunee Harbor	28
	Ludington Harbor	55
	Manistee Harbor	55
	Manistique Harbor	40

Lake or Connecting Channel	Name of Harbor or River Project	Future Annual Maintenance Dredging in 1,000 Cu. Yds.
	Manitowoc Harbor	35
	Michigan City Harbor	48
	Milwaukee Harbor	70
	Muskegon Harbor	105
	Pentwater Harbor	70
	Portage Lake Harbor	40
	Racine Harbor	30
	Saugatuck Harbor	55
	Sheboygan Harbor	23
	South Haven Harbor	74
	St. Joseph Harbor	80
	Two Rivers Harbor	51
	Waukegan Harbor	32
	White Lake Harbor	60
	Other small projects	37
		1,880
Lake Superior	Duluth-Superior Harbor	150
	Ontonagen Harbor	80
	Keweenaw Waterway	40
		270
Lake St. Clair, St. Clair River	Clinton River	20
	Lake St. Clair	200
	St. Clair River	200
	Other small projects	7
		427
	Total	10,837

4.2 Types of Dredges

4.2.1 General

Dredging can be defined as a process for the removal of materials from underwater and the subsequent disposal of them. The process includes the two operations: excavation of the material; and the conveyance to and disposal of the material at the disposal site. Equipment for dredging operations falls into two classes: mechanical; and hydraulic. The dipper and clamshell dredges used on the Great Lakes are mechanically operated, while the pipeline and hopper dredges are hydraulically operated. When excavation is by mechanically operated dredges, auxiliary equipment, consisting of scows and tugs, is required to receive the dredged material and transport it to the disposal site. Hydraulic dredges combine the digging and disposal operations in one piece of equipment. Each type of dredge and method of operation is described more fully in the following sections.

4.2.2 Dipper Dredge

The dipper dredge is a heavy duty excavator. Its main feature is a power operated dipper stick which, by sliding through the center plane of a boom, allows the operator to control forward, vertical, and horizontal movement of the bucket at the end of the dipper stick.

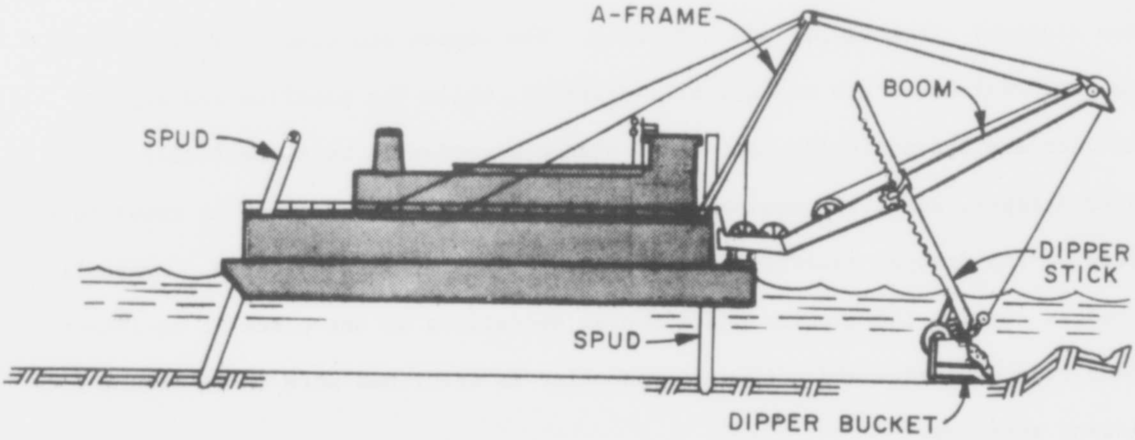

Figure 13 Dipper Dredge

The dipper dredge is especially useful for new work dredging and breaking up hard compacted material, including some types of ledge rock. When operating, the dredge is hoisted up on the two forward spuds, thereby making the hull a stable working platform. The rear spud is a trailing type which keeps the dredge in proper alignment when moving forward in a cut. The excavating operation is very similiar to that of the familiar crawler shovel. The boom is swung around to empty the bucket into a scow waiting alongside of the dredge. Rates of dredging depend on the size of the dipper bucket, the nature of the material and depth of cut, but can range as high as 400 cubic yards an hour.

4.2.3 Clamshell Dredge

In this type of dredge, a clamshell bucket is suspended by cables from a forward extending boom which can swing about the bow of the dredge.

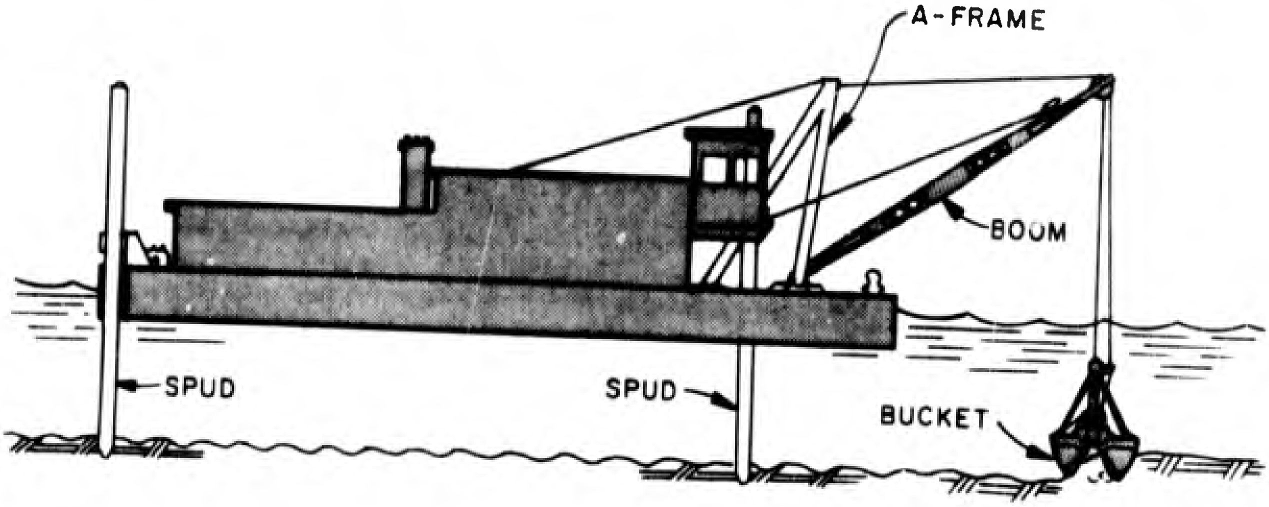

Figure 14 Clamshell Dredge

The clamshell dredge is used, for the most part, to excavate soft or cohesive underwater materials and is exceptionally useful for deep digging and for dredging in close quarters alongside structures. Maintenance dredging in winding river channels is usually done with a clamshell dredge. Spuds may or may not be used. When spuds are not used, anchor lines are required to position and maneuver the dredge. The boom and bucket are swung around to empty the bucket into a scow waiting alongside the dredge. Large clamshell dredges can excavate up to 400 cubic yards an hour when excavating soft, light-weight material and swinging a special 12 cubic yard, light-weight bucket.

4.2.4 Pipeline Dredge

The pipeline dredge excavates with a revolving cutter surrounding the intake end of a suction pipe. The cutter and suction pipe are mounted on a ladder frame hinged at the forward end of the dredge for vertical movement. A pumping unit sucks up material at the intake end of the suction pipe and discharges the material through a trailing pipeline to the disposal site. The dredge is generally equipped with two stern spuds and forward anchors to swing the hull around one of the stern spuds. By alternately raising each of the spuds, the dredge excavates transversely across the dredge area and walks ahead into the cut.

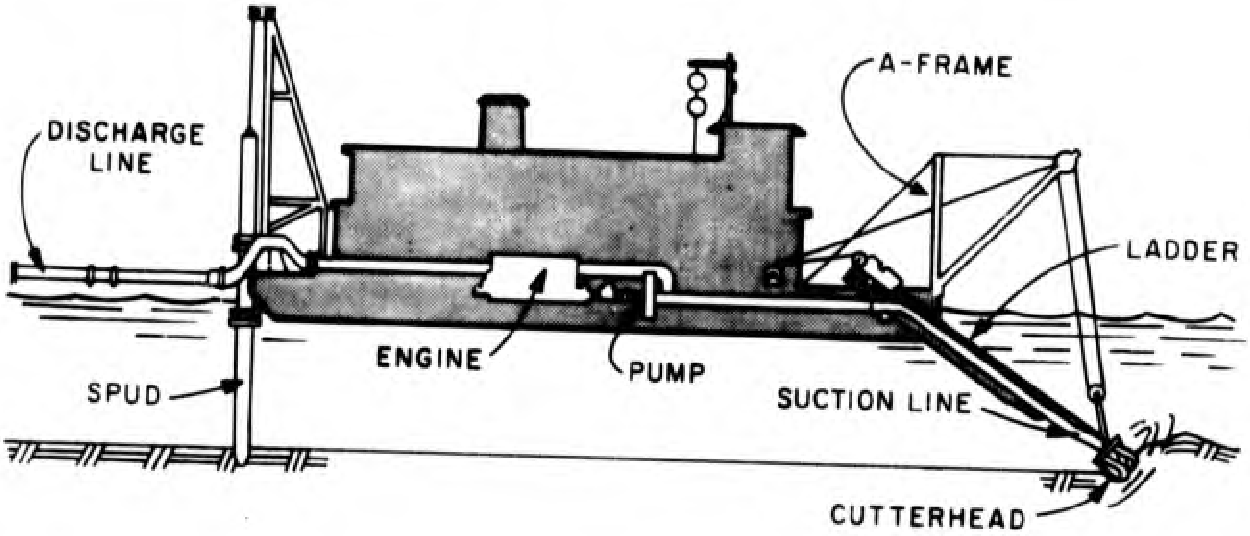

Figure 15 Pipeline Dredge

It is customary to designate the size of a pipeline dredge by the diameter of the discharge pipe. Sizes range from midget 6-inch portable dredges to 36-inch mammoths. Pipeline dredges usually contain their own power unit, but occasionally are electrically driven from onshore power supplies. Rates of output depend on factors, such as the horsepower of the pumping and cutter head machinery, the length of pipeline, the elevation of the disposal site, use of booster stations, and the nature of the material. Pipeline dredges are used most frequently for dredging sandy, clayey, or silty bottoms which have sufficient depths of cut for economical operation.

4.2.5 Hopper Dredge

A hopper dredge is essentially a self-propelled ship. The dredging apparatus consists of one or more dredging pumps located in the hold. Each pump is provided with a suction pipe leading out through the side of the hull to a flexible connection that permits raising and lowering the external portion of the suction pipe, which is equipped with a drag head at its intake. Pumping goes on while the dredge is under way at slow speed and while the drag heads slide over the sediments to be dredged. The dredgings are discharged into hoppers where they settle. Fines and excess water overflow at the top of the hoppers. Dredging continues until an economical load has been accumulated in the hoppers. Then the pumps are shut down, and the dredge itself transports its load to the disposal site.

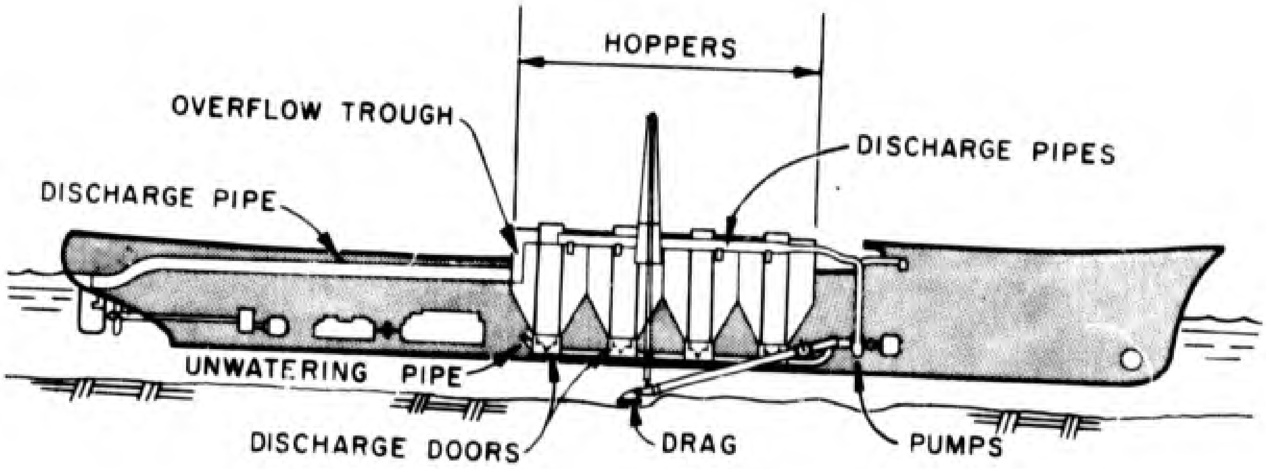

Figure 16 Hopper Dredge

Hopper dredges are not equipped with cutter heads and work well only in uncompacted materials deposited as sediments. They are particularly efficient in removing a thin layer of sediment covering extensive areas. The size of a hopper dredge is usually expressed as its hopper capacity in cubic yards. Its actual rate of performance depends upon the length of time required to fill the hoppers, and on the speed and length of travel of the vessel to and from the disposal site.

In turn, these measures change with the character of the material dredged and the pumping and propelling power of the vessel. Hopper dredges range in capacity from about 400 to about 8,000 cubic yards. Three of the four hopper dredges owned by the U. S. Army Corps of Engineers and in current use on the Great Lakes have a 900 cubic yard hopper capacity, while the other one has a 2,700 cubic yard hopper capacity.

Normally, the hoppers are emptied by opening doors at their bottoms while the dredge passes over the disposal site. However, in recent years, some of the hopper dredges have been equipped with piping through which they can pump out the hoppers to an on-shore or in-lake disposal site. The dredge ties up to a mooring, and connects its discharge pipe to a pipeline through which the dredgings flow to a disposal area that would otherwise be inaccessible to the dredge. Three of the four hopper dredges currently on the Great Lakes are so equipped.

Hopper dredges presently do about 75 percent of the approximately ten million cubic yards of annual maintenance dredging on the Great Lakes. Another 20 percent is being accomplished by clamshell dredges.

4.2.6 Comparative Costs

It is not reasonable to compare costs of dredging per cubic yard by the various types of dredges. In most cases, the type of dredge is dictated by the work to be done and the disposal sites to be used. Dipper dredges are employed on the hardest types of materials, and costs range upwards from about two dollars a cubic yard depending on the hardness of the material and other physical factors. At the other end of the spectrum is the hopper dredge, which can excavate for as little as twenty-five cents a cubic yard when the distance to an open water disposal area is short and the material settles rapidly. Pipeline dredges, when employed on work suited to them, usually excavate for under one dollar a cubic yard. Clamshell dredging costs range between one to two dollars a cubic yard.

4.3 Types of Disposal

4.3.1 Open Lake

Past dredging practices in the Great Lakes required the disposal of dredged material in the open lake areas designated by the Corps of Engineers. In general, areas were selected as close to the harbor as possible and of sufficient depth to preclude interference or obstruction to navigation. Moreover, disposal areas in the general proximity of intakes for public water supply or recreational beaches were avoided. Figures 17 through 21 are maps of the Lakes showing the areas, to scale, within which dredges or scows dropped dredged material.

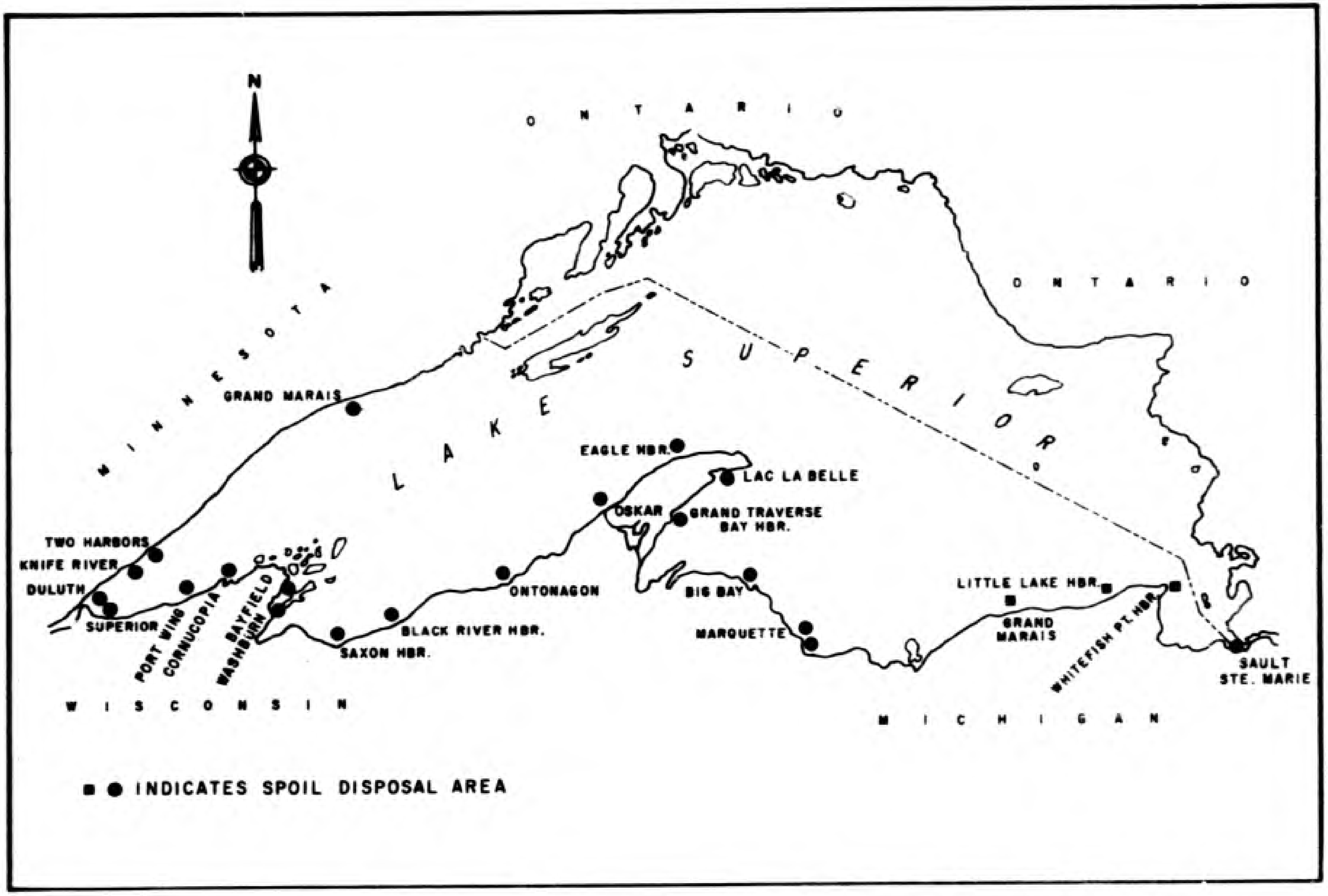

Figure 17 Disposal Areas on Lake Superior

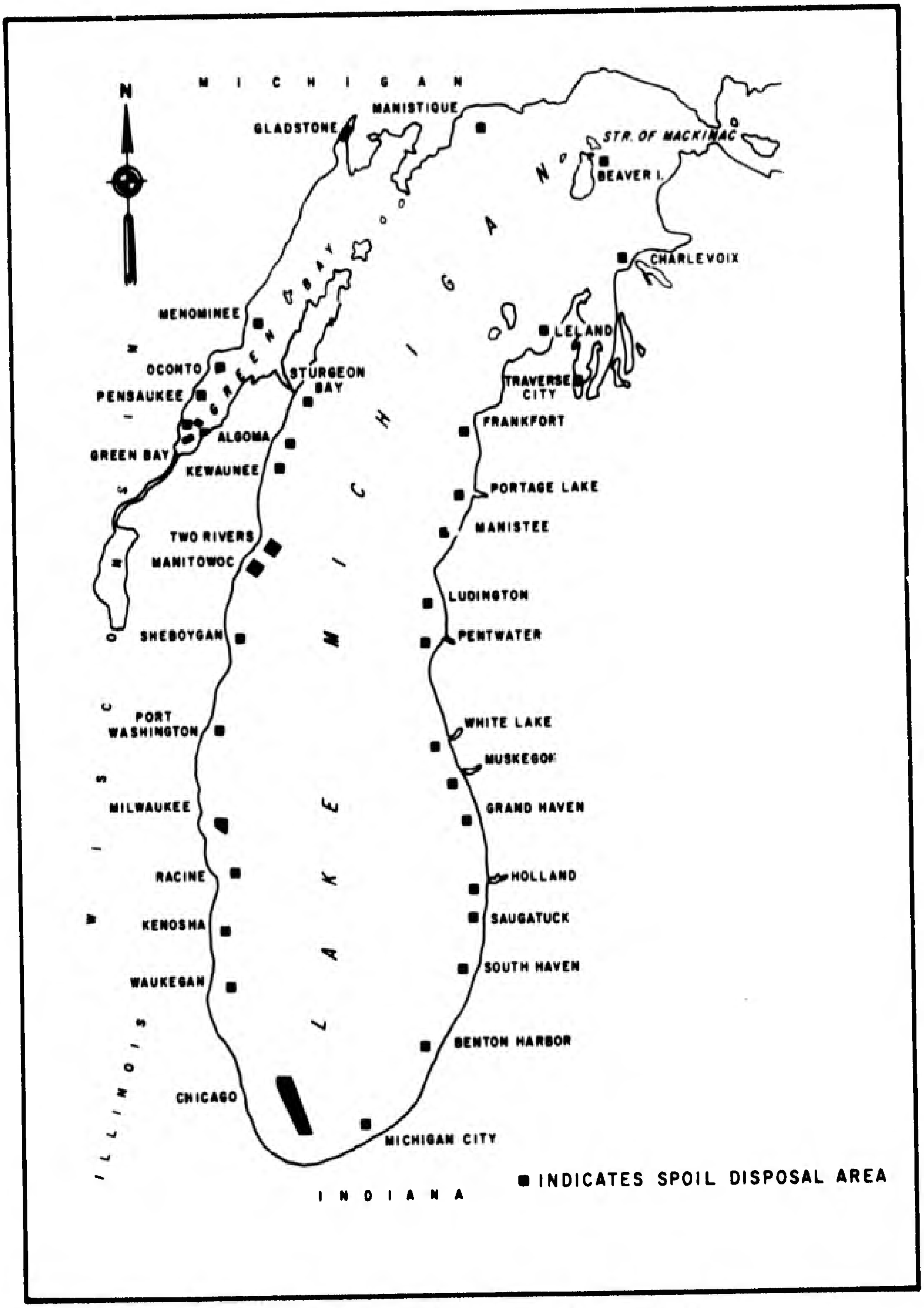

Figure 18 Disposal Areas on Lake Michigan

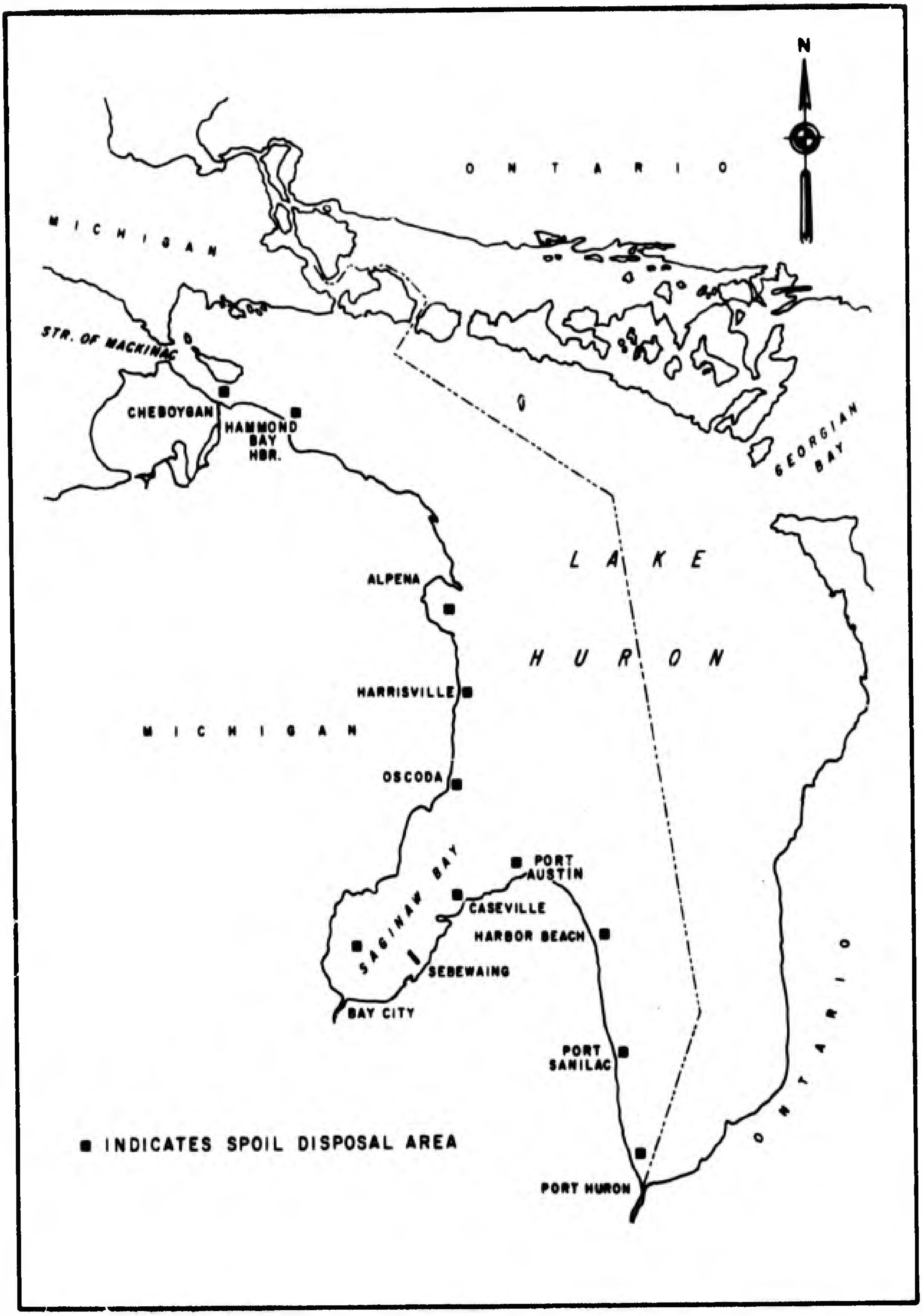

Figure 19 Disposal Areas on Lake Huron

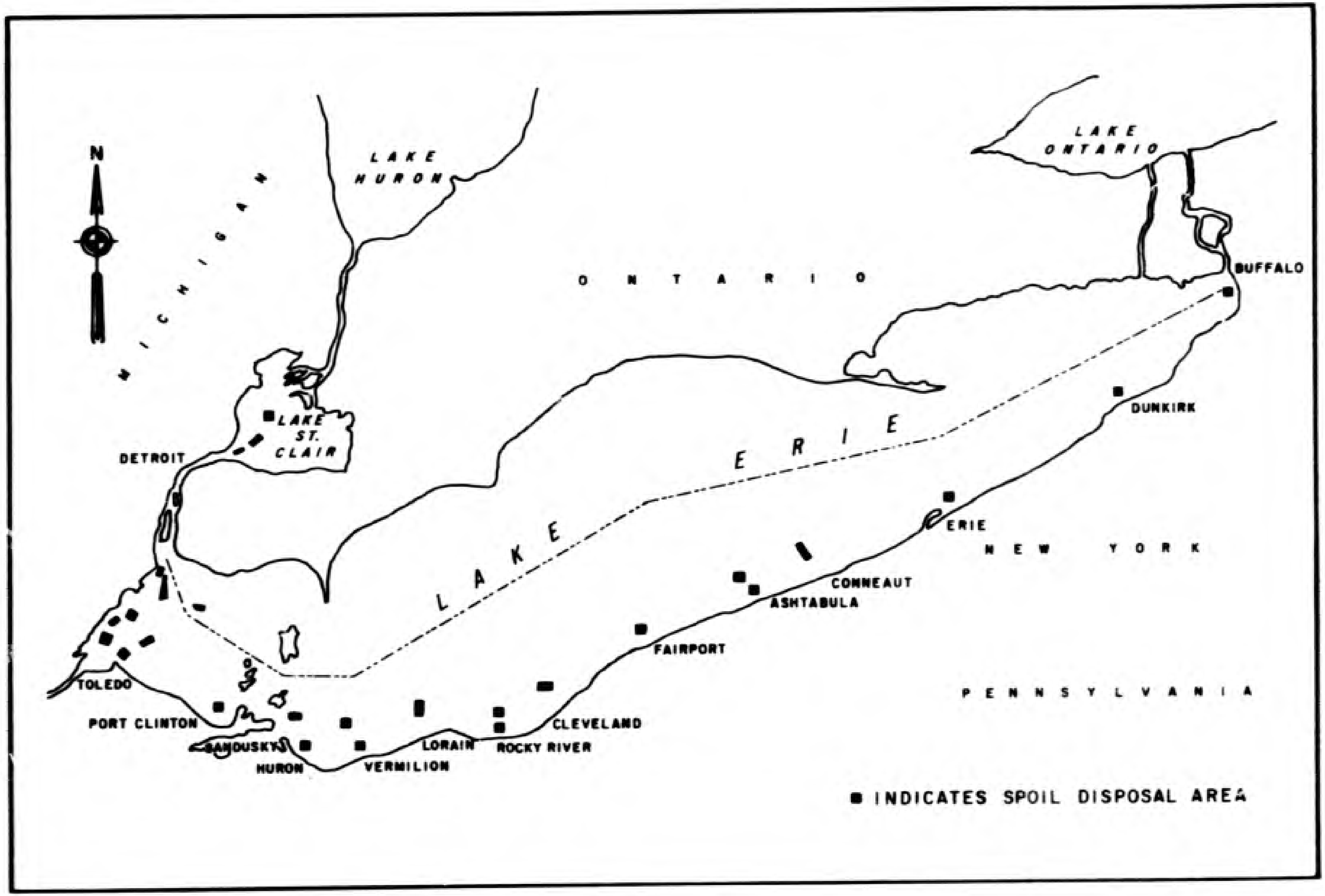

Figure 20 Disposal Areas on Lake Erie

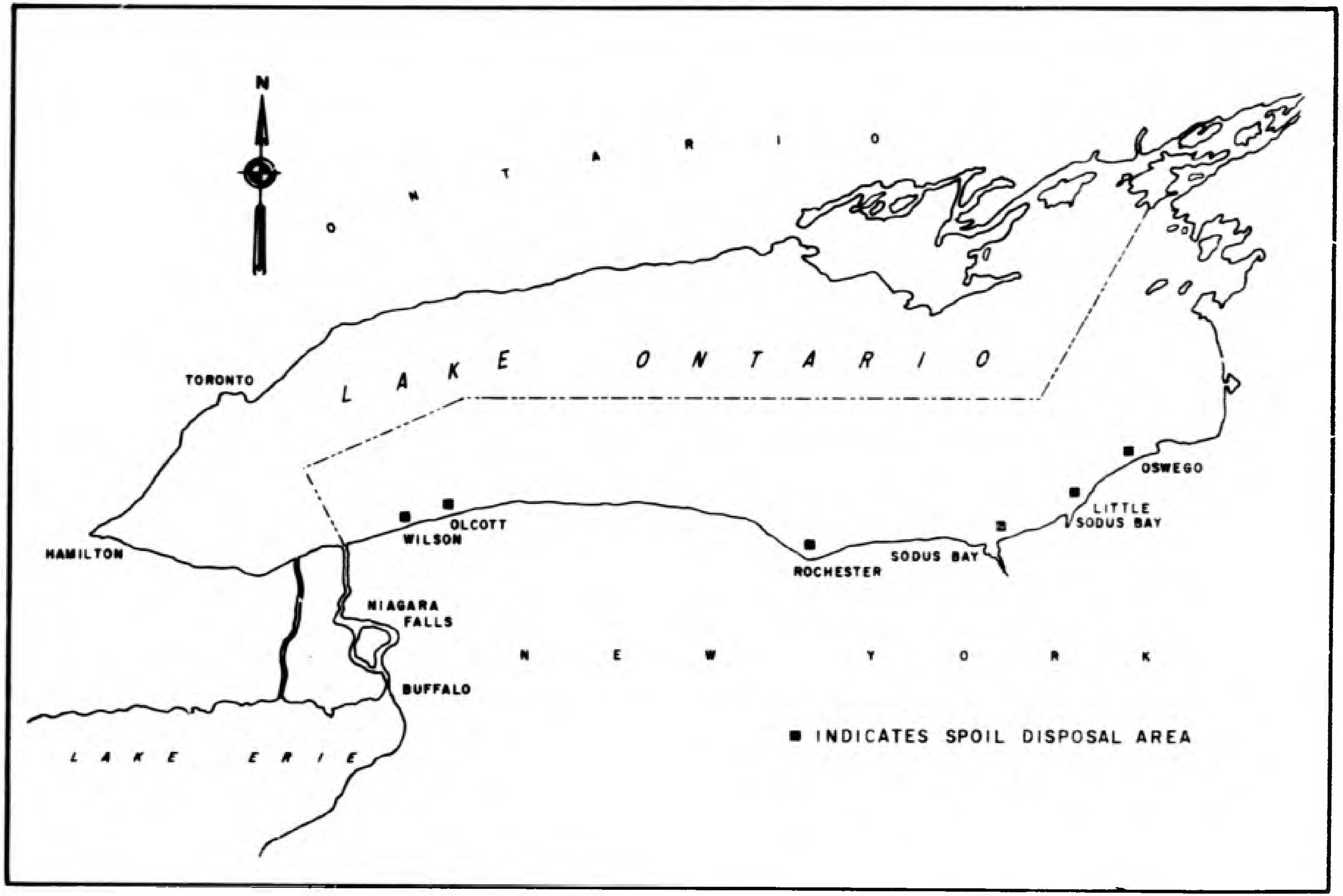

Figure 21 Disposal Areas on Lake Ontario

4.3.2 Offshore Diked Areas

Prior to 1967, materials from maintenance dredging on the Great Lakes were rarely deposited inside offshore or alongshore diked areas to create new land. The fine sediment dredged from harbors, particularly harbors polluted with industrial and domestic wastes, seldom provides a satisfactory fill because it is hygroscopic and lacks shear strength.

Maintenance dredgings from the Rouge River at Detroit and the Maumee River in Toledo have been deposited in diked disposal areas since 1960 and 1961, respectively. The bottom sediments from both of these rivers are of the same general nature, mostly clays and silts, polluted by municipal and industrial wastes. Three separate diked inclosures are used at Toledo. Two of the areas are land disposal sites which are side by side, adjacent to the dredging area, and the third is in Maumee Bay near the mouth of the Maumee River. Each of the three areas at Toledo is equipped with an overflow for runoff of excess water.

Rouge River spoil is deposited in the Grassy Island disposal area, located in the Detroit River, 4-1/2 miles downstream from the lower end of the Rouge River project. Grassy Island does not provide for regular discharge of the effluent because of its large ponding area. Excess water is lost largely by evaporation from the ponded water surface and by seepage through the earth dike. Core samples of the filled area were taken to determine strength characteristics. Results of these samples are discussed in Section 7.5.

From 1948 to 1952, maintenance dredgings from the Cuyahoga River were deposited in the area now occupied by the Burke Lakefront Airport at Cleveland, Ohio. The City of Cleveland also placed municipal wastes in the same area. The mixed fill was found to be unsuitable as a base for the runways, and therefore, a portion of the fill was excavated and replaced with suitable material.

In studies for the present report, alongshore diked disposal areas were constructed during 1967 at Buffalo, New York, and Cleveland, Ohio, to receive portions of the maintenance dredging spoil. In addition, an existing diked area at Indiana Harbor, Indiana, was used for a portion of the dredgings from that harbor in 1967. The results of sampling and other tests at these sites are evaluated in Section 6.

Construction of an offshore diked disposal area in Green Bay was initiated in 1967 using new work dredgings from a project to deepen the outer channel. It is planned to complete the dikes in 1969 and thereafter use them for disposal of maintenance dredging from appropriate sections of the outer channel.

4.3.3 Landfills

In the past, practically all landfills were constructed of new work dredgings. These materials, deposited in older geologic eras, contain few man-made wastes other than those included in a thin layer of recent sediments overlying older unpolluted bottom materials. Landfills with these dredgings usually have been suitable for beneficial use. There is no known record of a landfill consisting of polluted maintenance dredgings alone.

In studies for the present report, a landfill was begun along the Calumet River in 1967. Additional filling of this area with maintenance dredgings took place in late 1968. In addition, in 1967, a mixture of new work and maintenance dredgings was deposited in a land disposal site at Green Bay. The results of samples taken at these areas are presented in Section 6.

Section 5

SURVEYS AND INVESTIGATIONS

In Section 1, the present study was designated as a Corps of Engineers investigation with the cooperation of the *Federal Water Pollution Control Administration*. The list of cooperating agencies and participants in the study does not end there, however; a number of other government agencies, along with private firms and universities contributed in various ways.

The sampling studies were carried out by FWPCA, the *Detroit Testing Laboratory*, and the Corps' *Buffalo* and *Lake Survey Districts.* The sampling program is described in Section 6.2 and detailed sampling results at the harbors investigated are attached as Appendices A and B.

The *University of Wisconsin* was engaged to investigate the physical size, composition, treatability, and biological productivity of sediments collected from the eight pilot areas (see Section 6.1 for list of pilot areas). Their separate report (Appendix C5) is discussed in Section 6.4.3.

Dow Chemical Company studied the use of polyelectrolyte coagulant aids to settle out suspended solids in the dredgings: (1) on board the dredge; and (2) at a diked disposal area. On-board flocculation (Appendix C3) was studied at Saginaw Bay, Michigan, while the addition of coagulants to a diked disposal area (Appendix C4) was carried out at Toledo, Ohio. Both studies are discussed in Section 7.4.

The *Water Resources Center*, *University of Illinois*, was contracted to study the feasibility of evaluating benefits from improved Great Lakes water quality resulting from cessation of open lake disposal of polluted dredgings (Appendix C8). As a follow-up to the Illinois study, the consulting firm of *Greeley and Hansen* was engaged to employ the methodology set up by the Illinois study and evaluate the measurable benefits to municipal water treatment plants (Appendix C9) from cessation of open lake disposal. Section 8 of the present report contains further discussion of both studies.

The firm of Nebolsine, Toth, McPhee Associates studied the feasibility and cost of treating the dredgings by various waste treatment processes, such as: (1) aerobic stabilization; (2) anaerobic stabilization; (3) chemical stabilization; (4) wet oxidation; and (5) incineration. Their report (Appendix C6) is discussed in Section 7.4.3.

The Metropolitan Sanitary District of Greater Chicago and the Corps' Chicago District collaborated on a study of the feasibility and cost of disposing of dredgings in a municipal sewerage system. During 1968, a three-phase trial operation was conducted at Chicago, Illinois. This operation (Appendix C7) is discussed in Section 7.4.2.

The Marine Design Division of the Corps' Philadelphia District studied modifications of dredge equipment and procedures. These modifications are described in Section 7.3.2.

A bibliographical literature search was conducted by Wayne State University. This investigation (Appendix C11) is discussed in Section 1.4.

For the present study, an alternate method of disposing of dredged material considered was to contain the material within diked areas on shore, along shore in the harbor, or in the open lake. For such disposal, the Buffalo, Chicago and Detroit Districts made surveys of 37 harbors including the pilot areas: (1) to determine whether the dredgings indeed could be used beneficially for planned improvements; (2) to locate undeveloped land areas on which the dredgings could be deposited without local objections; and (3) to plan diked inclosures in or adjacent to the harbors. Studied, too, were methods and costs of rehandling the dredgings for transfer directly to near-by disposal sites, or for transport to distant disposal areas. All feasible sites and methods were considered, and a report was prepared for each harbor or channel project investigated. All of the survey reports are included as appendices to the present report, (Appendices K, L, and M). A summary of the survey reports for the pilot areas is contained in Section 7.5.

Section 6

DREDGING OPERATIONS: EFFECTS ON WATER QUALITY

6.1 General

Until 1967, little was known about the effects of dredging and the disposal of dredgings on water quality in the Great Lakes. Most of the studies and investigations conducted during the past two years were concentrated at eight localities which were selected to represent the range of conditions expected to be encountered at the 115 dredging projects currently maintained by the Corps. In addition, other studies were made at as many of the dredging projects, and inasmuch detail, as time and resources permitted. A complete inventory of the surveys and investigations appear in the appendices. Some of the studies and investigations were still underway at the end of 1968, but they are not expected to affect materially the conclusions and recommendations of the present report. The eight localities, hereinafter referred to as pilot areas, were:

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

Each harbor presents questions of its own for answer. 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 to be considered. Each of these factors affects the quality of the receiving water and each varies from place to place, and with time and season at a given place. The investigations of the past two years for the present study have helped to identify some of the effects, but much basic information will have to be collected before the nature and magnitude of the full effects of disposal of dredged materials in the Great Lakes can be critically evaluated.

This section of the present report contains the most recent information on the character of the materials dredged and on the effects of dredging and disposal operations on water quality, both within a given dredging area and at given disposal sites. Also described is the cooperative sampling and analysis program developed by the Corps of Engineers and the FWPCA to obtain data on water and sediment quality. The results of detailed sampling surveys are contained in the appendices to the present report.

6.2 Sampling Operations

6.2.1 Program

When the study was begun in the early spring of 1967, staff members of FWPCA and the Corps of Engineers agreed on a general list of useful and available water and sediment parameters, a pattern of locating sampling stations, and procedures to be followed in connection with the Cleveland Harbor project, which was the first project scheduled for dredging and sampling in the 1967 season. It was recognized from the beginning that manpower and laboratory facilities of the cooperating FWPCA program offices and the Corps Lake Survey District would be severely strained in conducting the sampling and laboratory analyses scheduled.

Surveys of open lake disposal areas were assigned to the Lake Survey District's vessel SHENEHON, which possesses necessary laboratory facilities, sampling equipment, and rigging for work in the open lake. Her mission was to sample at and in the vicinity of open lake disposal sites just prior to, during, and after completion of disposal operations. In most cases a new sampling cruise was begun each work day and the same stations were reoccupied. The parameters measured fell into four groupings: wind and wave data, suspended sediment and related parameters, dissolved ions and related parameters, and bottom samples. Water samples were normally taken near the surface and near the bottom. Bottom characteristics were derived from grab samples of the bottom surface material. Investigations at some harbors included the collection of biological data. Since four hopper dredges were operating on the Great Lakes during the 1967 dredging season, it became impossible to sample at all harbors to be dredged. Therefore, primary emphasis was placed on sampling Lake Erie harbors in the spring and summer and Lake Michigan harbors in the fall.

Samples of water, bottom sediments, dredgings, and disposal area effluents were obtained by the FWPCA at all of the pilot areas, except Toledo, and at many of the additional areas investigated. Samples were analyzed in FWPCA laboratories, and reports were prepared of their activities and findings. The results of the sampling operations at seven of the pilot areas were reviewed and a report, attached as Appendix C2, was prepared to summarize available data so that dredging operations, disposal of spoil in the Lakes, and disposal of spoil in diked areas could be evaluated as to their contribution to lake pollution. Appendix C2 also includes a discussion of the geochemical relationships of sediments, solutes, and solvents.

Since all of the desired sampling could not be accomplished in 1967, the sampling program was continued in 1968, but without the assistance of Lake Survey. Some sampling was still underway while the present report was in preparation.

The objective of the sampling program was to obtain, from the samples collected, analytical data on the following: (1) the degree of pollution of the sediments; (2) the effect of dredging operations on water quality in the dredging areas; (3) the effect of spoil disposal on water quality at the open water disposal sites; (4) the effectiveness of disposal of dredgings in diked disposal areas; (5) the effectiveness of various techniques for rehandling dredgings in connection with the diked areas; and (6) the effectiveness of different types of dike construction material.

During the progress of the study, it became apparent that the selected chemical and biological parameters of sediments and water would not adequately describe the effects on water quality of open lake disposal of polluted sediments. Therefore, the program was enlarged by adding laboratory tests that would: (1) determine, functionally, the effects of dredging disposal on lake biota; and (2) measure associated variations in the physical properties of overlying waters. Moreover, it was decided to perform studies of the anaerobic digestion of sediments in order to provide a rational base for the preliminary design of possible treatment works. The University of Wisconsin was engaged to obtain the requisite additional samples from each of the pilot areas and to perform the prescribed laboratory tests. Their report is attached as Appendix C5.

6.2.2 Significant Parameters

The water and sediment parameters selected for laboratory determination are listed below. Some of them apply only to water, while others only to sediment samples. Because of limitations of laboratory facilities, however, not all of these analyses were made on all samples.

Table 17
Significant Parameters

Parameter	Significance
Total and soluble phosphate	algal nutrients
Total nitrogen and ammonia, organic, and nitrate	nutrients and organic matter
Biochemical oxygen demand (BOD)	degradable organic matter
Chemical oxygen demand (COD)	oxidizable carbonaceous matter
Dissolved oxygen (DO)	a measure of aerobic condition
Oil and grease	objectionable matter
Chloride	taste producing
Iron	coloring
pH	relative acidity
Alkalinity	a measure of carbonates, in particular
Total solids	a
Dissolved solids	a
Suspended solids	a
Volatile solids	a measure of organic matter
Turbidity	a measure of light penetration
Eh	indicator of either aerobic or anaerobic conditions
Coliforms, total and fecal	pollutional organisms
Benthic organisms	indicators of pollutional status

a Self explanatory

For water samples, the parameters are those normally employed for assessing the quality of public water supplies. Corresponding parameters were unavailable on the significance and reliability of the degree of pollution of sediments. In the past, the quality of sediments generally has been determined by field observation of parameters, such as odor, color, particle size, and benthic fauna. Only two classifications, "polluted" and "unpolluted", were distinguishable from such observations. A study is now under way by FWPCA: (1) to relate measured chemical parameters to field observations and to determine which parameters are most significant and reliable; and (2) to determine whether the objective determination of chemical parameters is more meaningful than the highly subjective assessment of sediment quality by field observations.

For the purpose of its study, FWPCA examined the results of 21 to 79 samples from Lake Michigan harbors. These samples had been given overall ratings of lightly polluted, moderately polluted, or heavily polluted by field observations. The ratings were correlated with measured values of different parameters, and preliminary ranges were chosen for the measured parameter to cover the overall field ratings as closely as possible. Although the study is still incomplete, preliminary findings of the reliability of the individual parameters for Lake Michigan harbors are presented in Table 18.

Table 18

Chemical Parameters as a Measure of Pollution of Sediments

Parameter	Degree of Pollution			No. of Samples	Errors[a]
	Light[b]	Moderate[b]	Heavy[b]		
Ammonia (N)	0-25	25-75	over 75	53	19%
COD	0-40,000	40,000-120,000	over 120,000	28	18%
Total Iron	0-80,000	8,000-13,000	over 13,000	67	19%
Lead	0-40	40-60	over 60	21	14%
Oil & Grease	0-1,000	1,000-2,000	over 2,000	78	13%
Phenol	0-0.26	0.26-0.60	over 0.60	55	29%
Total Phosphorus	0-100	100-300	over 300	79	20%
Sulfide	0-20	20-60	over 60	21	24%
Volatile Solids	1-5%	5-8%	over 8%	78	15%
Zinc	0-90	90-200	over 200	21	19%

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[a] An error is defined as an overall rating which falls outside of its range for a particular parameter, e.g., a station with a "light" rating falling in the "moderate" range for a particular parameter.

[b] All values in mg/kg (dry) unless otherwise indicated.

A similar analysis for each factor involved in field observations showed errors of only 10 percent, and led the FWPCA to the preliminary conclusion that the visual observations are the most reliable indicators of sediment quality.

In the absence of objective criteria, the classification of harbor sediments employed in the present report is based upon field observations that distinguish sediments as "polluted" or "unpolluted." Table 19 shows the resulting classification for the listed Great Lakes harbors and channels as determined by FWPCA.

Table 19

Pollution Classifications for Great Lakes
Harbors and Channels

I. Unpolluted:

A. Lake Superior:

- Big Bay Harbor, Michigan
- Black River, Michigan
- Cornucopia, Wisconsin
- Grand Traverse, Michigan
- Keweenaw Waterway, Michigan
- Lac LaBelle Harbor, Michigan
- Little Lake, Michigan
- Ontonagon Harbor, Michigan
- Port Wing, Wisconsin
- Preque Isle Harbor, Michigan
- Saxon Harbor, Wisconsin
- Whitefish Point Harbor, Michigan

B. Lake Michigan:

- Charlevoix Harbor, Michigan
- Frankfort, Michigan (outer harbor)
- Grand Haven, Michigan (harbor)
- Green Bay Harbor, Wisconsin (outer channel)
- Holland Harbor, Michigan (entrance channel)

II. Polluted:

A. Lake Superior:

- Duluth - Superior Harbor Minnesota & Wisconsin

B. Lake Michigan:

- Calumet River and Harbor, Illinois & Indiana
- Frankfort, Michigan (inner harbor)
- Grand Haven, Michigan (river)
- Green Bay Harbor, Wisconsin (inner channel)
- Indiana Harbor, Indiana
- Holland Harbor, Michigan (inner channel)
- Kenosha Harbor, Wisconsin
- Kewaunee Harbor, Wisconsin
- Manitowoc Harbor, Wisconsin (river)
- Menominee Harbor, Wisconsin
- Michigan City Harbor, Indiana
- Milwaukee Harbor, Wisconsin
- New Buffalo Harbor, Michigan
- Sheboygan Harbor, Wisconsin

Table 19 (cont'd)

I. Unpolluted: (contd):

B. Lake Michigan:

- Ludington Harbor, Michigan
- Manistee Harbor, Michigan
- Manistique Harbor, Michigan
- Manitowoc, Wisconsin (outer harbor)
- Muskegon Harbor, Michigan
- Oconto Harbor, Wisconsin
- Pensaukee Harbor, Wisconsin
- Pentwater Harbor, Michigan
- Portage Lake Harbor, Michigan
- Port Washington Harbor, Wisconsin
- Racine Harbor, Wisconsin
- Saugatuck Harbor, Michigan
- South Haven, Michigan (outer harbor)
- St. Joseph Harbor, Michigan (outer channel)
- Sturgeon Bay Ship Canal, Wisconsin (approach channel)
- Two Rivers Harbor, Wisconsin (outer channel)
- Waukegan, Illinois (outer harbor)
- White Lake Harbor, Michigan

C. Lake Huron & Connecting Channels:

- Alpena, Michigan
- Au Sable Harbor, Michigan
- Lake St. Clair, Michigan
- Les Cheneaux Island Channels, Michigan
- Sebawaing River, Michigan
- Cheboygan, Michigan (except turning basin)
- St. Clair River, Michigan
- St. Mary's River, Michigan

D. Lake Erie:

- Bolles Harbor, Michigan
- Dunkirk Harbor, New York
- Monroe Harbor, Michigan (outer channel)
- Rocky River Harbor, Ohio

II. Polluted (contd):

B. Lake Michigan:

- South Haven, Michigan (turning basin)
- St. Joseph Harbor, Michigan (inner channel)
- Sturgeon Bay Ship Canal, Wisconsin (canal)
- Two Rivers Harbor, Wisconsin (inner channel)
- Waukegan, Illinois, (inner harbor)

C. Lake Huron & Connecting Channels:

- Detroit River, Michigan
- Harbor Beach Harbor, Michigan
- Rouge River, Michigan
- Saginaw Harbor, Michigan
- Cheboygan, Michigan (turning basin)

D. Lake Erie:

- Ashtabula Harbor, Ohio
- Buffalo Harbor, Black Rock Channel and Tonawanda Harbor, New York
- Cleveland Harbor, Ohio
- Conneaut Harbor, Ohio
- Erie Harbor, Pennsylvania
- Fairport Harbor, Ohio
- Huron Harbor, Ohio
- Little River Harbor, New York
- Lorain Harbor, Ohio
- Monroe Harbor, Michigan (inner channel)
- Sandusky Harbor, Ohio
- Toledo Harbor, Ohio

E. Lake Ontario:

- Oswego Harbor, New York
- Rochester Harbor, New York

Table 19 (con't)

I. Unpolluted (contd):

E. Lake Ontario:

Great Sodus Bay Harbor,
New York
Little Sodus Bay Harbor,
New York

6.2.3 Sampling Methods

6.2.3.1 Water Samples

For chemical and biological analysis, water samples were collected with a Kemmerer, PVC, or APHA sampler. Bacteriological samples were obtained at the surface by immersing bottles by hand and at depths with a Zobel sampler. For continuous sampling, a pump and hose were employed in a study of the effects of coagulants. The depth characteristics of bodies of water were determined by sampling at individual depths, usually at the water surface and immediately above the bottom sediments. Samples were also taken at mid-depth where the water was deep enough to warrant additional sampling. Depending on program need, samples were kept separate or they were composited into a single sample for later analysis. Dredging areas were sampled in conformity with a selected station network. Open water disposal areas were sampled generally on transects crossing the areas and extending beyond them to points at which lake background conditions were thought to exist. Special sampling methods and patterns were devised to suit the objectives of special studies for determining the effects of diked disposal areas.

6.2.3.2 Sediment Samples

Samples of bottom sediment for chemical and biological analyses were collected with a Petersen, Ekman, Shipek, or Smith-McIntyre sampler. The Petersen sampler was most commonly used. However, the Lake Survey normally employed a Shipek sampler.

Two or three grabs were usually required to collect sufficient amounts of sediment for chemical analysis. Grabs were composited and suitable quantities were preserved with chloroform, zinc acetate, or by icing. Samples to be analyzed for benthic organisms were washed through a No. 30 U.S. Standard bronze mesh sieve. The materials retained on the sieve were preserved by transferring them to containers of formaldehyde.

The samplers pick up material from the top several inches of the sediment, and are believed to collect representative samples of the material removed in maintenance dredging. To counter criticisms voiced by dredging contractors that surface samples are not representative of the materials dredged, especially when the work is performed by clamshell or dipper dredge, a core sampler was used during the 1968 sampling of Rouge River sediments. Top, bottom, and middle sections of the cores were analyzed separately for several samples. The variations of measured parameters indicated progressively greater concentrations of pollutants with depth. During sampling at Conneaut Harbor, Ohio, in 1968, comparative samples were taken by both a Petersen dredge and a core sampler at six stations. For two of the stations in this harbor, the top, middle and bottom sections of the cores were analyzed separately. For the parameters measured, variations with depth did not give conclusive information. However, concentrations of pollutants were slightly higher in samples collected with the Petersen dredge than those taken by the core sampler. Since most maintenance dredging is performed by hopper dredges, the surface type of sampler was considered better for the purposes of the present study.

6.2.3.3 Samples of Hydraulic Pipeline Dredgings

Samples of slurry being pumped can be collected only from the discharge end of the pipeline. Efforts to obtain a representative sample of the slurry in order to determine the solids content failed because of difficulty of access.

6.2.3.4 Samples of Scow Dredgings

Material dredged by clamshell was sampled after the dredgings had been placed in the scows for transport to the disposal area. Representative samples were obtained from different locations in the scow and composited into a single sample. Grabs were obtained: (1) by a scoop attached to a pole long enough to reach the different parts of the scow; or (2) by a container that could be plunged into the scow and closed to withdraw a grab from given depths within the scow load. Samples were composited for laboratory analysis in the same manner as described in Section 6.2.3.2.

6.2.3.5 Hopper Dredging Samples

At present, part of the normal procedure during hopper dredging is to continue pumping sediments even after the hoppers have been filled initially. This procedure, described earlier in Section 4.2.5, increases the density of the slurry retained in the hoppers in order to obtain an economical load. The continued pumping also results in overflows from the hoppers and a subsequent discharge of some of the dredgings back into the harbor waters (see a, figure 22). Lighter particles in the slurry tend to be discharged in the overflow, while the heavier particles tend to settle in the hoppers (see b, figure 22).

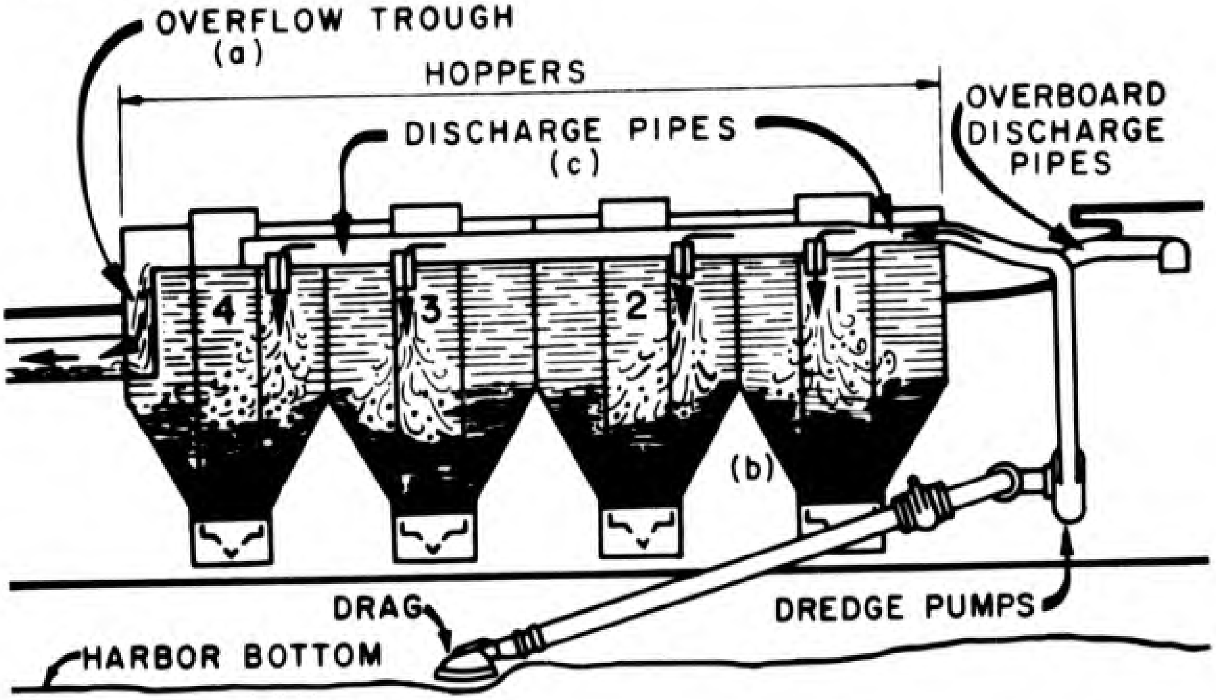

Figure 22 Lengthwise Section through Hoppers

In the sampling program for hopper dredgings, an attempt was made to analyze separately: (1) the material picked up from the harbor bottom; (2) the material in the overflow; and (3) the material left in the hoppers. Sampling of the harbor bottom sediments was discussed in Section 6.2.3.2. No problems were encountered in sampling the overflow. Grab samples were collected at given time intervals from the overflow stream and composited into a single sample.

Sampling the material left in the hoppers has presented a problem, though, because the material becomes segregated in several ways. At the end of the dredging cycle, the most dense material is located in the bottom of the hoppers. From there, the material becomes progressively less dense with vertical distance to the top of the hoppers, where the material is essentially a liquid containing suspended matter (see b, figure 22). In addition, the material becomes segregated horizontally to a degree because of the physical arrangement of the discharge pipes (see c, figure 22). The heaviest particles tend to be discharged into the hopper closest to the pump end of the distribution system (hopper 1, figure 22). Progressively lighter particles tend to be discharged into the hoppers with increasing distance from the pump end (hoppers 2, 3, and 4, figure 22).

As a result of the density variations discussed above, it would be necessary to obtain numerous core samples from all the hoppers in order to obtain a composite representative sample. Thus, sampling directly from the hoppers was deemed impractical.

From the beginning of the present study, it was believed that the best method available to determine the material left in the hoppers was to deduct the measured contents of the overflow from the measured contents of the inflow to the hoppers. In fact, this method was employed for most of the program for sampling hopper dredgings. Locations considered for sampling the inflow to the hoppers were: (1) from the material discharging into the hoppers from the discharge ports or nozzles (see a, figure 23); and (2) from the dredge piping prior to discharge of the material into the hoppers (see b, figure 23).

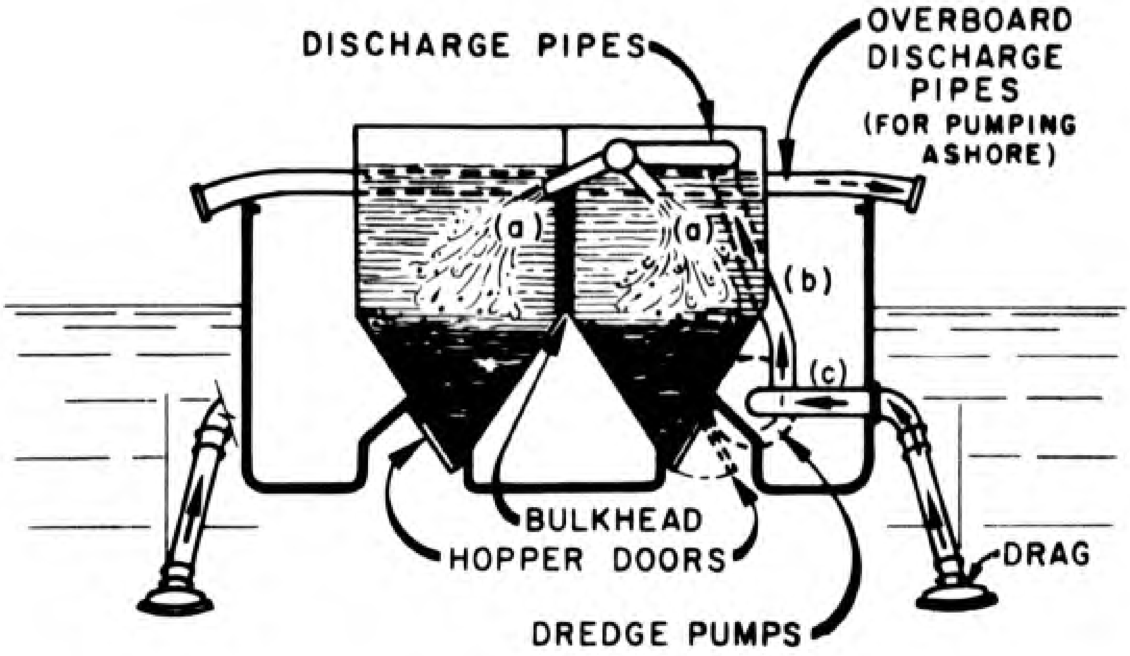

Figure 23 Cross-Section through Hoppers

Sampling of the material discharging from the ports or nozzles was accomplished by using a pole-mounted container having a height two to three times its base. The sampling device was passed rapidly through the inflow stream in order to obtain a small portion of the stream but avoid washing the contents of the container. Grabs from all ports were taken throughout the loading period until the slurry level in the hoppers reached the level of the ports. The grabs were composited to a single sample. It was recognized that sampling had to stop about half-way through the dredging cycle, but it was assumed that the character of the inflow material remained essentially uniform throughout the dredge cycle.

Computations of the material left in the hoppers at the end of the dredging cycle were made by deducting the contents of the overflow from that of the inflow. However, these computations gave inconsistent results and failed to indicate the segregation of material known to take place during the dredging cycle.

Sampling from the dredge piping at the suction side of the dredge pumps was impractical because of the vacuum created by the pumps (see c, figure 23). Sampling from the discharge side was more feasible because the material was under pressure and samples could be collected from a number of available taps in the discharge piping (see b, figure 23). In December, 1967, samples were so collected. At the same time, samples also were collected from the stream entering the hoppers. Comparison of the results of the subsequent analyses indicated that sampling the discharge piping does not produce a representative sample.

In 1968, the feasibility of sampling the hoppers themselves was reconsidered. The liquid portion of the hopper load was able to be sampled satisfactorily with a standard water sampler. A coring device was considered for sampling the settled portion of the load, however, the device was not used because of the difficulty in capturing the layer of very fine material at the top of the settled material. In addition, a coring device was not employed because of the problem of retaining the loosely deposited material in the bottom of the hopper. However, a suitable sampling device was fabricated consisting of six, separate, sampling cups equally spaced vertically on a rod (figure 24). The cups were equipped with caps which could be removed at any time in the sampling procedure. In use, the sampler could be lowered into a hopper before dredging starts. At a selected time after the dredging cycle is completed, the caps could be removed from the cups by means of a tag line. The sampler then could be withdrawn with six samples recovered intact from six equally spaced vertical locations in the hopper.

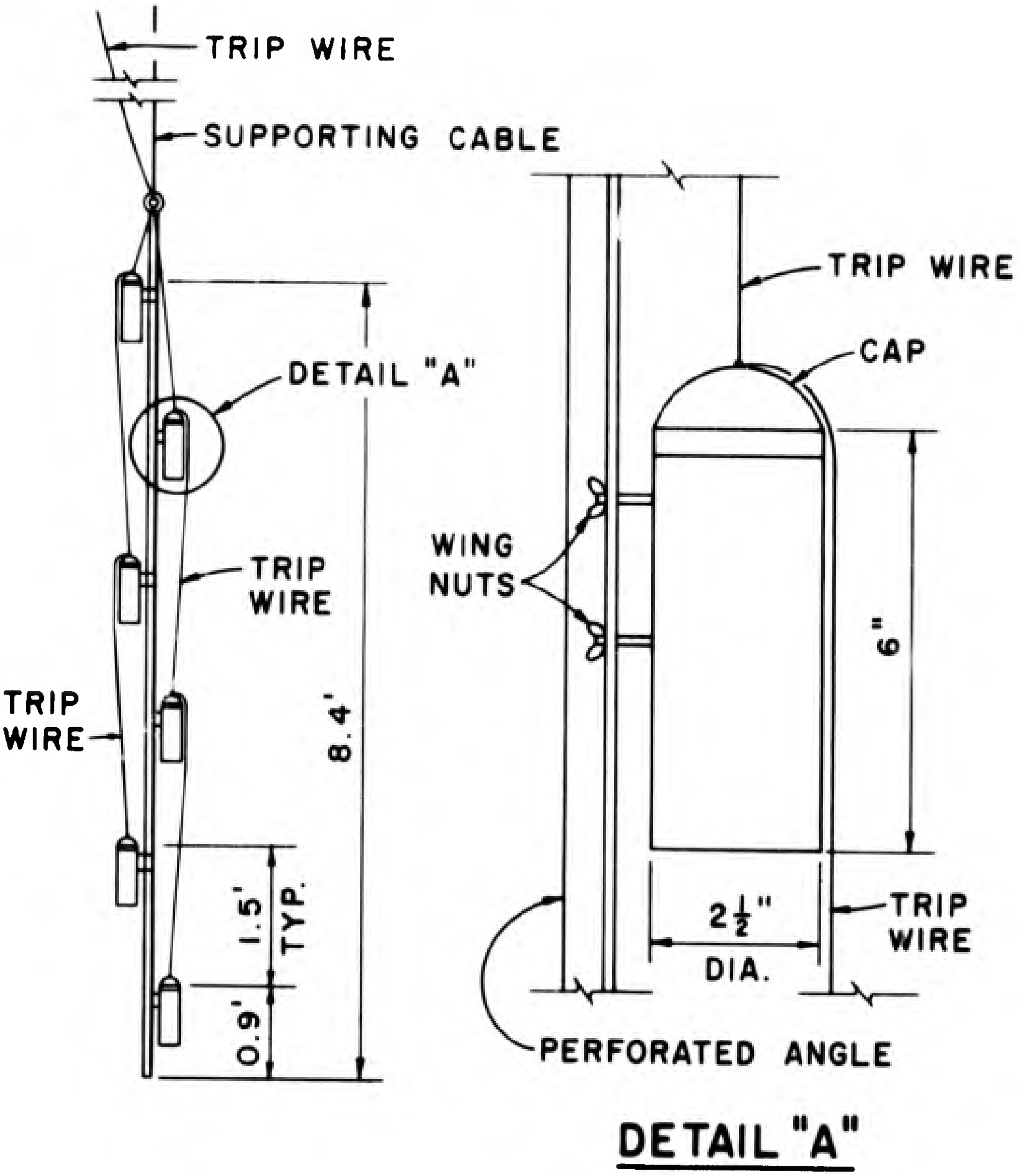

Figure 24 Hopper Bin Sampler

Trial use of the device late in 1968 showed promising results and confirmed the expected bottom-to-top density variation of the material in the hoppers. More of these devices will be fabricated to permit sampling of an entire hopper load. Pending further tests with the device, the best available method of determining the hopper contents is that of computing the difference between inflow and outflow contents.

6.2.4 Analytical Methods

Early in the sampling program it became evident that the cooperating laboratories were using different methods for measuring the various water and sediment parameter and that their results were not comparable. Therefore, a committee was instructed to prepare a set of standard methods for use in this study and make a manual available to all concerned. This manual, dated January 1968, is attached to this report as Appendix C10. It should be noted that all references to "oil and grease" in the present report denote hexane extractable material.

6.3 Characteristics of Dredged Sediments

6.3.1 Introduction

The volume of sediment accumulating in a harbor is influenced by the climate, topography, and land use within the basin. Erosion of agricultural lands generally supplies the greatest amount of sediment to streams. Sediment delivered to tributary streams of most of the Great Lakes harbors also can originate in the surface runoff from urban areas, and may become large when substantial amounts of soil have been disturbed for the construction of highways and housing. Erosion of stream banks, discharges from storm sewers and overflows from combined sewer systems, and discharges of industrial wastes are further sources of sediment.

After entering a stream, these sediments are transported in suspension and as bed load. The sediment transport capacity of a stream is related to its velocity and the configuration and roughness of its channel. Silts and clays are deposited during periods of low flow, resuspended during high flows, and thus moved progressively downstream.

As the stream-transported material enters the relatively quiet waters of navigation channels and harbors, it deposits and forms shoals. The bed load and heavier sediments settle out near the head of navigation. For example, at Cleveland, Ohio, the Cuyahoga River often deposits eight feet of sediment near the head of navigation between December and March, and as much as 13 feet of sediment has been recorded. Finer material is dispersed along the navigation channel and harbor bottom.

6.3.1.1 Sources of Sediment Pollution

Sediments become polluted before, during, and after transport into harbors. In general, the sources of pollution can be categorized as municipal, industrial, and agricultural. Agricultural pollution derives from animal wastes and from the use of fertilizers and pesticides, whose residues are washed or leached into streams and other drainage channels. Some contamination of sediments and water must be ascribed to municipal wastewaters that are emptied into receiving waters as stormwater discharges, overflows of combined sewers, spillage from surcharged and broken sewers, and effluents from sewage treatment plants. Industrial wastewaters may be added along with municipal sewage or directly through industrial outfalls.

Little is known about the ability of sediments to sorb and hold specific pollutants except for recent work on the sorption of phosphorus and nitrogen on particulate matter.

While phosphorus commonly exists in solution in different ionic forms, direct precipitation of phosphatic salts is probably of little importance as a mechanism for their removal in nature. However, removal of phosphorus by sorption appears to be a significant mechanism, with clay minerals, limestone, dolomite, and iron, all having capacities to remove phosphatic salts from solution. Experiments have shown that sediments have a great capacity to adsorb phosphorus, but to date the mechanics of anionic sorption have not been fully identified. The removal of phosphorus from solution is discussed further in Appendix C2.

Total nitrogen in a stream is the sum of nitrogen occurring as ammonia, nitrite, nitrate, and organic nitrogen. Fifty to ninety percent of the total nitrogen probably is precipitated as organic particles or sorbed on sediments as molecules. Ammonia (NH_3) is electrically neutral, but is a highly polar molecule, and is capable of being adsorbed on clay. Nitrite (NO_2^-) and nitrate (NO_3^-) may be transported by anionic sorption mechanisms, but they probably are transported as sorbed organic nitrogen compounds or as nitrogen in discrete organic particles. Additional data on nitrogen nutrients is contained in Appendix C2.

In general, most of the river beds in the Great Lakes appear to be in equilibrium with the river water. Constant agitation and long periods of sediment-water contact apparently give sorption reactions sufficient time to reach equilibrium. The agitation tends to fix phosphorus and other nutrients with respect to small changes in the river environment.

For the most part, sediments from upstream sources are deposited in river channels and inner harbors. In addition, sand is piled against the windward side of breakwalls by littoral drifts. During storm conditions, wind and wave action blow and wash sand particles over the breakwalls and into the relatively calm waters of the harbor, where they settle as shoals. These sediments are susceptible to pollution by watercraft in the harbors and waterways, as well as from municipal and industrial discharges.

6.3.1.2 General Characteristics of River and Harbor Sediments

To describe the harbor environments, a series of functional tests were initiated to determine the feasibility of treating dredgings and to determine the possible effects of open lake disposal on the biota. The physical properties of sediments and the response of contained pollutants to aerobic and anaerobic digestion and to heavy chlorination were determined in the Sanitary Engineering Laboratory, University of Wisconsin at Madison.

The sediments varied widely in their physical and chemical characteristics, not only between harbors, but also within harbors. Firm conclusions, therefore, cannot be drawn from functional tests unless the number of samples taken from each harbor is adequate. The general trend of the results obtained at Madison was for the river samples to have much higher concentrations of specific chemical pollutants, COD's, and volatile solids than outer harbor sediments.

Sieve separation and inspection of sediments at each of the eight pilot harbors show that 95 percent of the sediments are less than two millimeters in size, but the proportions of sand, silt, and clay fractions vary from harbor to harbor and within each harbor. For example, sediment samples taken from the upstream end of the navigation channel at Buffalo, New York, and Cleveland, Ohio, showed 51.4 and 8.9 percent, respectively, of sand. Similar variations occurred in other harbor sediments and must be expected from year to year at the same sampling station.

Because of differences in size and composition, the settling characteristics of sediments also vary considerably from harbor to harbor, as well as within each harbor. Variations from 60 percent within 15 minutes to essentially no settling in a 2-hour period were encountered. Such settling as occurred usually took place within the first hour. Scrubbing by vigorous aeration for a period of three minutes and grit removal from the sediments generally improved sediment settleability. Observed settling curves for the harbors sampled are shown in Appendix C5. After 2 hours settling, supernate samples were taken and analyzed. The COD was usually below 500 milligrams per liter. The organic nitrogen in the supernate was only about 2 percent of that in the original sediments. Phosphate phosphorus supernate values for most samples analyzed were less than 2.0 milligrams per liter. Comparing supernate values with sediment values showed that most of the phosphorus originally present was carried down by settling.

Filterability studies showed that the specific resistance of sediments was generally higher than the specific resistance of conditioned sewage sludges.

During four days of aeration of a 10 percent solids slurry, up to 64 percent of the COD was removed. BOD values of the effluent were low for some sediments, but the effluent was no better than that produced by plain settling. The COD of air-washed supernate was not reduced by further aeration. In some instances, indeed, there was an increase in COD, but this was accompanied by an increase in volatile solids in the effluent. After aeration, the total phosphates in the effluent supernate ranged from 2.2 to 7.7 milligrams per liter. These values were considerably higher than those in the supernate from plain settling of samples taken from the same station. The increase was probably due to a washing out of phosphates by aeration.

The amount of gas released during anaerobic digestion of slurries was relatively small in comparison with that encountered in the digestion of sewage solids. Observed curves of cumulative gas production are shown in Appendix C5. The values ranged from 0.036 to 0.941 cubic feet of gas per pound of volatile solids added. For comparison, fresh sewage solids release about 12.5 cubic feet of gas per pound of volatile solids. The age of the volatile solids probably explains the difference. Chlorine demand was high for almost all samples.

Adiabatic fuel values were calculated by observing the temperature in a calibrated water bath surrounding a bomb calorimeter. Three sediments with the highest volatile solids content were ignited, but ignition was not sustained. The samples were then oven-dried and ignited again. One sample with the highest volatile solids content sustained combustion. Its heat value was calculated to be 852 calories per gram or 4,480 calories per gram of volatile solids. The corresponding value for fresh sewage solids is also close to 5,000 calories per gram of volatile solids; however, the similarity in heat values means little in this single instance.

Other questions of interpretation of results arise when dredgings are subject to standard waste treatment processes. These questions may be related to the presence in dredgings of a high percentage of inorganic matter and of organic matter that is degraded only with difficulty. Possibilities are that the most easily degradable compounds have been stablized in the course of their travel to and storage in the sediments. Also, it is possible that there are present toxic substances that inhibit biological treatment processes.

The sections that follow discuss in detail the characteristics of the sediments dredged from the eight pilot harbors. In addition, characteristics of sediments in other harbors are found in Appendices A and B. However, a full investigation of sediments at all Great Lakes harbors was beyond the scope of the present study.

6.3.2 Great Sodus Bay Harbor, N. Y.

Two sampling surveys were made at Great Sodus, where the Corps of Engineers performed maintenance dredging with a hopper dredge. The first, in 1967, included sampling of water and sediments in the dredging area at the entrance to the Bay, and at two stations in the Bay (Photo 1). The Corps does not dredge at the Bay stations, but private interests dredge from time to time at the shipping terminal (lower right, Photo 1). A second survey, in 1968, included sampling before, during, and after dredging in the dredged area. Appendix A1 is the report on the 1967 survey, and Appendix A2 is the report on the 1968 survey.

Table 19 shows that the sediments are principally fine sand. Stations 9, 10, and 11 are located in the area dredged by the Corps.

Table 20

Undisturbed Sediments at Great Sodus Bay[a]

	Station No.[b]			Station No.[c]	
Parameter	9	10	11	10[d]	11
% Total Solids	-	-	-	30.6	77.1
% Volatile Solids	1.37	0.93	1.32	26.97	0.47
% Silica	87.0	92.0	90.0	16.3	72.4
COD	12.4	2.8	15.9	32.3	2.0
N-Total	0.47	0.124	0.64	13.7	2.3
$N-NO_3$	0.02	0.01	0.02	0.6	0.21
PO_4-Total	1.23	0.84	1.27	33.2	1.97
PO_4-Sol	0.13	0.025	0.12	0.1	0.002

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[a] All values in mg/g except where noted

[b] FWPCA 1967 data, Appendix A1, Table I

[c] FWPCA 1968 data, Appendix A2, Table II

[d] This sample is obviously not representative of the actual conditions at Station 10 because: (1) the discrepancy between the 1967 and 1968 values is too large to be attributed solely to temporal changes; and (2) the value of 26.97% volatile solids is indicative of a heavily polluted harbor.

The harbor sediments are, in general, closely similar to sediments immediately outside the harbor or what was reported to be a typical Lake Ontario mud sample. High differences (as much as tenfold) between 1967 and 1968 samples

Photo I Aerial View of Great Sodus Bay Harbor, New York suggest great variations from year to year in sediment quality or in the analysis or reporting of data. Biologically, species diversity and presence of "clean water" species indicate that the harbor environment is not polluted.

Although similar to open lake water in its conductivity, harbor water has high concentrations of total PO_4 and nitrate, and a higher COD. The dissolved oxygen content was satisfactory for "clean water" organisms. There were slight differences between 1967 and 1968 observations; turbidity, nitrates and suspended solids were lower in 1968.

The lack of significant pollution sources may account for the bottom sediments in the dredged areas being essentially free of pollution. The drainage area of Great Sodus Bay is only 63 square miles, which, in itself, places a limit on land runoff and agricultural pollution.

Table 21 compares the quality of the water in the dredged area with limits set on raw water quality for municipal use in the Sodus, New York, area.

Table 21

Water Quality in the Dredged Area at

Great Sodus Bay[a]

	Water Quality[b]			
	Station No.			Municipal Raw Water Quality Limits[c]
Parameter	9	10	11	
BOD	-	-	1.4	1.0 - 5.3
Chloride	-	29.2	26.3	25 - 27
Dissolved Oxygen	-	9.1	13.3	6 - 11
Dissolved Phosphates	-	0.08	0.06	0.02 - 0.04
$N\text{-}NH_3$	-	0.08	0.1	0.06 - 0.12
$N\text{-}NO_3$	-	0.26	0.22	0.1 - 0.31
pH	-	8.2	8.0	8.4 - 8.6

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[a] All values in mg/l, except pH.

[b] FWPCA 1968 data, Appendix A2, Table I

[c] FWPCA and New York State Health Department, A Water Pollution Control Program for the Minor Tributary Basins of Lake Ontario, February, 1968, Table 9-1.

The water in the dredged area is seen to meet the requirements in all but two instances: (1) its chloride content at Station 10; and (2) its phosphate content at both Stations 10 and 11. The fact that one value of dissolved oxygen is above the requirements is unimportant because the only significant limit is the minimum level of dissolved oxygen.

6.3.3 Buffalo Harbor, New York

The Buffalo River, essentially an artificial channel dredged to a suitable navigation depth, is a combination of Cayuga, Cazenovia, and Buffalo Creeks. Flowing northwestward through a series of almot level plains broken by steep escarpments, the creeks drain an area of about 446 square miles. After they come together, they enter the navigation channel within the city limits of Buffalo, New York. Channel flows become sluggish, and remain moderately low until they empty into the eastern end of Lake Erie.

At present, all of Buffalo Harbor is so heavily polluted that it is practically devoid of benthic organisms. Only sludgeworms and similar pollution-tolerant organisms are present in appreciable numbers. Concentrations of phosphorus are significantly large throughout the harbor system. Pollutants are derived from up-river agricultural and municipal sources. Down-river pollution comes principally from industries along the lower river stretches. As a result, volatile solids, COD, oil and grease, as well as iron reach relatively high concentrations in most of the harbor as well as in Black Rock Channel and Buffalo River.

Deepening and widening the navigation channel changed it into a large pond with little or no significant flow over prolonged periods of time. As a result, Buffalo River industries reused and concentrated their wastewaters. In the spring and fall, freshets flushed out the concentrated wastes and seriously polluted the Niagara River. However, on 20 February 1967, a pumping station in Buffalo Harbor began supplying water to five Buffalo River industries: Donner-Hanna; National Aniline; Mobile Oil; Republic Steel; and General Chemical. The water is used for cooling and other non-process operations and is discharged into the Buffalo River. The rate of discharge of wastewater into the river is regulated to keep a minimum stream flow of 160 cubic feet per second in the river. Although there are no data to show any change in water or sediment quality, it is generally recognized that the project has improved the condition of the Buffalo River.

In 1967, FWPCA collected sediment and water samples before, during, and after dredging operations in the Buffalo River, Buffalo Harbor, and Black Rock Channel. A summary of the sediment analyses along with the location of sampling stations is included in Appendix A3. Average values for 1967 constituents are shown in Table 22. According to FWPCA, preliminary analyses of samples collected in 1968 recorded improvements in the quality of Buffalo River sediments. The improvements may be attributed: (1) to the flows from the pumping plant now supplying industrial non process waters; and (2) to the corrective measures presently underway to reduce waste inputs.

Table 22

Comparison of Sediment Quality at Buffalo, N. Y.[a]

Parameter	Buffalo River[b]	Black Rock Channel[b]	Buffalo Harbor[b]	Eastern Basin Lake Erie[c]
COD	147	138	111	48.1
Total Volatile Solids	95.2	102	94.9	57
Chlorine Demand (15 min.)	-	-	4.13	-
Oil and Grease	13.63	7.43	6.81	-
Total Phosphorus	1.15	1.13	0.778	0.93
Total Nitrogen	2.62	2.51	2.23	1.9
Total Iron	60.7	44.8	80.9	35.1

[a] All values in mg/g (dry basis), and are average concentrations.
[b] FWPCA 1967 data, Appendix A3, Table 3.
[c] Lake Erie Surveillance Data Summary 1967-1968, FWPCA, May 1968, Table 7.

As shown by settling tests (Appendix C5), the bottom sediments are very fine and light, but washed mud settles relatively well after it has been aerated for four days.

Photo 2 Aerial View of Buffalo Harbor, New York

Longitudinal profiles, based upon the limited sampling results of 1967, were drawn. In general, the values increased from the upstream limit to the vicinity of industrial discharges, but then decreased markedly to the river mouth where a significant dilution with Lake Erie water takes place.

In the Buffalo Outer Harbor, parameters high at the south end of the harbor decrease toward its north end. Iron concentrations are particularly noticeable. From a high of 125 mg/g at the south, they drop gradually to 50.2 mg/g at the north. In general, concentrations of all pollutants for which tests were made ran higher in Buffalo River than in the harbor or channel.

The quality of the sediments from the south end of Black Rock Channel is influenced strongly by the Buffalo River. A report, (BLUM 1964), prepared as part of a study by the International Joint Commission and the Public Health Service, indicates that the Buffalo River mixes with the water from the outer harbor, and moves into the entrance of Black Rock Channel (Photo 2). Further studies indicate that some water from Black Rock Channel filters through the Bird Island Pier into the Niagara River. Sediments from the north portion of Black Rock Channel are influenced in part by pollutants from Scajaquada Creek.

6.3.4 Cleveland Harbor, Ohio

The Cuyahoga River meanders for 103 miles through deep gorges and flat farm lands and two major cities before it discharges into the central basin of Lake Erie through Cleveland Harbor (Photo 3). The size of its drainage area is approximately 813 square miles. Below Akron, Ohio, the river becomes a rapidly flowing stream, and continues this way until it reaches the navigation channel in Cleveland, through which it moves slowly toward Lake Erie.

Pollution is carried to the lower Cuyahoga River from many upstream sources. Although they are treated, municipal wastes and the wastes from the rubber and chemical industries drastically change the physical, chemical, and biological properties of the upper river.

The lower Cuyahoga River is a complex and variable body of water with many different waste sources: combined sewer overflows; wastewater treatment plant effluents and by-passes; and direct industrial waste discharges. Heavy waste loads have degraded the water and sediment quality of the navigation pool appreciably. Iron and other metal ions form precipitates with dissolved solids and these carry down organics with high oxygen demands. It has been argued that these waste loads benefit water quality in this way. At present, 96 percent of the iron, 86 percent of the phosphates, and 44 percent of the total solids settle out in the lower part of the river. As concentrations of flocculated precipitates build up, they reduce the dissolved oxygen concentrations to near zero. Flow of river water through the harbor is influenced by the wind direction. Havens and Emerson estimate that during 60 percent of the time, 80 percent of the river flows through the eastern outer harbor with relatively little circulation of Lake Erie water into the Harbor.[1] Large quanti-

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1 - Havens and Emerson, Master Plan for Pollution Abatement, Cleveland, Ohio, 1968, p. 76.

Photo 3 Aerial View Of Cleveland Harbor, Ohio

ties of total solids, organic materials, metallic salts, oxygen consuming pollutants from the river, and debris from many drainage outlets are moved into the eastern basin where they settle. Thus, the quality of outer harbor sediments is determined mainly by the quality of Cuyahoga River water.

In-place sediment and water samples of river, harbor, and disposal areas were taken throughout the summer of 1967. The report on the sampling is attached as Appencix A4. Average concentrations of river, harbor, mid-lake sediments are compared in Table 23.

Table 23

Comparison of Sediment Quality at Cleveland, Ohio[a]

Parameter	Cuyahoga River[b]	Outer Harbor[b]	Central Lake Erie[c]
Chlorine Demand	30	12	-
COD	240	95	41
BOD	15	5	1
Volatile Solids	125	65	63
Oil and Grease	35	8	-
Phosphorus	4	1.5	0.7
Nitrogen	5	1.6	1.8
Iron	110	45	35.5
Silica %	55	72	-

[a] All values mg/g (dry weight) unless otherwise noted.
[b] FWPCA 1967 data, Appendix A4.
[c] Lake Erie Surveillance Date Summary 1967-1968, FWPCA, May 1968, Table 7.

With the exception of silica, the concentration of pertinent parameters of sediment quality decreased slowly with distance downstream, before dropping rapidly in the last mile of the river to much the same concentrations as in the outer harbor. Average concentrations of outer harbor sediments were generally half those of river sediments.

Total nitrogen in the Cuyahoga River sediments varied with time. Samples in Mrach, 1967, had much higher nitrogen content, than later samples. Slower breakdown of ammonia at low temperatures may account for its accumulation.

Phosphorus was remarkably high in the river sediments. Although the precipitation of phosphorus in the navigation channel is believed to be brought about by iron-bearing waters, it is thought (Appendix C2) that most of it is sorbed on particulate matter, while smaller amounts are co-precipitated by some natural chemical reactions. The method of precipitation that predominates cannot be determined until more mineralogical data are made available and sorption capabilities for each soil type are obtained. In comparing the longitudinal phosphorus and iron profiles in the river, Figure 25, there does not appear to be any direct relationship between the two parameters.

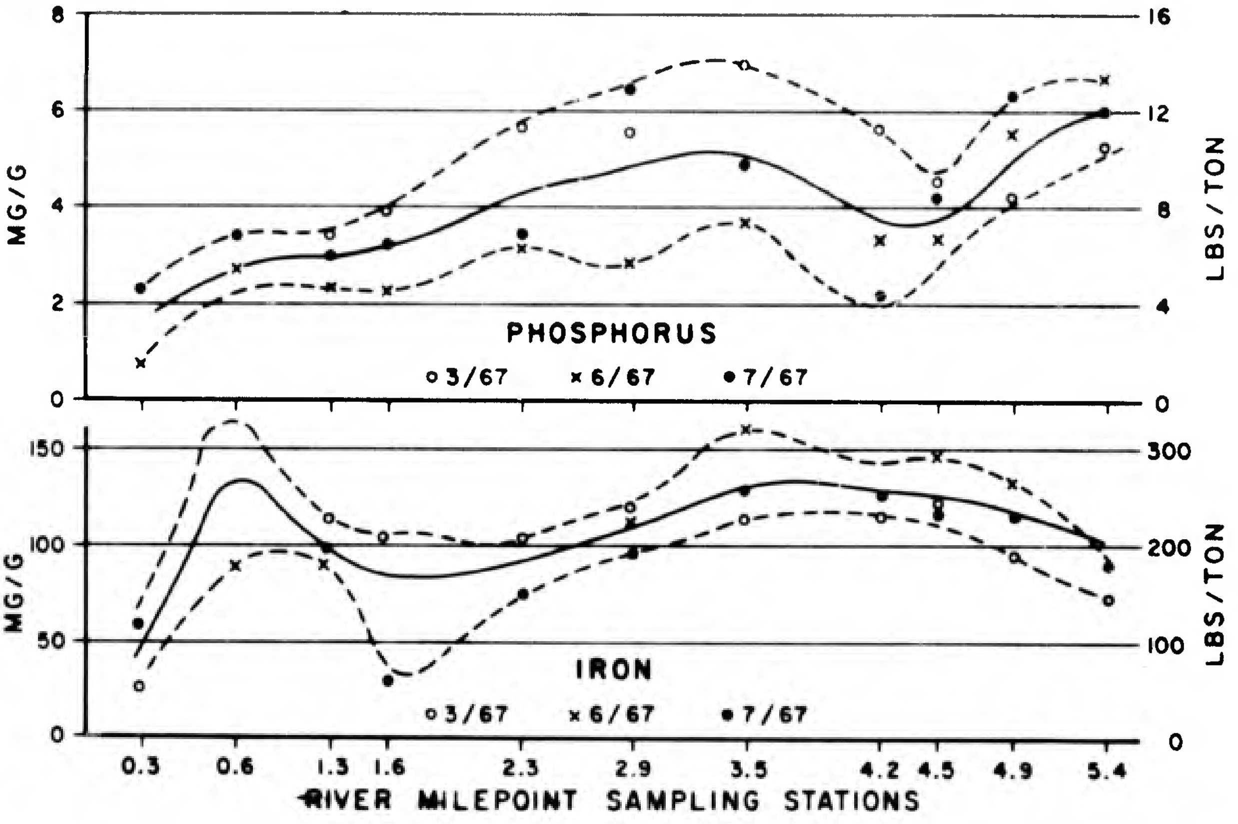

Figure 25 Cuyahoga River, Phosphorus and Iron Profiles.

Wherever benthic organisms were found, most of them were sludgeworms; they were essentially the only organisms found in the river. In March, 1967, they were very low numbers in the river, slightly more numerous at the upper end of the navigation channel, and quite abundant near the river mouth. By July, no benthic organisms remained in the river, except at the lower half mile. Depletion of dissolved oxygen may account for their disappearance. Their near-absence in March suggests the possible presence of toxic substances in the sediments.

In March and April, benthic organisms were rather abundant in the outer harbor. Sludgeworms predominated overwhelmingly, but significant numbers of fingernail clams and a few snails were also present.

6.3.5 Toledo Harbor, Ohio

Toledo Harbor (Photo 4) lies at the mouth of the Maumee River, a river which drains an area of about 6,586 square miles of bordering lands in Indiana, Michigan, and Ohio. Much of the basin consists of flatlands, and over 90 percent of its land area is agricultural. Stream flows are low during dry weather because the soils are relatively impermeable. The stream characteristics of the Maumee Basin are listed in Table 24.

Table 24

Stream Characteristics, Maumee River Basin[a]

River	Drainage Area (sq. mi.)	Length of Main Stem (mi.)	Average fall (ft./mi.)	Period of Record (yrs.)	Yield[b] (cfs)
St. Joseph	1,060	93	1.6	13	21
St. Mary's	817	100	2.9	29	10
Tiffin	804	103	1.3	29	12
Auglaize	1,313	102	3.2	44	14.5
Blanchard	762	91	0.9	30	4
Ottawa	373	53	4.0	27	15
Maumee	1,457	136	1.3	34	90

[a] Report on Water Pollution in the Lake Erie Basin - Maumee River Area, FWPCA, Tables 4-1 and 4-2, 1966

[b] Low seven-day, once-in-five-years flow.

Photo 4 Aerial View of Toledo Harbor, Ohio

By contrast, the rivers tend to back up into their tributaries and flood flatlands when rainfalls are heavy. As flows recede, heavy loads of finely divided organic matter and silt are washed into the streams. This happens also during times of normal precipitation. Nutrients entering the waterways increase the collodial matter content.

Estimates of the chemical constituents in rural runoff in the Maumee River Basin are shown in Table 25.

Table 25

Estimated Chemical Constituents in Rural Runoff

In the Maumee River Basin[a]

Parameter	Auglaize	Upper Maumee	Lower Maumee	St. Joseph	St. Mary's	Tiffin
Ammonia	0.9	0.1	0.4	1.2	0.3	0.5
Organic Nitrogen	1.6	0.4	0.6	1.2	0.3	0.9
Nitrate	1.5	0.3	0.7	2.7	0.5	1.0
Total Nitrogen	3.6	0.6	1.5	5.0	1.1	2.1
Phosphate	0.[illegible]	0.1	2.0	1.4	0.2	0.5
Sodium	18.0	3.8	6.0	41.0	3.9	15.0
Silicate	34.0	9.0	10.0	37.0	4.9	20.0
Potassium	7.0	0.8	3.4	8.0	2.8	29.0
Sulfate	65.0	4.4	37.0	200.0	32.0	55.0
Chloride	20.0	2.1	11.0	65.0	9.0	18.0
Magnesium	70.0	9.0	35.0	90.0	29.0	34.0
Calcium	145.0	27.0	55.0	300.0	39.0	105.0

[a] Report on Water Pollution in the Lake Erie Basin - Maumee River Area-FWPCA, Table 6-4, p. 6-4, 1966. All values in 100 tons/year.

It is generally recognized that major long-term pollution of the Maumee Basin streams comes from agricultural land. Two of the principal crops are corn and soybeans, which leave the soil bare and open to erosion during the winter. As a result, extensive sheet erosion follows.

In general, only small percentages of the sediments come from industrial sources. Most of the sediments derive from river-bank and land sheet erosion. The sediments, for the most part, are comprised of about 80 percent silt and clay and 20 percent sand, with a higher content of silt and clay in the Maumee River and of sand in Maumee Bay channel. Lake level fluctuations and wave action tend to keep colloidal particles in suspension and redistribute fine material.

In 1967, the Lake Survey collected bottom sediments, biological data, and water samples in the Maumee River, in the Maumee Bay channel, in the Bay just north of the diked disposal area, and in the vicinity of the open lake disposal area. The Lake Survey report is attached as Appendix A27. Table 26 summarizes the characteristics of the sediments dredged from Maumee River and Bay.

Table 26

Characteristics of Dredged Sediments in Maumee River and Bay[a]

Parameter	Range	Mean
Volatile Solids (%)	5.8-10.5	8.3
Total Solids (%)	36.5-71.0	45.2
Oil & Grease (mg/g)	0.5-4.1	1.48
BOD (mg/g)	0.54-2.22	1.5
Settleability (% 1st hr.)	0.0-43.0	7.7
Settleability (hrs. for 90%)	20.0-59.0	41.5
pH	6.6-7.1	6.8
eH (volts)	-0.11-0.0	-0.09

[a] 1967 Lake Survey Data, Appendix A27.

Bottom sediments analyzed by the University of Wisconsin also showed that the sediments were high in organic matter, because the volatile solids content was near 8 percent, and rich in organic nitrogen, ammonia, and total phosphorus.

The settling characteristics of the dredged sediments were low, 7.7 percent per hour. Because of the fine sediment in the river deposits, 41.5 hours would be required to settle 90 percent of the sediments.

6.3.6 Rouge River, Michigan

The Rouge River rises northwest of Detroit, flows in a southwesterly direction, and empties into the Detroit River at a point 19 miles north of Lake Erie (Photo 5). It has two tributaries, the Middle and Lower Branches, and drains an area of about 467 square miles. Since much of the basin occupies an old lake bed, it is relatively flat and impervious except in its upper reaches, and has practically no natural surface storage.

The lower 3.5 miles of Rouge River, through Short-Cut Canal, comprise a dredged channel that serves the industries in the area. The principal wastes discharged by the industries of the area are iron, oxygen-demanding material, bacteria, suspended solids, oil, pickling liquors, phenols, chlorides, cyanides, toxic metals, and ammonia.

FWPCA sampling surveys in 1967 and 1968 included water quality measurements in the Rouge and Detroit Rivers during dredging, chemical characteristics of undisturbed and dredged bottom sediments, water quality of overflows of the disposal area and water quality in wells driven into dikes forming the disposal area. The 1967 report is attached as Appendix A6. A preliminary report on the 1968 survey is attached as Appendix B1.

As a result of waste loadings, the Rouge River sediments are polluted physically, chemically, and biologically. They are oily in appearance and possess an oil or sewage odor. Chemically, the sediments contain high concentrations of iron and organic materials. Greases, phenols, nitrogen, and phosphates are present in varying degrees and add to the over-all contamination of the sediments. Table 27 is a brief summary of several parameters measured in 1967 in bottom sediments in Rouge River.

Photo 5 Aerial View of Rouge River, Michigan

Table 27

Composition of Bottom Sediments in Rouge River[a]

Parameter	Main Channel	Old Channel	Short Cut Canal
Phenol ug/g	0.76	1.66	0.96
Total - PO_4	3.23	1.12	0.84
Ammonia	0.088	0.036	0.012
Organic - N	0.085	0.034	0.023
Iron	44.2	9.9	7.9
Oil and Grease	42.7	17.2	6.3
Volatile Solids %	16.2	16.2	20.0
BOD	6.8	6.1	7.3

[a] FWPCA 1967 data, Appendix A6, Table 3, all values are averages in mg/g except when noted.

Examination of the data suggests some differences in degree of pollution. The main stem of the river, above the "Short-cut Canal" is more polluted. These differences probably reflect the degree of mixing of Rouge River water with Detroit River water.

Analysis of core samples of the sediments show some variation in the concentration of oil and grease, volatile solids and, in one instance, total phosphorus, between various segments of the cores. No trend can be established, however, since in one core the oil and grease content was greater in the bottom part of the core and in another it was smaller. In general, the sediments appear to have much the same chemical characteristics to depths ranging from 3.5 to 6 feet.

The benthic community of the main channel of the river was dominated by large numbers of pollution-tolerant oligochaetes, indicating a badly polluted environment. The "old channel" fauna included some snails and leeches, which suggests a lesser degree of pollution, probably due to some mixing of Rouge River with Detroit River water.

6.3.7 Indiana Harbor, Indiana

Indiana Harbor is an artificial harbor formed at the mouth of Indiana Harbor Canal, which connects the south end of Lake Michigan with Lake George and the Grand Calumet River (Photo 6). The drainage area for the waters flowing into Indiana Harbor is less than 10 square miles, smallest for all the pilot harbors. The area is highly populated and heavily industrialized. Possibly, excepting Cleveland, the concentration of heavy industry is greatest.

Dredging operations at Indiana Harbor were terminated on 14 October 1967 and later resumed on 6 November 1967. Between dredging periods, samples were collected from Indiana Harbor Canal, at the harbor entrance and at the lake disposal area. The Lake Survey report on Indiana Harbor is attached as Appendix A25 and the FWPCA report is attached as Appendix A7.

Table 28 shows that the volatile solids in the sediments dredged from Lake George Branch are exceptionally high and that a large percentage of the volatile material is oil and grease. In addition to organic wastes, the sediments contain high levels of toxic metals, nitrogen, and phosphorus. Table 28 also points out the discrepancies in the analysis and reporting of comparable data. This is discussed further in Section 6.4.4.

In the Indiana Harbor channel itself, the sediments begin to show some change for the better, probably because of the diluting waters of Lake Michigan. Appendix C5 shows that the channel sediments settle slowly except for those at the mouth of the harbor channel. The sediments at the mouth of the main canal settled to only 50% of their original volume in two days.

Bottom water samples have high counts of total coliforms and streptococci. Because of the heavily polluted bottom sediments in the inner canal reaches, no benthic organism can survive. Bottom fauna were found only in the harbor channel probably because incoming Lake Michigan water wedges below the outflow from the harbor.

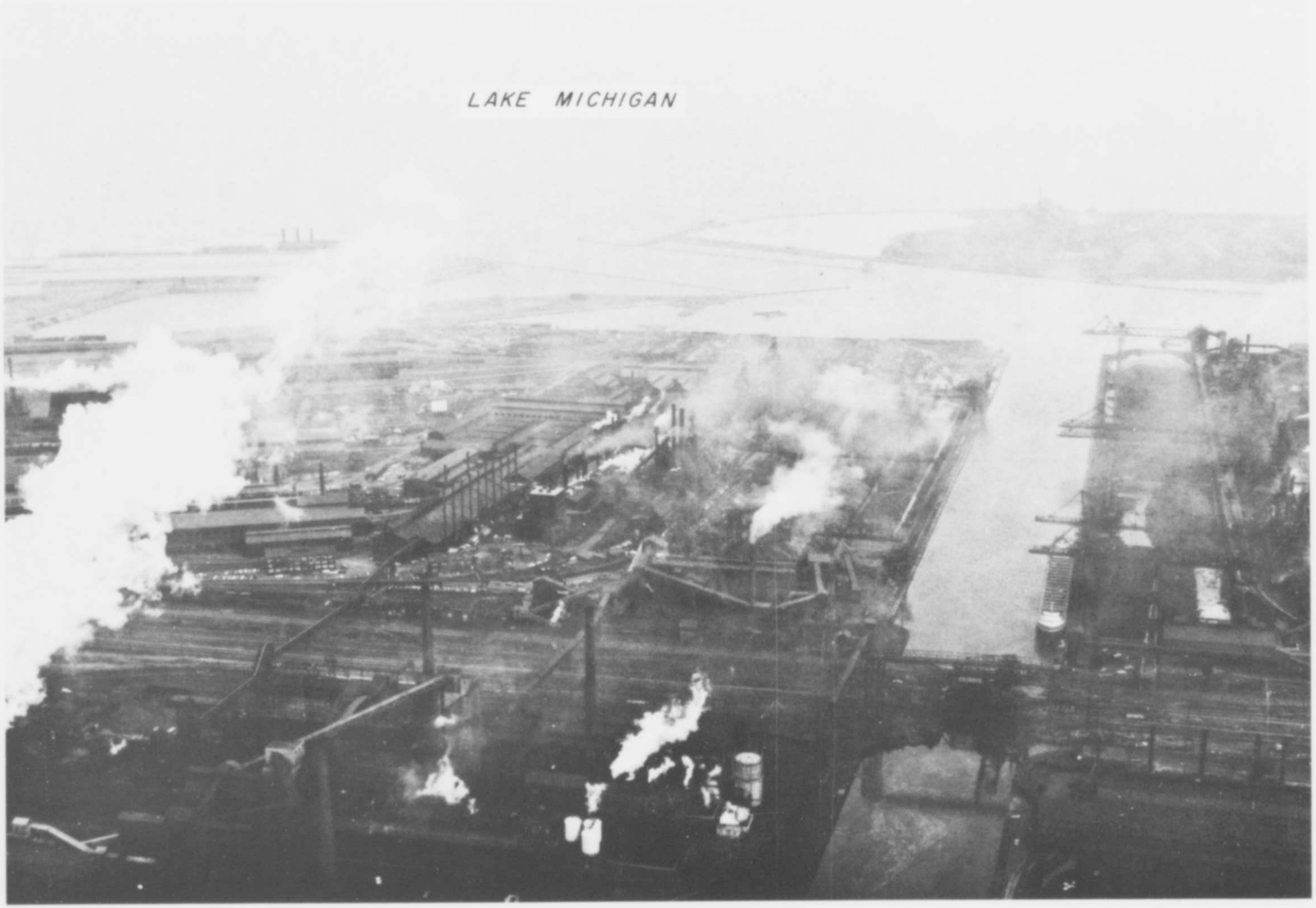

Photo 6 Aerial View of Indiana Harbor, Indiana

Table 28

Composition of Sediments Dredged from Indiana Harbor[a]

Parameter	Lake George Branch[b]	Grand Calumet River Branch[b]	Main Canal Comparable Station Numbers		Harbor Channel Comparable Station Numbers		
			21[b]	I-5[c]	18[b]	12-0[d]	I-1[c]
Total Solids %	42.5	40.9	73.6	47.5	60.5	37.9	45.0
Volatile Solids %	20.7	15.2	9.0	16.1	6.1	6.6	6.1
Oil and grease %	14.2	5.92	-	-	0.32	2.79	-
BOD	6.24	4.17	5.25	-	1.13	-	-
COD	-	-	-	461	-	261.5	117
NH_3-N	-	-	-	0.07	-	0.26	0.09
Organic - N	-	-	-	2.98	-	0.76	1.68
Phosphorus - P	-	-	-	1.05	-	0.79	0.48

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a All values mg/g dry basis except where noted.
b Lake Survey 1967 data, Appendix A25,Table 3, all values are averages.
c University of Wisconsin data, Appendix C5, Tables A-21 and A-25.
d FWPCA 1967 data, Appendix A7, Appendix A.

6.3.8 Calumet Harbor, Illinois

In 1922, the Calumet Sag Channel was constructed to provide a navigable connection between the Illinois Waterways System and the deep draft project at Lake Calumet, and the upper limit of Calumet Harbor. After completion of the channel, the normal easterly flow of the Calumet River was reversed so that, in effect, the river was flowing away from Lake Michigan (photo 7). At present, Lake Michigan water and effluent from the Calumet Sewage Treatment works, are diverted through the Calumet, Des Plaines, and Illinois Rivers to the Mississippi River. However, the total diversion from the Lake Michigan basin to the Mississippi River, including the diversion at Calumet will be limited be decree of the Supreme Court to 3,200 cubic feet per second after 1 March 1970. The present flow of the Calumet River is away from Lake Michigan, but in the past the flow has been directed toward the Lake during periods of high runoff.

In 1967, FWPCA took samples of water and sediments in the dredging area; their report is attached as Appendix A8. Table 29 shows the concentrations of constituents in the bottom sediments in the Calumet River.

Photo 7 Aerial View of Calumet Harbor, Illinois

Table 29

Sediment Concentrations for Calumet River[a]

Parameters	Calumet River 12 July 1967
% Total solids	54.1
% Volatile solids	7.76
Organic nitrogen	0.97
Total phosphorus	1.20
Oil and grease	14.8
COD	139.7
Total iron	69.9
Sulfide	0.401
Copper	0.014
Cadmium	b
Nickel	0.010
Zinc	0.227
Lead	0.338
Chromium	0.28

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[a] FWPCA 1967 data, Appendix A8, Table 1. All values are averages and are in mg/g (dry weight) except where noted.

[b] Not detected at sensitivity level of test.

In general, parameters increased in concentration from Lake Michigan to the vicinity of the midpoint of the dredging project, and then decreased again downstream. The sediments are highly polluted according to FWPCA data on concentrations of total phosphorus, oil and grease, COD, total iron, and metals along the Calumet River.

6.3.9 Green Bay Harbor, Wisconsin

Green Bay Harbor lies at the mouth of the Fox River, a river which drains a 6,443 square mile area into the southern end of Green Bay. Green Bay itself is approximately 118 miles long and has a mean width of 23 miles and a mean depth of 65 feet. Based on current temperatures and wind data, it appears that Green Bay acts as an independent lake. Portions of the northern reaches of the Bay are affected by interactions with Lake Michigan; the southern reaches of the Bay probably are not affected by inflows from the lake.

The Fox River is the major tributary to Green Bay (Photo 8). It is also the largest stream in the Lake Michigan Basin. With its principal tributary, the Wolf River, the Fox River forms an irregular-shaped basin with a maximum north-south dimension of 150 miles and a maximum width of 75 miles. In general, the soils of the basin are loamy and poorly drained. Agricultural activities are extensive in both river basins. Approximately 85 percent of the agricultural income comes from the sale of livestock and livestock products.

In 1967, a survey was made at Green Bay in connection with dredging of the channel in Fox River and Green Bay. Water and sediment samples were collected from the dredging areas. Another survey was made in 1968 to determine the degree of pollution of the sediments which would be removed during the 1968 maintenance dredging operations. The 1967 survey report is attached as Appendix A9, while the 1968 survey report is attached as Appendix A13.

Dredging had been under way for about three weeks before the sampling program was started in the Fox River. Consequently, data may represent conditions during dredging only. In fact, it is noted in Appendix A9 that samples were taken at RM1 after dredging. Data from this station do not represent the normal environment prior to dredging, but the information is useful in didicating possible beneficial effects of dredging. This is discussed later in Section 6.4.12. Table 30 shows the results of analyses of bottom sediments collected during dredging in 1967, and the result of analysis of a single sample in 1968, which was taken before dredging.

Photo 8 - Aerial View of Green Bay Harbor, Wisconsin

Table 30

Composition of Sediments at Green Bay, Wisconsin[a]

Parameter	Fox River[b]	Green Bay[b]	Green Bay[c]
% Total Solids	25.3	24.8	29.91
% Volatile Solids	18.4	17.8	46.72
COD	219	215	251.8
Phosphorus-Total	4.37	3.35	0.35
Phosphorus-Soluble	1.02	0.6	-
N-Total	5.34	6.89	-
$N-NH_3$	0.63	0.47	0.55
N-Organic	4.7	6.4	6.34
Phenol	0.004	0.003	0.014
Oil and grease	32	15	6.88
Sulfide	0.68	0.37	0.23

a All values are averages and in mg/g (dry weight) except where noted.
b FWPCA 1967 data, Appendix A9, Table I.
c FWPCA 1968 data, Appendix A13, Table II, one sample only.

Biological data were not presented, but it has been established in previous reports that southern Green Bay and the Fox River are suitable environments only for pollution-tolerant organisms. "The type of bottom found at the southern tip of Green Bay was mostly organic sediment. This is a favorable habitat for the pollution-tolerant sludgeworms and bloodworms which are the predominant organisms. Total populations in 1962 and 1963 ranged from 5,000 to 15,000 organisms per square meter near the mouth of the Fox River and gradually decreased to about 500 organisms per square meter ten miles out into the Bay"[1]

A report from the University of Wisconsin (BEETON, in press) shows that southern Green Bay has undergone progressive deterioration since a survey in 1938-39. Greater numbers of pollution-tolerant oligochaetes are found today, but the zone of maximum abundance has moved farther out into the Bay from the mouth of the Fox River.

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1 - FWPCA, Comprehensive Water Pollution Control Program, Lake Michigan Basin, Green Bay Area, 1966, p. 6-5.

6.4 Effects on Water Quality

6.4.1 General

This section is concerned with the effects of dredging operations on water quality: (1) at the dredging site; and (2) at the disposal site either in open lake or diked areas. Visible surface effects in dredging areas, at open lake disposal areas, and along the route to such areas are covered in Section 6.4.2.

During the course of the present study, it became apparent that the sampling program could not generate sufficient data to make a definitive determination of the effects of dredging operations on water quality, particularly at open lake disposal areas. As a result, bio-assays were added to determine the influence of sediments on selected bottom organisms, plankton, and algae. The results of the bio-assays are discussed in Section 6.4.3.

To determine the effects at dredging and disposal sites, samples of water and bottom sediments were collected for physical and chemical examination as described in Section 6.2. The difficulty of relating causative changes in water quality to the properties of the sediments, as determined by the sampling program, is discussed in Section 6.4.4.

Based upon the available data, the effects of dredging and disposal operations are discussed for each pilot area in Section 6.4.5 et seq. Undoubtedly, the effects are in direct relation to the nature of the sediments dredged, and variations occur in the quality of the dredged sediments within a particular pilot area and even within a given time at a specific sampling station. Therefore, dredging and disposal effects should be considered in terms of specific sets of conditions in time and location.

6.4.2 Visible Surface Effects

Different types of dredges were described briefly in Section 4.2. A more detailed account of hopper dredge operations is presented in the following paragraphs in order to facilitate the discussion of the effects on water quality of that type of dredge.

Hopper dredges are designed primarily to dredge materials hydraulically. They load and retain the dredged solids in their hoppers, and then haul the material to a disposal site where the dredgings are either dropped through the doors in the bottom of the hoppers or pumped through a pipeline to a shore disposal area. During dredging, the sediments are pumped into the hoppers as a slurry of mud and water. After the hoppers have been filled initially, pumping continues for a period of time to increase the density of the material in the hoppers and to obtain an economical load. The length of time for additional pumping depends upon the settling characteristics of the dredgings and the time required to haul them to the disposal site. As a result of the additional pumping, excess sediment-laden water overflows the hoppers and discharges behind the dredge.

The economic load and total pumping time are determined by a series of tests conducted periodically during normal dredging and hauling operations. An economic load is dredged when the retained volume of solids per unit of total cycle time (pumping, turning, round trip time to disposal area, and disposal) equals the incremental retained volume of solids per unit of additional pumping time. Experience at most Great Lakes harbors is that economic loading requires pumping for a little less than twice the time required to fill the hoppers initially with the dredged slurry. This makes for some differential accumulation of the heavier solids and discharge of the lighter solids. Most maintenance dredgings consist of silt and clay with slow settling rates, and the overflow contains appreciable quantities of suspended solids. Consequently, the harbor in the vicinity of the dredging area becomes highly turbid.

Retained loads are dropped through the bottom doors of the hoppers while the dredge is turning at the disposal site to return to the harbor, (Photo 9). Some dredgings, principally clays and sand, have a tendency to stick in the hoppers after the doors have been opened. The hoppers of the LYMAN class dredges must be washed to remove this material. On the MARKHAM, however, washout is rarely needed because of the size and shape of the hoppers. The washwater, discharged by the dredge at or above the waterline, disperses dredgings into the waters around the dredge. Often, the washings are visually more evident or objectionable than the dredgings which are dropped initially, (Photo 10). Unfortunately, washing is required to prevent buildup in the hoppers which could become unmanageable and extremely difficult to remove. After the hopper doors are closed, dewatering the hoppers also releases some turbidity.

During transport to the disposal site, some dredgings may be lost because of the occasional malfunctioning of hopper-door seals or door operating mechanism. Occasionally, too, there may be leakage through the piping when valves stick or jam. Generally, valves can be repaired in place; whereas, a torn seal or other serious malfunction of a hopper door usually requires shipyard correction that may take several weeks. Some of the hopper load may be lost overboard during rough weather when dredges heave and pitch badly.

In dipper or clamshell dredging, the bucket biting into the bottom and the washing of the bucket as it is drawn up for loading may make the surrounding waters turbid, dislodge floatable debris, and cause an oily scum to form on the surface of the surrounding waters. The loaded scows are towed to the disposal site where the material is dropped through bottom doors.

Scow dumping effects are quite like those of hopper dredges. During the trip back from the disposal area, remaining dredgings are washed through the

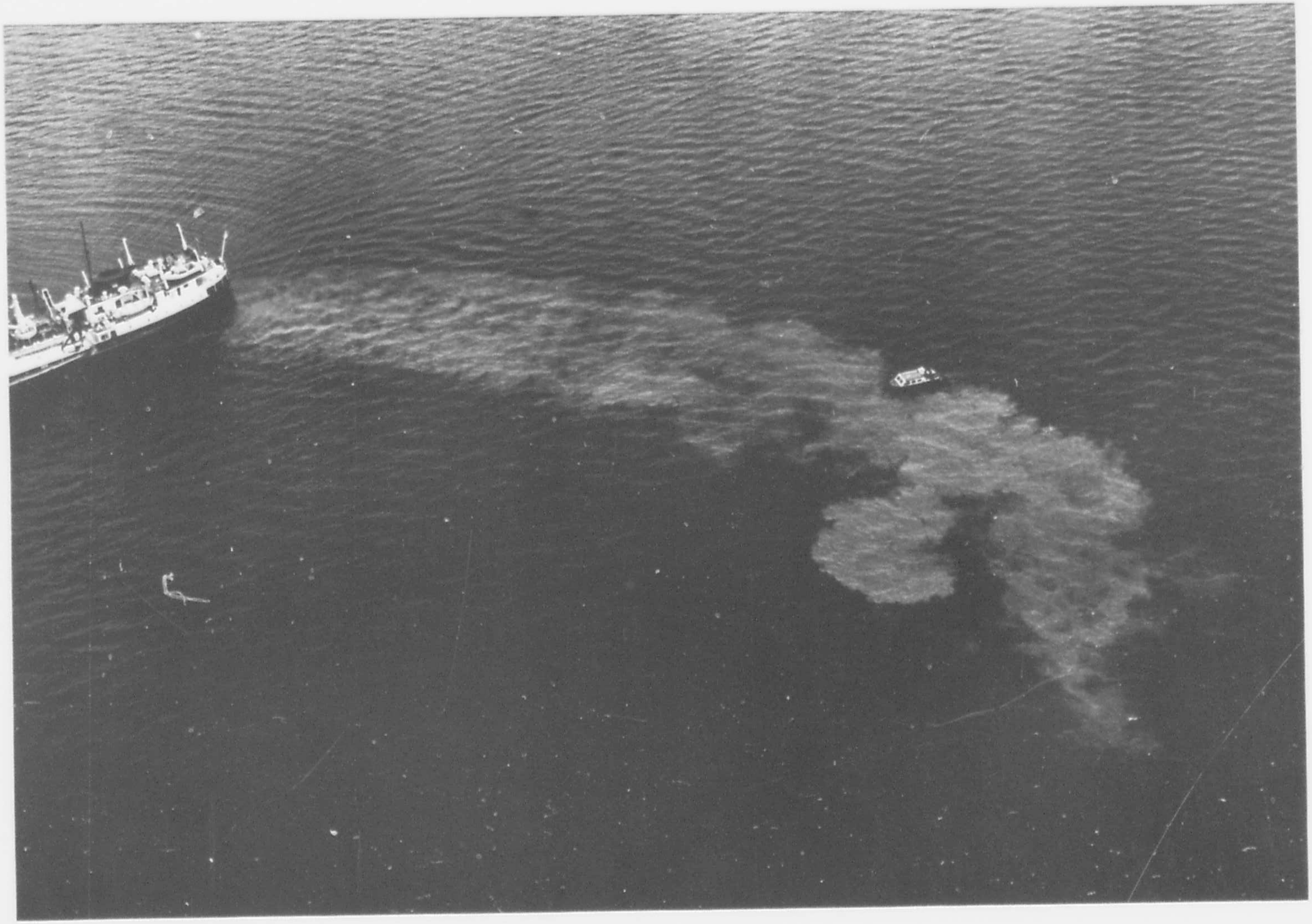

Photo 9 Open Lake Disposal by Hopper Dredge Making Turn at Disposal Site

Photo 10 Washing Out Hopper Bins at Disposal Site

door openings and leave a turbid trail behind. Where in the dredging cycle the scow doors are closed is governed by the door operating mechanism. In some older scows, it may be done manually or by power from the tug or dredge. Often this cannot be accomplished in the open lake. Newer scows are normally provided with onboard power. The low freeboard of loaded scows normally does not permit them to be towed to the disposal site in rough weather. It is possible for scows to leave a trail of suspended sediment behind: (1) when the dredgings spilled on the deck are washed into surrounding waters during the tow; or (2) when door seals are not tight or door operating mechanisms do not function properly. A recent requirement that their decks be washed in the dredging area before scows are towed to the disposal site has eliminated this kind of deck spillage. Adequate maintenance will prevent material losses due to mechanical malfunctions.

Spillage and the washing of hoppers and scow compartments are not objectionable when dredgings are placed in a diked inclosure within a harbor or onshore near the harbor. Hopper dredges normally unload directly into dikes areas hydraulically, and sediments can escape only with effluents from the area. As yet, there is no standard procedure for unloading scows and transferring sediments to a diked inclosure. Several methods have been investigated as part of the present study.

At the Buffalo pilot diked disposal area, a clamshell dredge was used to unload scows in 1967. The dredge was moved along-side the dike, and the boom carrying the loaded bucket was swung over the inclosure to drop its contents. A chute under the path of the bucket directed drippings into the diked area. By careful operation, losses to the waters in the vicinity of the operation were held to a minimum.

At the Buffalo and Cleveland pilot diked disposal areas, a small hydraulic pipeline dredge was used to unload scows in 1968. No dredgings were lost to the surrounding waters, but there were frequent shut downs because the hydraulic dredge pump clogged.

At the Indiana Harbor pilot area, scow loads were deposited directly into a diked area after they had been towed through an opening in the dike. Small amounts of oil and floating debris were seen to escape through the opening. At the Cleveland pilot area, scows were dumped in a slip, and a hydraulic dredge reexcavated the material and discharged it into the diked area. There was some coloration and increase in turbidity of adjacent harbor waters.

6.4.3 Effects on Aquatic Life

Bio-assays were performed at the University of Wisconsin's Center for Great Lakes Studies on about 40 samples of sediments collected from the pilot areas. The results of these bio-assays are discussed in Appendix C5. In terms of the response of test organisms employed, the sediments fall into five categories that form the following natural ecological sequence:

(1) Not toxic, stimulating growth of phytoplankton but not of Cladophora.

(2) Not especially toxic, not stimulating growth of algae;

(3) Somewhat toxic, lethal to some test animals, but not to others, avoided by Pontoporeia, but not by midge larvae, stimulating growth of phytoplankton or of Cladophora;

(4) Toxic to test animals, stimulating growth of phytoplankton or of Cladophora;

(5) Toxic, avoided by benthic animals, not stimulating growth of phytoplankton or of Cladophora;

All samples from Buffalo River, Buffalo Harbor, and Black Rock Channel, Calumet River, Cuyahoga River, Indiana Harbor, and Rouge River, and the Maumee River sample near the outfall of the Toledo Sewage Treatment Plant fell into categories (5) and (4). The least objectionable or cleanest sediments were those from Calumet outer harbor, Great Sodus Bay entrance channel, and the upstream portion of the Fox River.

Sediments from the outer harbor at Calumet were the cleanest. This harbor differs from the others in that Lake Michigan waters of high quality flow through the outer harbor on their way to the Calumet River. The reversed flow also explains why the sediments from the mouth of the Calumet River in comparison are somewhat better than those of the inner river.

The sediments from Green Bay and Fox River, which are considered heavily polluted, were in general of much better quality than those from the other pilot areas, with the exception of Great Sodus Bay Harbor. However, the samples probably did not represent normal conditions because they were collected after the completion of dredging.

The Wisconsin study suggested that the number of samples tested was not large enough to develop firm conclusions and that the mortality of test organisms may have been due not to the toxicity of the sediments but to low dissolved oxygen concentrations induced by the high oxygen demand of the sediments.

6.4.4 Effects on Water Quality

As indicated earlier in the present report, facilities of the Corps and FWPCA were severely taxed by the sampling program and it was not always possible to reach the objectives of the program nor to characterize fully the properties of the sediments and waters and relate them to causative events.

Sampling programs were carried out at the pilot harbors in 1967 and 1968, but the results of the 1968 samplings were not available for several harbors at the time the present report was being prepared. Where sampling data were available for both years, the reliability of some values was questioned because of discrepancies between 1967 and 1968 findings. For instance, at Green Bay station GBAY-1, the percent volatile solids in the bottom sediments increased from 20.3% in 1967 to 46.72% in 1968, even though both samples were taken at the same time of the year. Another case in point is Great Sodus Bay station 10, where percent volatile solids of bottom sediments rose from 0.93% in May, 1967, to 26.9% in June, 1968, even though both samples were taken before dredging began. Such discrepancies probably are accounted for as a lack of a representative sample and not as a temporal change. Statistical analyses for the variance of data were prepared only for Toledo and Indiana Harbors.

In several instances, lack of appropriate data interfered with objective evaluation of the effects of dredging either at the site or at the disposal area. For the dredging site, data on water and sediment quality were needed: (1) before dredging; (2) upstream and downstream of the dredge during dredging; and (3) after dredging. For several dredging sites in the pilot areas, there was no information on one or more of these three conditions.

Only a limited amount of data on the effects of open lake disposal could be obtained from the pilot areas because (1) no open lake disposal of maintenance dredgings took place at the Rouge River, Calumet, and Green Bay projects, (2) most of the Toledo dredgings were put into diked disposal areas, (3) the Buffalo open lake disposal area was not sampled in 1967, and (4) the sediments at Great Sodus Bay were considered unpolluted and acceptable for open lake disposal. To supplement the open lake disposal data from the pilot areas, the Lake Survey collected data from open lake disposal areas for the following projects: Au Sable, Michigan; Sandusky, Ohio; Manistee, Michigan; Alpena, Michigan; Frankfort, Michigan; Ashtabula, Ohio; Erie, Pennsylvania; and Lorain, Ohio. (Appendices A20 through A24, A26, A28, and A30, respectively, contain the separate reports on these projects.) Open lake disposal areas were sampled before, during, and after disposal in order to evaluate associated effects. The predominant finding in these studies is that water quality changes attributable solely to open lake disposal cannot be detected. In general, effects of disposal could not be differentiated from lake background conditions which reflect variations and influences of other factors not related to disposal operations.

To evaluate the effectiveness of diked disposal areas, the quality of the inputs of dredged material and of the outputs of water leaving the disposal area either through an open gap or an outflow pipe in a weir had to be known. In addition, conditions inside and outside the dikes had to be examined to determine the quality of the waters, if any, seeping through the dikes.

6.4.5 Great Sodus Bay, New York

The dredgings from the Great Sodus Bay project are deposited in an open lake disposal area in Lake Ontario. Table 21 of Section 6.3.2 shows that the water overlying the bottom sediments in the dredging area is good enough to serve as a source of raw water for municipal use for which water quality limits are the most restrictive. Thus, it is apparent that the undisturbed sediments of the dredging area have no adverse effect on the quality of the overlying waters.

Tables I, III, and IV of Appendix A2 record the results of a 1968 FWPCA sampling for various parameters of water quality during predredging, dredging, and post-dredging conditions. In addition, Tables II, III, and V, of Appendix A2 show the results of sediment quality for various parameters under the same conditions. Comparison of the bottom sediments under predredging and post-dredging conditions indicates that dredging can evidently improve the sedimentary environment because of reduced BOD and COD at the site. Based upon benthal analyses by FWPCA, there are no biological changes. The generic composition of the benthic fauna remains essentially unchanged at all stations after dredging.

During dredging, several short-term changes take place in water and sediment quality. When the sediments are disturbed by dredging, the turbidity and suspended solids increase greatly. In other words, some of the sediments returned to the harbor waters through overflow from the hopper dredge are slowly redeposited in or near the dredged channel unless they are carried out into Lake Ontario or into the Bay depending on the direction of flow. During dredging, total phosphates increase in the water and decrease in the sediments apparently because the water/sediment ratio of phosphates is upset. The effect, however, is of short duration as shown by the postdredging total phosphate closely paralleling that of the predredging phosphate.

Tables 31 and 32 compare values for parameters sampled at the disposal site in Lake Ontario before and after disposal.

Table 31

Water Sampling Results at Disposal Site for Great Sodus Bay Dredgings[a]

	Before Disposal		After Disposal [b]		After Disposal [c]	
Parameter	Top	Bottom	Top	Bottom	Top	Bottom
pH [d]	8.2	8.0	8.35	8.3	8.4	8.5
Spec. Cond. [e]	340	340	300	304	270	272
Turbidity	0.8	0.9	1.7	0.8	f	f
DO	11.5	12.3	9.7	f	8.8	8.3
BOD	1.0	1.2	1.6	1.3	0.8	3.0
N-total	0.244	0.764	0.54	0.54	f	f
$N-NO_3$	0.09	0.28	0.04	0.05	0.02	0.16
$N-NH_3$	0.1	0.56	0.06	0.06	0.03	0.03
PO_4-Total	0.09	0.09	0.1	0.1	0.08	0.09
PO_4-Sol.	0.05	0.07	0.06	0.06	0.07	0.08
Solids-Susp.	4	15	3	3	5	5
Solids-Vol. Susp.	3	7	2	2	4	3
Alkalinity	98	102	94	88	89	92
Chlorides	26.5	26.5	27.1	26.7	27.1	27.4

[a] FWPCA 1968 data, Appendix A2, Tables I, IV, and IVA, all values in mg/l except where noted.

[b] 1 August 1968

[c] 15 August 1968

[d] no units

[e] micromhos/cm

[f] not analyzed

Table 32

Sediment Sampling Results at Disposal Site for Great Sodus Bay Dredgings[a]

Parameter	Before Disposal	During Disposal
BOD	0.327	0.392
COD	1.26	2.09
N-total	0.4	0.14
$N\text{-}NO_3$	0.07	0.03
PO_4-total	1.62	0.727
PO_4-sol.	.0052	.0005
% Total solids	76.2	76.5
% Volatile solids	1.11	0.74
Oil and grease	0.22	0.39
Chlorine demand	0	0
% SiO_2	69.4	70.5
% Water	23.76	23.56

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[a] FWPCA 1968 data, Appendix A2, Tables II and IIIA, all values in mg/g (dry weight) except where noted.

The very limited data from the open-lake disposal area indicate that the sediments contain about the same or lower concentrations of nitrate, and of total and soluble phosphorus as the typical lake sediments. The increase in BOD at the disposal site during dredging is insignificant in view of the dissolved oxygen contained in the waters at the disposal site and the similarity of the BOD of the waters before and after disposal. Even though sediments were not analyzed at the disposal site after disposal, FWPCA concluded that the bottom fauna in the vicinity of the disposal site are not affected by disposal operations. No samples of sediment could be found at the disposal site after a lapse of two weeks, and it must be assumed that there is a high degree of dispersion of spoil over the rocky bottom of the lake.

6.4.6 Buffalo Harbor, New York

The Buffalo River is dredged annually by clamshell dredge. Until 1967 disposal of the dredgings was in Lake Erie. In the fall of 1967, about 100,000 cubic yards of Buffalo River dredgings were placed in an alongshore diked inclosure in Buffalo South Outer Harbor, approximately 2.5 miles from the Buffalo River entrance (Photo 11). The disposal site is roughly a square, approximately 1,000 feet on a side. The shoreline forms the eastern boundary; an existing dike was put to use at the northern end; and west and south dikes were constructed with open hearth slag. Since the slag was expected to act as a filter, there was no provision for effluent discharge. In 1967, dredgings were removed from the dump scows with a clamshell dredge and deposited in the inclosure. 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 diked area before, during, and after dredging. Available data showed no changes in water quality outside the inclosure.

In the fall of 1968, an additional 120,000 cubic yards of Buffalo River dredgings were placed in the diked area directly from scows by hydraulic methods. Necessary dilution waters were taken from the inclosure. Analytical information on the effects of disposal by this method was not available at the time the present report was prepared.

The outer harbor and Black Rock Channel are dredged with a hopper dredge, and the spoil is carried to a site 1.4 miles southwest of the South Buffalo Pierhead Light. According to FWPCA, visually observed turbidity and floating oils in the Buffalo River and Black Rock Channel are markedly increased during dredging. Oil films persist for some time. However, dredging effects at the site cannot be completely evaluated at the present time because of lack of data.

Photo 11 Aerial View of Diked Inclosure at Buffalo, N.Y.

Under existing physical conditions of sedimentation, dredging probably reduces pollution concentration slightly in the area of dredging; mechanical agitation and mixing of polluted sediments with already polluted water also provides some opportunity for oxidation; and removal of large volumes of polluted sediment from the entire area offers a potential for pollution reduction in the immediate area of dredging.

In viability tests of bottom and planktonic organisms (Appendix C5), sediments from the Buffalo River caused a severe mortality of Amphipods. Midge larvae, the water flea Daphnia and other zooplankters died off in bioassay tests of both river and harbor sediments. By contrast, small quantities of the sediments stimulated the growth of algae.

The effects of open lake disposal were not determined in 1967 because it was believed that observations would be obscured by wastes, from Bethlehem Steel and other industries, entering Lake Erie in the immediate vicinity of the disposal area. Sampling the lake site before, during, and after dredging was included in the 1968 sampling program, but analyses had not been completed at the time the present report was prepared.

6.4.7 Cleveland Harbor, Ohio

Appendix A4 shows that dredging and the disposal of dredgings exert little, if any, significant lasting effect on the quality of surrounding waters. At Cleveland, tests by Lake Survey showed nothing but passing local effects, such as depression of dissolved oxygen levels and an increase in suspended solids. Changes in other chemical parameters were masked by the high levels of the parameters occurring even when dredging was not in progress.

The Cuyahoga River is dredged under contract by a clamshell dredge, and the dredgings are transported to Lake Erie in scows. The FWPCA report on Cleveland concluded that clamshell dredging is an effective and fairly efficient method of sediment removal, causing only minimal disturbances in the quality of the overlying river water manifested mainly by a temporary increase in turbidity and the rise of additional oily scum and debris to the water surface in the immediate vicinity of the dredge. There were no apparent lasting effects; but there were beneficial reductions in noxious materials.

At Cleveland, the outer harbor is dredged by hopper dredge. The resulting immediate effects upon water quality are an increase in suspended solids from the normal value of 50 mg/1 up to 200 mg/1 and a depression of dissolved oxygen levels by as much as 25 percent that do not extend any great distance beyond the dredge location. Sediments from the Cuyahoga River were toxic to benthic organisms, zooplankton, and algae, whereas the outer harbor sediments were not especially toxic to benthic animals, although they killed zooplankton and promoted the growth of phytoplankton and Cladophora according to the bioassays (Appendix C5).

In the harbor, benthic populations appear to decrease in the dredging area, probably because organisms are removed rather than suppressed. Changes in chemical and microbiological quality of the waters in the vicinity of hopper dredging are minimal and lie within ranges observed also in the absence of dredging.

The effects of disposal of dredgings in an open lake area on the north side of the east breakwall of Cleveland Harbor were investigated as part of the 1967 sampling program. The disposal site contains two small areas, one for outer-harbor hopper dredgings and the other for clamshell river dredgings. Sampling stations and schedules are recorded in Appendices A4 and A29.

Sampling before disposal operations showed that existing bottom sediments were generally objectionable and that they had a significant oil content. As expected, they became worse as disposal progressed and dredgings spread over the bottom. The oil did not break down biologically but built up in volume.

Studies of time changes in BOD profiles through the disposal area showed that much of the spoil settles immediately, but remains subject to creep, flow, and resuspension. Figures 10 and 11, in Appendix A4, show the longitudinal profiles of COD, volatile solids, BOD, oil and grease, phosphorus, nitrogen, and iron in the lake sediments in the area north of the east breakwall. Concentrations in the disposal areas stand out in these profiles, the area receiving river dredgings showing the highest values.

In all but the disposal site for river dredgings, benthic organisms increased after disposal began. As more and more river sediments reached the site, its benthal populations decreased, thus suggesting the presence of toxic substances and lateral spread of the dredgings. How great the spread was is not known. However, it seems to have gone beyond the areal limits of the study.

Lake Survey developed chronological, areal sampling patterns along the line of drift at the lake site while river dredgings were being discharged. Transparency of the lake water decreased as the mass of turbid water drifted down current. However, similar correlations between time or distance and other quality parameters were not obvious. Thus, the surface waters at a given location might show a slight increase in specific conductance with time while the bottom waters might either remain unchanged or decrease with time. Hence, it must be assumed that the suspended material responsible for the decreased transparency did not create a corresponding increase in the dissolved ions. Although chloride might remain fairly constant with time at a given point, it decreased along the line of drift. Progressive changes in pH at a given place did not seem to be related to disposal because the change did not rise and subsequently fall as the cloud passed by. Appendix A29 is the report by Lake Survey.

In 1967, FWPCA sampled the waters while river sediments were being discharged. As shown by their report, Appendix A5, no significant immediate effects were observed on the overlying waters. In the course of time, however, the oxygen content of the lower waters was reduced by as much as 20 percent. There was no correlation between coliform concentrations and dredging operations because it appears that similar coliform concentrations could have occurred in the lake disposal area due to river outflow and the effluent from Cleveland's Westerly Sewage Treatment Plant. At Cleveland's four water intakes, no changes in water quality could be attributed to dredging.

In 1964, a special study of benthal deposits was made by personnel from the Public Health Service's Lake Erie Field Station (presently Lake Erie Program Office of FWPCA). In connection with the 1964 study, two samples were taken within the site of a spoil disposal area abandoned in 1957. Samples from this area, which lies approximately nine miles from the mouth of the Cuyahoga River, were quite like muds from the central basin of Lake Erie, and, accordingly, show no evidence of previous disposal of polluted dredgings.

In 1967, a diked disposal area was constructed at Cleveland in the eastern outer harbor as part of studies for the present report (Photo 12). The dike was constructed of limestone and protected against wave action by dolomite riprap on the lake side. Its inside face was lined with a sand-filter blanket 7 ft. thick with 30 percent pore space. Because the dike is pervious, no overflow

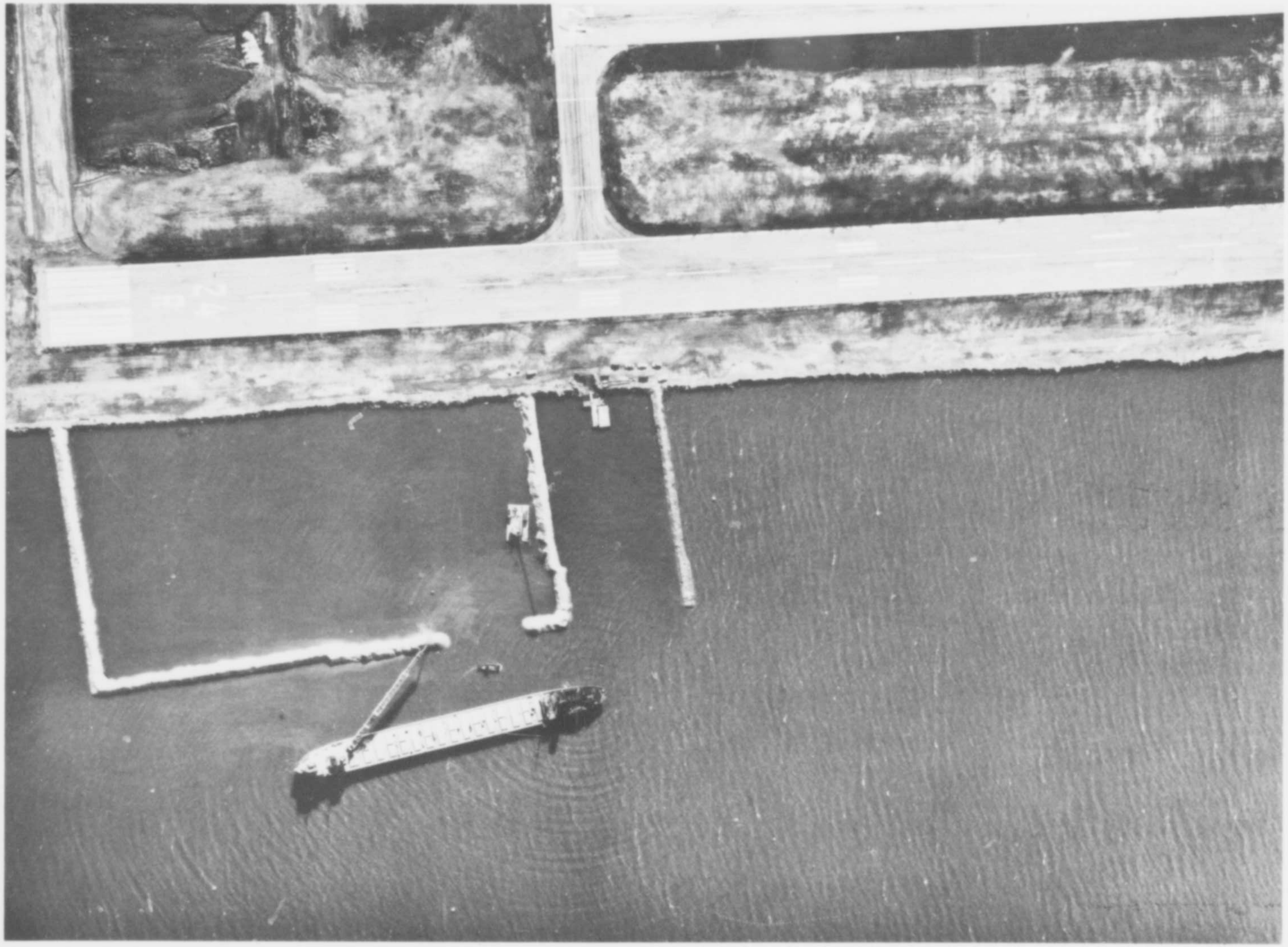

Photo 12 Cleveland Diked Disposal Area Under Construction In 1967

structure was provided. The capacity of the inclosure is approximately 375,000 cubic yards. To provide an unloading slip and study alternative methods of dredgings handling, a spur dike was constructed parallel to the west side of the diked area. To assist in sampling, a well was constructed in the dike near its northeast corner. Two water level recorders, one inside and one outside, and a wind recorder were installed to evaluate the effectiveness of the diked area.

In the spring and summer of 1968, two methods were employed to place Cuyahoga River sediments in the diked area. Between 1 May and 12 June 1968, loaded scows were delivered to the slip area and moored next to a hydraulic dredge. Dredgings were pumped directly from the scows into the inclosure. The hydraulic dredge was redesigned to jet slip water simultaneously into the scow and pump the diluted dredgings from the scow (Photo 13).

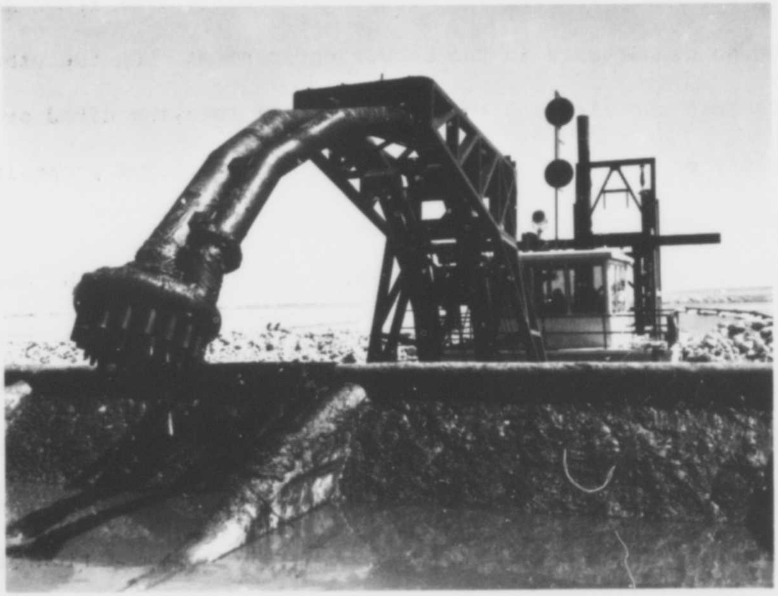

Photo 13 Suction Pipe on Redesigned Hydraulic Dredge

The discharge pipe was carried over the dike and, supported on pontoons, extended into the center of the inclosure. One scow load was pumped into the diked area each day. The discharge from the pipe varied in solids content from that of the water in the slip to that of the sediments in the scow. The volume of dredgings added in this way was 45,555 cubic yards. Based on percent solids and pumpage, the average ratio of water to sediment was 5 to 1, making the estimated input to the diked area 273,000 cubic yards.

From 21 June to 1 August 1968, dredgings in scows were bottom dumped into the south end of the slip, pumped from the bottom with the hydraulic dredge, and discharged to the diked area as before. The volume of dredgings added in this way was 45,092 cubic yards, the total input volume being 496,000 cubic yards at an estimated ratio of 10 parts water to 1 part sediment.

Sediment and water samples were collected in and around the diked disposal area before, during, and after disposal operations. Sediments transported to the diked area were very similar to the Cuyahoga River sediments analyzed in the 1967 sampling program. Pumping the dredgings directly from scows into the diked area caused no disturbance in the harbor environment. On the other hand, dumping sediments into the slip and then pumping them into the diked area degraded water quality markedly in the vicinity of the slip. Tug propellor wash added to the disturbance.

Aerobic conditions and relatively good water quality within the diked area before disposal were transformed rapidly into anaerobic and noxious conditions shortly after disposal began. Nutrients rose to high concentrations. Suspended solids concentrations rose and remained fairly stable throughout the study period, but large decreases were noted in the interim between the two operations and toward the end of the second operation. Three weeks after completion of the study period, dissolved oxygen in the overlying water reached 5.6 mg/l and conductivity dropped. High increases in green coccoid algae and an unidentified plankter were accompanied by oxygen replenishment of the waters.

The diked area contained the dredgings and 99 percent of nearly all their measured constituents effectively. Table 33 shows the estimated total loads and the percent retention. Loads are based on the reported sediment volume of 90,647 cubic yards. Samples of dilution waters were obtained by compositing grab samples taken below the surface of the slip near the inlet pipe to the pump.

Table 33

Loads to Diked Area at Cleveland, Ohio[a]

Parameter	Scow Sediment	Dredge Dilution Water	Total Load to Dike	Dike Effluent	Dike Retention
Total Solids	54,000	174	54,500	255	99.6
Total Suspended Solids	b	22		62	99.9
Volatile Suspended Solids	b	12		17	
Total Volatile Solids	7,200	b	7,200		99.8
Chlorine demand	1,750	88		6	99.7
COD	10,500	b	10,500		
Total Phosphorus	215	0.016	215	0.5	99.8
Total Nitrogen	175	1.15	176	12	93.2
Oil and Grease	2,000	b	2,000		
Phenols	b	0.001		0.005	
Total Iron	7,500	b	7,500		
Lead	25	0.01		0.08	99.7
Nickel	50	0.05		0.05	99.9
Chromium	13	0.02		0.05	99.6
Cadmium	11	0.005		0.005	99.9
Cobalt	1	0.01		0.007	99.3

a FWPCA 1968 data, Appendix A5, Table 6, all values in tons.
b Analysis not made

To study the effectiveness of an air barrier in preventing the escape of suspended matter from the slip, an air bubbler system was installed across the open end of the slip. The air barrier was created by blowing 500 cubic feet per minute through 61 perforated pressure lines laid across the bottom of the outer 150 feet of the slip. It was employed during the last two weeks of the disposal operation.

Aerial photographs (Photos 14 and 15) of the disposal operation with and without benefit of the air curtain indicated that the curtain, by keeping the sediments in suspension, assisted rather than retarded the movement of suspended solids out of the slip. Scows were towed to the land end of the slip and then dumped. In Photo 14, it appears that the suspended material in the area where the scow was dumped is beginning to settle. However, in the area where the air lines were laid (from the vicinity of the dredge to the open end of the slip) the sediments appear to be still in suspension. Further, the two lobes which extend past the air-barrier area show that the curtain did not contain the suspended material within the slip. In Photo 15, it appears that the suspended material is settling in all parts of the slip.

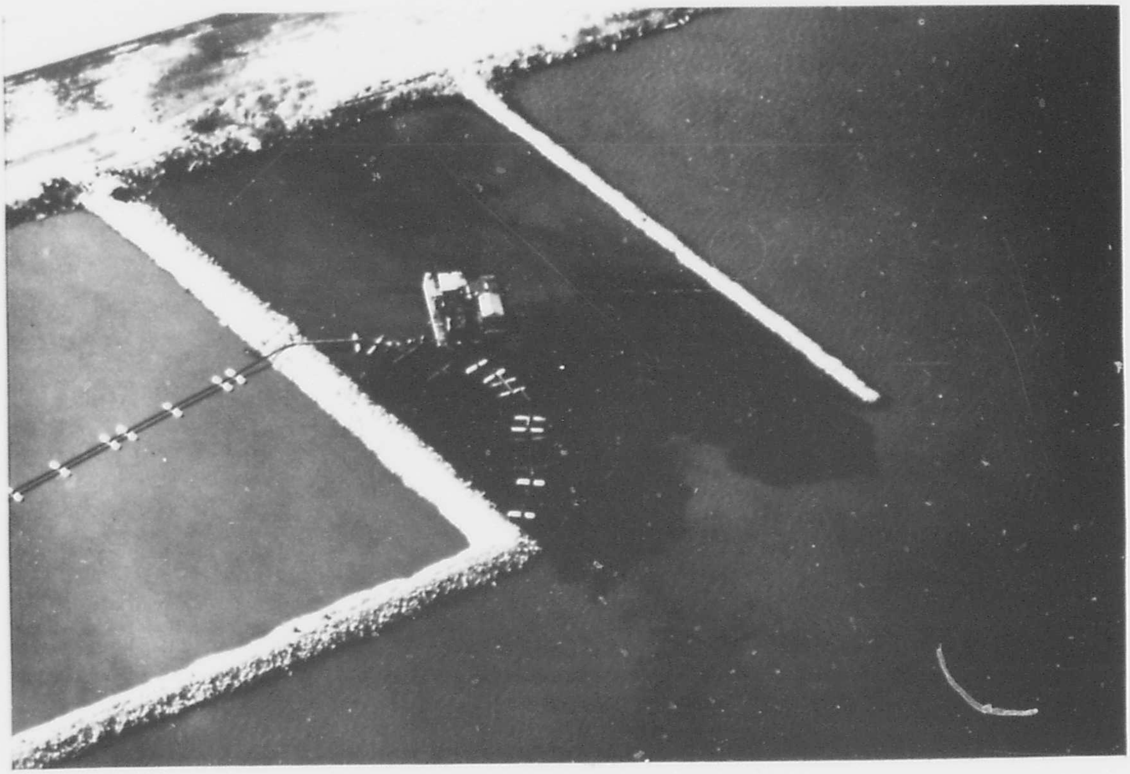

Photo 14 Aerial View of Slip Showing Turbidity with Bubbler in Operation

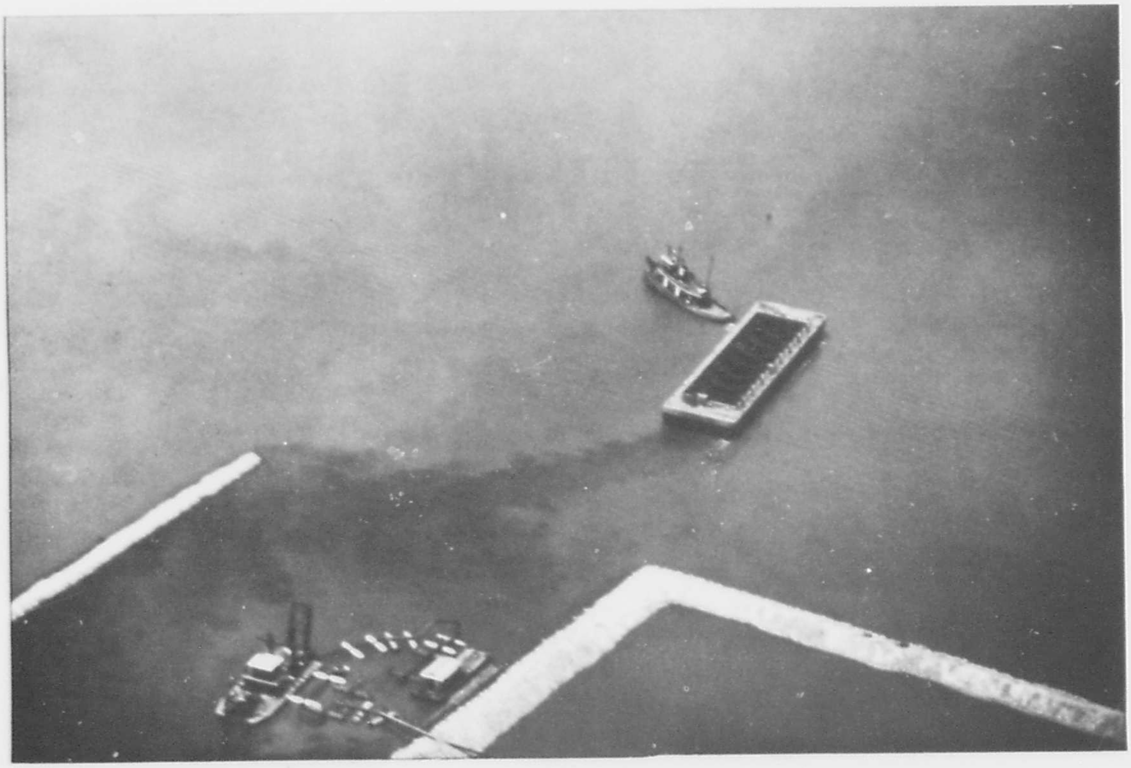

Photo 15 Aerial View of Slip Showing Turbidity without Bubbler in Operation

6.4.8 Toledo Harbor, Ohio

The materials dredged from the Maumee River and the inner 5 miles of Maumee Bay channel at Toledo are placed in a diked inclosure 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. Table 26 in Section 6.3.5 gives the characteristics of river and bay sediments. The average values for the parameters listed are repeated below in parallel with values for Maumee Bay at the diked disposal site and for Lake Erie at the open lake disposal site.

Table 34

Comparison of Maumee River Sediments

at Dredging and Disposal Sites[a]

Parameter	Dredging Site	Diked[b] Disposal Site	Lake Disposal Site Before	Lake Disposal Site During	Lake Disposal Site After[c]
% Volatile Solids	8.3	9.1	7.9	8.1	
% Total Solids	45.2	45.4	30.6	39.7	
% Oil & Grease	0.148	0.15	0.06	0.16	
BOD (mg/g)	1.5	0.8	-	0.8	
Settleability (% 1st hr.)	7.7	-	6.8	7.7	
Settleability (hrs. for 90%)	41.5	-	43.7	43.5	
pH	6.8	7.2	6.7	7.7	
eH (volts)	-0.09	-0.08	-0.08	-0.08	

[a] Lake Survey 1967 data, Appendix A27, Table 2 and pgs. 14-17, all values are averages.

[b] Bay area north of diked area.

[c] No sampling was done after disposal operations had been completed because dredging was terminated very late in 1967.

During dredging, the volatile solids content in Maumee River sediments remains unchanged. Total solids in river dredgings is uniformly low during and after dredging, but random variations do occur. No obvious changes in oil and grease nitrogen, phosphorus, or dissolved oxygen arise from dredging operations. Whereas the BOD of the river sediments increases during dredging, the increase can be attributed in part to changes in inputs or flow conditions. Suspended sediment concentrations seem to correlate generally with the position of the dredge, higher values occurring nearer the actual dredge location. In its normal flow, the Maumee River carries a heavy suspended sediment load, which, along with the rate of flow, affects the total suspended sediment concentrations.

The naturally high turbidity of the Maumee River makes it difficult to determine the effect of dredging operations on transparency. Appendix A27 discusses in detail the effects of dredging on water quality in the river. In general, changes in dissolved ions are due to changes in inputs or flow conditions and not to the passage or operation of the dredge.

Effects at a disposal site depend upon the nature of the dredged sediments and, in the case of diked disposal, on the effectiveness of the containment area. At Toledo, the diked disposal area is a 1.5 mile by 0.5 mile inclosure on the north side of the channel about one mile from the mouth of the Maumee River (Photo 16). Excess water flows into Maumee Bay through a pipe in a weir at the northeast corner of the inclosure (lower right, Photo 16). The effectiveness of the diked area at Toledo is best measured by comparing the quality of the overflow through the pipe with the quality of the dredged material introduced into the dike. Table 35 shows various concentrations of suspended sediments at the diked disposal site. Station 9 is located at the outfall of the overflow pipe; station 11 is about 700 feet north of station 9.

Photo 16 Maumee Bay Diked Disposal Area

Table 35

Suspended Sediment at Diked Disposal Area At Toledo[a]

1967 Date of Sampling	Suspended Sediment Station 9	Suspended Sediment Station 11
9/26	986.6	248.6
9/27	4374.8	63.6
9/29	6564.8	59.2
10/4	12619.8	74.0
11/15	3197.6	--
11/15	119.6	--
11/16	25.2	59.6
11/16	72.0	30.2
11/17	37.6	--

[a] Lake Survey 1967 data, Appendix A27, Table 6, all values in mg/l.

It is obvious that prior to 15 November 1967, the diked area did not limit the overflow of suspended sediments effectively. On 15 November 1967, remedial changes were made including the raising of the weir to allow ponding to occur within the inclosure. As shown by Table 35, the changes were effective immediately. There was greater settling of suspended material because of the longer retention time and slower velocity of flow within the diked area.

There are other indications, too, that the diked area at Toledo became more effective after the changes. The nitrate and phosphate concentrations of the outflow were 17.2 mg/l and 1.0 mg/l, respectively, or approximately one-half the values of the source area. Sulfate and chloride showed similar trends. The change in soluble solids was due in part to dilution of the dredgings with bay water during unloading of the hopper dredge. In general, the concentration of ions in the overflow was rapidly dissipated.

Normally the open lake disposal area receives dredgings from the outer 12 miles of the navigation channel in Maumee Bay and Lake Erie. The immediate effect of disposal in the open lake area is shown by Table 34. Long-term effects cannot be determined at present because of lack of data. Settling rates in

Maumee River and in the open lake disposal area are similar because of the fine grained nature of the source sediments. The sediments were toxic to certain bottom organisms and some zooplankters, and stimulated growth of phytoplankton and *Cladophora*, except for one sediment sample from the vicinity of the sewage treatment plant, which was toxic to algae as well as animals.

6.4.9 Rouge River, Michigan

The water quality of Rouge River is affected greatly by the nature of the sediments. Most of the bottom material is light and easily disturbed. This makes for resuspension of the sediments during storms, and by passing watercraft and similar disturbances.

Table 6 of Appendix A6 contains the 1967 FWPCA results of analysis of water quality measured during dredging operations at Rouge River. Values for temperature, pH, alkalinity, chlorides, nitrate-N, nitrite-N, organic-N, and sulfate show no immediate or extended effect of dredging. Other parameters, conductivity, and phenol are inconclusive in their values. The most significant effect of dredging on the water quality of Rouge River results from overflows from the hopper bins. The overflows increase turbidity and surface oil behind the dredge and decrease dissolved oxygen levels. Other immediate effects are determined by the nature of the sediments dredged; among them, high iron content, suspended solids, volatile suspended solids, and BOD immediately behind the dredge. Futher, Table 6 of Appendix A6 shows that iron, suspended solids, transparency, and BOD, all returned to near normal levels within one-half mile behind the dredge. FWPCA concludes in Appendix A6 that changes in the water quality of the Detroit River can not be attributed either to dredging or to disposal operations.

All of the material dredged from Rouge River is transported to and confined in the diked disposal area at Grassy Island, in the United States waters of the Detroit River (Photo 17). Visual observation by FWPCA shows no leakage of dredgings from the hopper bins during transit to Grassy Island, nor during unloading operations.

Table 7 of Appendix A6 summarizes the 1967 FWPCA sampling results at the Grassy Island disposal site. Completed in 1960, the earth-dike inclosure has no overflow weir, but does have a valved drain pipe to remove water after settling.

Seven wells along the dikes are used to determine the rate and quality of effluent seepage. The level of water in the wells on Grassy Island remains near the elevation of the Detroit River. Seepage through the dikes is, therefore, low. Evidently, the Grassy Island disposal site serves as a settling basin and stabilization pond. Table 7 of Appendix A6 shows a decrease with time in BOD, COD, total phosphates and suspended solids. The quality of the water discharged periodically through the overflow pipe meets effluent recommendations set by the Public Health Service and the Michigan Water Resources Commission for discharges to the Detroit River (see Table 12 of Appendix A6).

Photo 17 Grassy Island Diked Disposal Area

6.4.10 Indiana Harbor, Indiana

The effects on water quality at the dredging site cannot be determined objectively at present because of lack of data. According to the Lake Survey report, Appendix A25, sampling at Indiana Harbor was deferred until dredging was about 75 percent complete. Bioassays of sediments from the canal revealed that the sediments would severely restrict the survival of pollution-tolerant organisms as well as "clean-water" animals.

The lack of sampling data in advance of disposal operations also precludes an objective evaluation of their effects on water quality at the open-water disposal site in Lake Michigan. The conditions of the bottom sediments at this site at the time of sampling, i.e., after dredging was 75 percent complete, are summarized in Table 36.

Table 36

Bottom Sediments at Lake Disposal Site

During Disposal[a]

Direction	Miles from Center	Percent Solids	Percent Volatile Solids	Percent Oil and Grease	BOD (mg/g)
Center	0	59	6.2	0.55	1.9
West	1	74.8	5.4	0.17	1.23
West	2	82.3	3.6	0.01	0.11
West	4	82.1	4.9	0.05	0.15
North	1	82.8	1.2	0.29	0.0
North	2	86.5	4.9	0.01	0.0
North	4	88.7	5.8	0.04	0.0
East	1	81.4	4.6	0.04	0.83
East	2	83.6	3.1	0.04	0.0
East	4	82.4	6.1	0.01	0.53
South	1	81.8	4.3	0.03	0.31
South	2	83.2	5.4	0.05	0.38
South	4	81.3	4.7	0.01	0.31

[a] Lake Survey 1967 data, Appendix **A25, Table 3.**

Sediments at the center of the disposal area, show the greatest presence of source material; solids are the lowest recorded and volatile solids, oil and grease, and BOD are the highest recorded. Figures 14 through 17 in Appendix B6 trace the decrease away from the center. At the disposal site bottom sediments take on the characteristics of the source material over an area of about 3.5 square miles. Although the concentration of oil and grease is only about one-tenth that at the dredging site, it is still almost 20 times greater than the lake background values.

Counts of pollution-tolerant fauna in the center of the disposal area were low, and disposal operations seem to have affected the existence of tolerant organisms.

Until October 1967, the materials dredged from Indiana Harbor were deposited in an open water disposal area in Lake Michigan. Then, permission was received to dispose of dredgings in a diked landfill lagoon of Inland Steel Company.

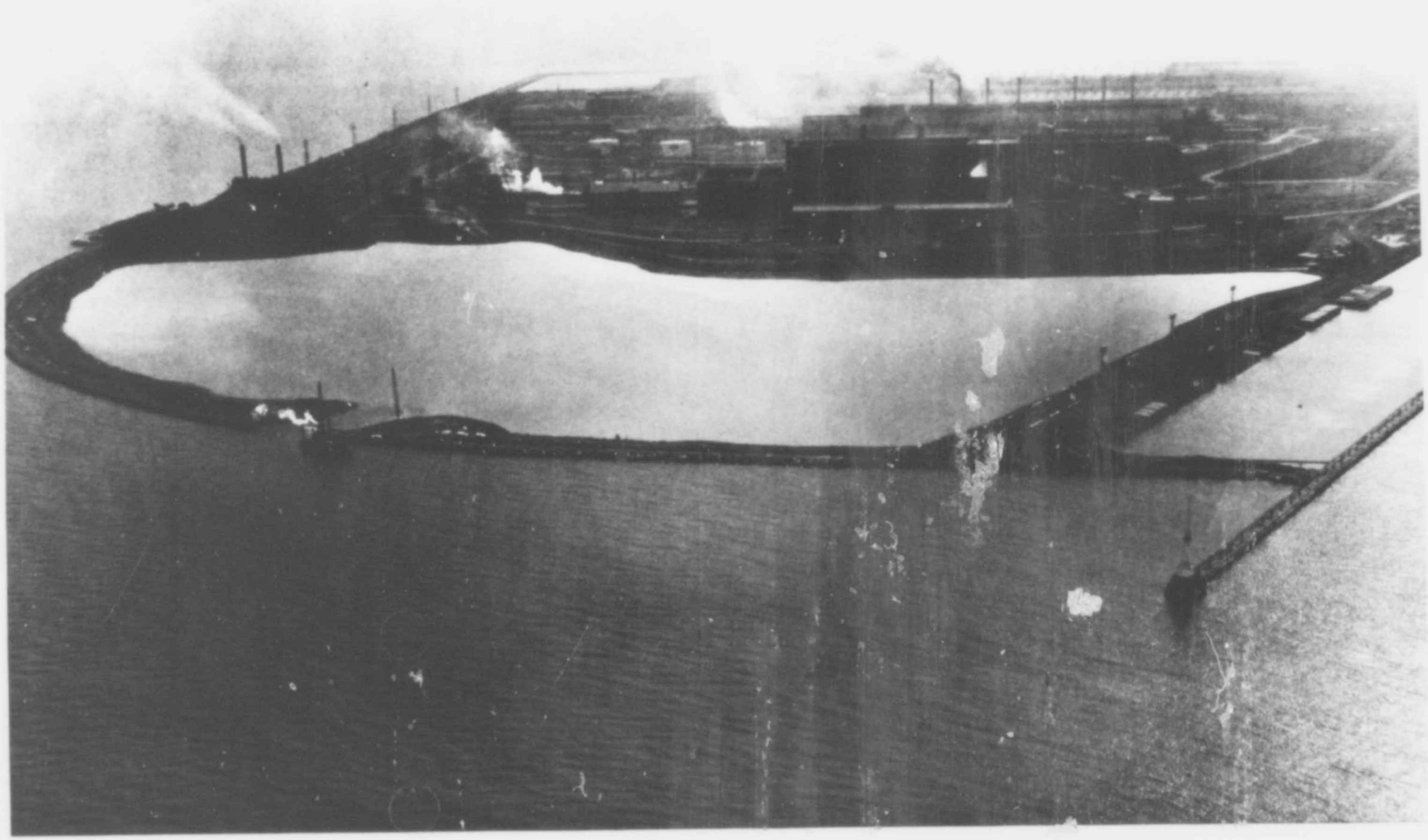

Photo 18 Inland Steel Company Landfill Area at Indiana Harbor

In addition, three scowloads of dredgings were deposited earlier in a diked disposal area owned by Youngstown Sheet and Tube Company.

The Inland Steel Company landfill lagoon is an 82 acre site formed by a cofferdam of concrete-filled cells of steel sheet piling (Photo 18). The diked area is impervious except for a 150-foot gap open to Lake Michigan. The water in the gap (12-14 feet) is deep enough to bring loaded scows into the lagoon. An air barrier system was installed in the open gap by employing a 2-inch perforated polyethyene pipe through which a pressure of 50 p.s.i. was maintained by a 315 c.f.m. air compressor. The surface oil was not effectively contained by this system, and a higher pressure may be needed to contain surface oil within the inclosure.

Table 3 of the FWPCA sampling report, Appendix A7, shows that total phosphorus, COD, suspended solids, and dissolved solids increased within the diked area after disposal. Figures 6, 8, and 9 of Appendix A7 show some local deterioration of water quality for total phosphorus, suspended solids, and oil and grease at the gap. However, deterioration is insignificant at station CE 4-0, which is only about 1,400 feet from the gap. Physical examination of bottom sediments shows furthermore, that little, if any, organic matter is discharged from the diked area.

In reference to the area owned by Youngstown Sheet and Tube Company, the Lake Survey report, Appendix A5, concludes that since the concentration of volatile material was higher just outside the Youngstown diked area than it is inside, detrimental effects of disposal operations were insignificant.

6.4.11 Calumet Harbor, Illinois

Biological tests on the sediments reported in Appendix C5 stated that the outer-harbor bottom would readily support "clean-water" organisms intolerant of pollution. However, the sediments collected in the river were toxic to benthic organisms and less likely to stimulate phytoplankton productivity.

Water samples were taken on seven different occasions during the dredging operations in the Calumet River. Four samples taken upstream and downstream of the dredging operation showed no significant changes in water quality, except for increases in suspended solids, dissolved solids, and turbidity.

In 1967, all material dredged in the Calumet River was under Federal contract and ultimately was disposed of in a 91-acre land disposal area in the vicinity of Lake Calumet. The material was dredged by clamshell dredge, deposited in a temporary disposal slip in Lake Calumet and then pumped by hydraulic dredge to the land site (Photo 19). A submerged dike at the mouth of the slip served to contain the dredgings in the temporary disposal area. Effluent from the land area drained southward to Calumet River through a ditch and outfall.

Water samples were collected in the vicinity of the temporary spoil area and from the land disposal outlet. The effectiveness of the disposal method can be based on an evaluation of results of the sampling program as outlined in Appendix A8.

Turbidity and suspended solids were higher in the temporary spoil area after disposal; however, outside the submerged dike at the mouth of the slip, there was no significant change in turbidity or suspended solids before or after disposal. In the land disposal site, there was very little ponding. As a result, water containing large amounts of suspended solids discharged through the outlet culvert into the Calumet River. Table 37 shows the average values of constituents in the water in the outlet ditch.

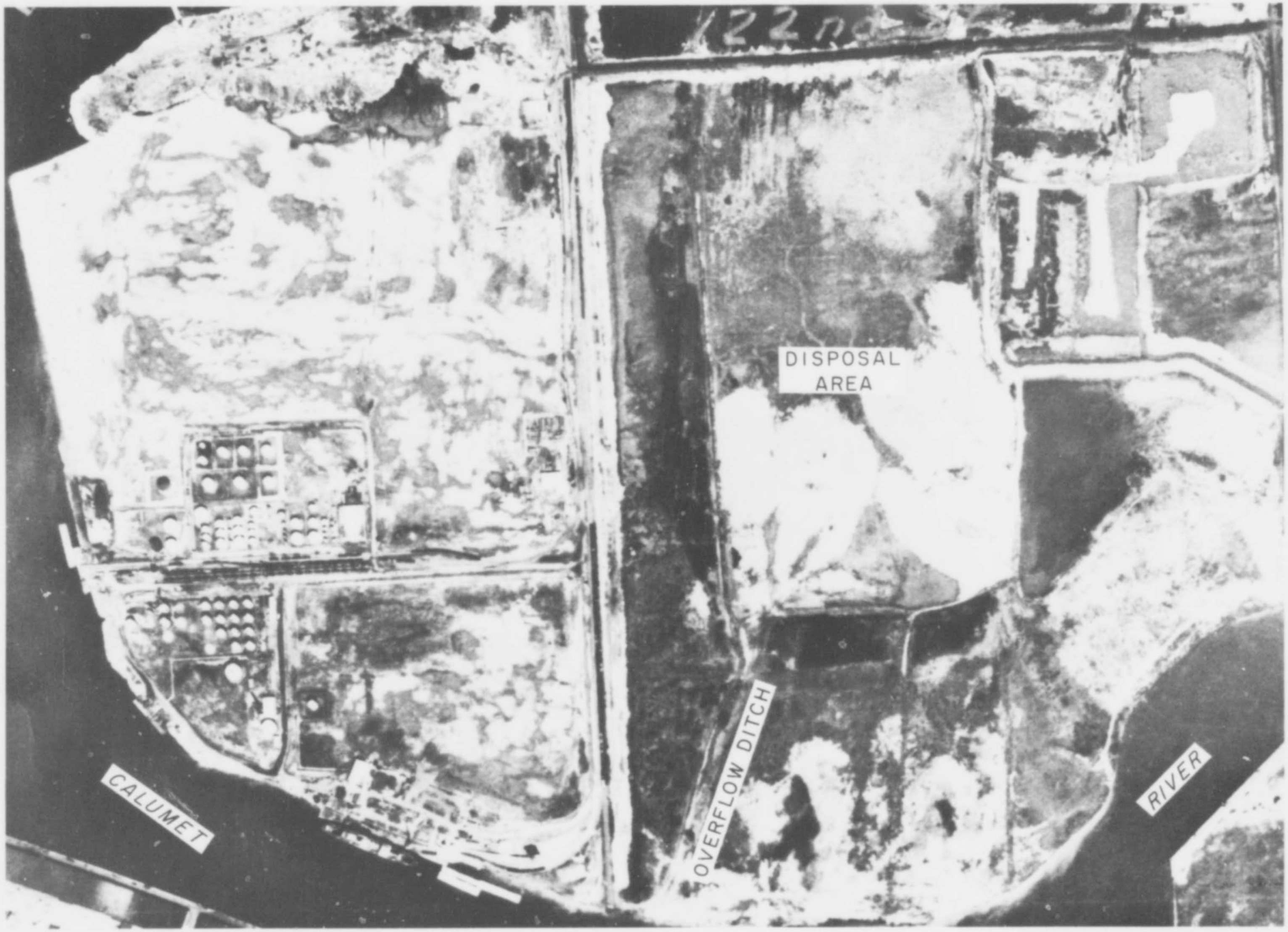

Photo 19 Land Disposal Site at Calumet River, Illinois

Table 37

Water Quality of Discharge from

Calumet Land Disposal Site[a]

Parameters	Outlet Ditch
Suspended solids	10,830
Dissolved solids	520
Total phosphorus	4.67
N - organic	10.1
N - NH_3	5.6
N - NO_3	1.0
COD	1,250
Oil and grease	14.4

[a] FWPCA 1967 data, Appendix A8, Table 6, all values are averages and in mg/l.

The land disposal site was relatively ineffective, because of the insufficient settling time. Thus, the effluent contained high values of suspended solids and, consequently, in other parameters.

The 1968 dredging was by hopper dredge, with the material pumped directly from the dredge into the same disposal areas as was used in 1967. However, in 1968, an outlet system was designed and employed for the land disposal area in order to increase the detention in the basin and thus minimize the release of suspended solids. Data from the 1968 operations were unavailable for use in preparing the present report.

6.4.12 Green Bay Harbor, Wisconsin

There are no data on the effect of dredging on the water quality in Green Bay Harbor. Table 38 shows that the sediment sample collected at River Mile 1 after dredging suggest that dredging may improve the sedimentary environment. Volatile solids, oil and grease, total phosphorus, COD, and nitrogen (NO_3, NH_3, total, organic) concentrations were lower than in the adjacent river or bay.

The sediments used in bioassay tests were collected after the channel had been dredged. They were classified as belonging primarily in Category 2 and may reflect an improvement by dredging.

A land diked disposal site at Atkinson Marsh was utilized in 1967 (Photo 20). Material dredged from the Fox River channel by two clamshell dredges was placed in a temporary spoil area in Green Bay, and later pumped to the land disposal area by a hydraulic dredge. The temporary spoil area consisted of a sump, 200 feet by 750 feet, dredged to a depth of approximately 25 feet below the natural bottom of the Bay. The hydraulic dredge, working the channel section from the mouth of Fox River to Grassy Island in Green Bay, pumped spoil directly to the disposal site. Construction of a possible future diked disposal site (Photo 21) was initiated in Green Bay with material dredged from the channel between Grassy Island and Long Tail Point.

Sediment samples collected from the sump in Green Bay, understandably, indicate that they are similar to the sediments dredged from Fox River. The only set of water quality data in the area of the sump was taken during disposal operations.

FWPCA in comparing data from the sump disposal site and the river concluded that, "... water quality in the sump area after the disposal of

Photo 20 Land Disposal Site at Green Bay, Wisconsin

Photo 21 Partially Completed Diked Disposal Area In Green Bay

Table 38

Sediment Comparison in Fox River [a]

Parameter	During Dredging	After Dredging
Total solids %	13.0	42.5
Volatile solids %	23.7	8.0
Oil and grease	46.2	11.3
Phosphorus - Total	6.5	1.63
Phosphorus - Soluble	0.14	0.02
COD	3.00	47.6
NO_3-N	0.02	0.01
NH_3-N	1.24	0.05
Organic - N	6.58	1.48
Total - N	7.82	1.53

[a] FWPCA 1967 data, Appendix A9, Table 1, all values are in mg/g except where noted.

dredging was much worse than water quality in the river or bay channel."[1] This is verified by high concentrations of turbidity, ammonia, and suspended solids. However, significant increases at Bay Mile 1 cannot be attributed solely to the dredging operation, because the high concentrations could be influenced by a nearby sewage outfall.

According to the 1967 sampling report, there was little seepage through the dikes of the 380 acre land disposal site. Phosphorus and nitrogen levels, suspended solids and turbidity were all generally higher inside the diked area as shown in Table 39.

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[1] FWPCA, Appendix A9, p. 6.

Table 39

Green Bay Water Samples, Diked Land Disposal Site[a]

Parameter	Inside Dike		Ditch Along Dike		Ditch Across Road	
	8-17-67[b]	10-11-67[c]	8-17-67[b]	10-11-67[c]	8-17-67[b]	10-11-67[c]
Turbidity (APHA units)	24	14	1.1	12	2.5	7.7
Dissolved Solids	386	324	452	353	378	354
Suspended Solids	117	68	4	18	7	24
COD	98	65	49	71	57	40
Total Phosphorus	0.59	0.273	0.04	0.105	0.14	0.119
Sol. Phosphorus	0.18	0.123	0.03	0.04	0.04	0.032
NH3-N	5.8	0.9	0.08	0.23	0.06	0.2
NO_3-N	2.9	0.36	0.3	0.06	0.19	0.06
Organic - N	4.2	2.6	1.3	1.4	1.9	1.1

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[a] All values in mg/l, except where noted

[b] FWPCA 1967 data, Appendix A9, Table 5, (Stations 1, 2 and 3).

[c] FWPCA 1967 data, Appendix A9, Table 6, (Stations 7, 8 and 9).

Table 40 compares water and sediment quality in the sump area with the quality of the overflow from the land disposal site. Such a comparison shows the effectiveness of the disposal site in containing the dredged material from Fox River and Green Bay channel.

Table 40

Inflow and Outflow Quality at Green Bay Land Disposal Site

Parameter	Inflow Quality		Outflow Quality		
	Sediment[a]	Water[b]	7-17[c]	7-31[c]	8-17[d]
Total Solids	291	-	-	-	-
Volatile Solids	153	-	-	-	-
Dissolved Solids	-	260	351	345	406
Suspended Solids	-	2,088	22	16	92
NH_3 - N	0.469	3.6	5.5	3.55	6.9
NO_3 - N	0.09	0.19	6.1	0.82	1.9
Organic - N	3.526	-	1.7	2.3	6.1
Total Phosphorus	1.165	2.41	0.15	0.21	0.72
Sol. Phosphorus	0.078	0.07	0.11	0.16	0.18
COD	167.4	-	64	67.5	107
Turbidity (ALPH units)	-	740	2.7	4.3	9.0

[a] FWPCA 1967 data, Appendix A9, Table 3, all values in mg/g (dry weight) except where noted.

[b] FWPCA 1967 data, Appendix A9, Table 2, all values in mg/l except where noted.

[c] FWPCA 1967 data, Appendix A9, Table 4, all values in mg/l except where noted.

[d] FWPCA 1967 data, Appendix A9, Table 5, all values in mg/l except where noted.

Since a hydraulic dredge removed the sediments from the sump area to the land disposal area, many of the suspended solids in the water in the sump area are transferred to the disposal site. Low suspended solids in the effluent from the land diked area are measures of its effectiveness. The diked area is also effective in reducing total phosphorus probably because they become attached to the suspended particles that settle out in the diked area. Since the quality of the water receiving the discharge from the outflow pipe of the diked area was not determined, the effects of the discharge cannot be ascertained. In summary, it can be said that the land disposal site at Atkinson Marsh is an effective means of disposal for dredgings from Fox River and Green Bay channel.

CONTROL MEASURES

7.1 Introduction

This section is concerned with methods of managing dredging and disposal operations to improve lake water quality and estimating the additional costs that would be incurred. Discussion and evaluation of benefits that would accrue are discussed in Section 8.

The best control of pollution is at the source. Regulatory agencies are engaged presently in a concerted effort to require municipalities and industries to treat their wastewaters more intensively to decrease their pollutants. Control of land erosion, which could reduce the contribution of agricultural pollution, is discussed in Section 7.2.

Control at the source, whether municipal, industrial, or agricultural, will require time and funds. Estimates of how soon control measures at the source will result in the reduction of pollutants to an amount equal to the natural assimilation capacity of the receiving waters is only conjecture. However, some definite period must be assumed for the purpose of estimating costs of other, more immediate control measures. It was assumed for the purposes of the present report that 10 years will elapse before control of pollution at the source will result in sediments clean enough, in the opinion of knowledgeable observers, to be deposited in open lake waters without detriment to water quality.

Alternate disposal methods considered include: (1) alteration in equipment and procedures used in connection with open lake disposal, discussed in Section 7.3; (2) treatment of dredged materials to remove or stabilize pollutants to a degree that the sediments could be deposited into open lake disposal areas, discussed in Section 7.4; and (3) disposal of dredgings in diked disposal areas, covered in Section 7.5.

7.2 Control of Upstream Areas

Most of the sediment deposited in existing harbor and channel projects originates from land erosion. Thus, a method of reducing pollution loadings is to control the rate of erosion and subsequent supply of sediment from upstream sources. Natural factors of climate, geology, and topography influence the rates of sediment production, but it appears that the controlling factor is man's use of the land.

The U. S. Department of Agriculture has made some erosion control studies in the Great Lakes, one of which resulted in a streambank stabilization project on the Buffalo River upstream from the navigation area. After completion of the project, there was a 40 percent reduction in maintenance dredging in the river. It is believed that the bank stabilization program resulted in this reduction in dredging volume.

Unfortunately, no other reductions in dredging volumes have been indentified as possibly resulting from soil conservation measures in the Great Lakes region. This is probably because the current control measures have been implemented only for small watersheds. While several small measures have been implemented for the Maumee River Basin, no corresponding reduction in dredging volume has occurred. Implementation on a large scale is expected to be a costly and time-consuming undertaking.

The Great Lakes Basin Commission is developing a study of sedimentation and erosion problems in the Great Lakes, and the U. S. Department of Agriculture is continuing to provide erosion control measures whenever possible. However, during the 10-year period assumed in the present study for the need of alternate disposal practices, it is anticipated that there will not be any pronounced decrease in sediment loads to harbors.

7.3 Modification of Dredging Practices

7.3.1 General

Consideration was given to the feasibility and economics of modifying both dredging procedures and the dredging plant in order to minimize any pollutional effects that may be attributed to dredging operations. Descriptions of the principal types of dredging plant in use on the Great Lakes and modes of operation are contained in Section 4.2. More detailed descriptions of plant operations are included in Section 6.4.1.2. Studies of hopper dredge modifications made by the Marine Design Division, Philadelphia District, Corps of Engineers, are summarized in the following sections.

7.3.2 Dredge Modifications

7.3.2.1 Overflow Closure Structures

Spillage of dredgings from a loaded hopper dredge often occurs during the trip to open lake disposal areas. The pitch and roll of the vessel causes a portion of the hopper contents to spill through the open overflow discharge pipe. The Philadelphia District designed a temporary closure structure for the MARKHAM class hopper dredge. To prevent discharge, a gate valve would be installed in the entrance of the discharge pipe. It was estimated that the cost of the installation would be about $4,600. A similar problem exists on the LYMAN class dredge. The original equipment for this class vessel included a one-foot high weir gate which was used to increase the capacity of the hoppers. During modification of the hoppers a number of years ago, the weir gate was removed. It could be reinstalled at costs similar to those discussed above for the MARKHAM class.

7.3.2.2 Deep Disposal Method

Consideration was given to modifying the MARKHAM to reduce surface effects in the disposal area by discharging the dredgings at least 45 feet below the water surface. Philadelphia District designed a temporary "jury rig" structure to test the feasibility of the plan. A 24-inch diameter piping system could be installed in lieu of the existing starboard shore pumpout connection (figure 26). A 65-foot section of piping could be lowered with a cargo boom after the vessel had come to a complete stop in the open lake disposal area. Spoil could be pumped from the hoppers while the vessel was stationary. The estimated cost of installing the temporary structure was $28,000. Additional operating costs for using this method would be $0.06 per cubic yard.

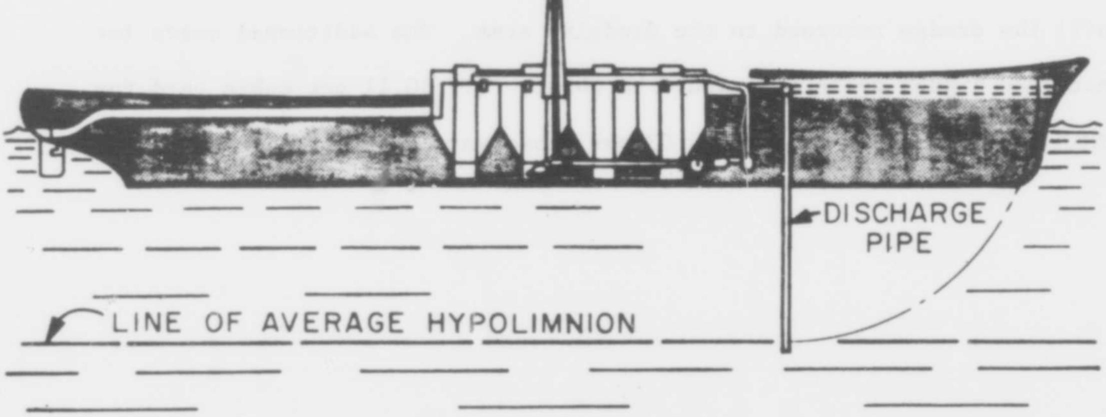

Figure 26 Piping Modification for Deep Disposal

7.3.2.3 Stationary Disposal

Disposal of dredgings from hopper dredges in open lake areas normally is accomplished while the vessel is in motion. To reduce surface effects, consideration was given to stopping the dredge before discharging the dredgings. Tests were conducted on the dredge LYMAN during maintenance dredging operations at Rochester and Buffalo in 1968. Aerial photographs and water samples were taken to determine the effects of stationary disposal (Photo 22) compared with disposal while the dredge was underway (see Photo 9 following page 6.52). Stationary disposal reduces the extent of surface effects; but the dredge is required to remain stationary for a period of time or move very slowly as it leaves the area. Further, stationary disposal does not eliminate the need for washout, and this would become the major source of surface effects (see Photo 10 following page 6.52). Accordingly, the washout would have to be delayed until the dredge returned to the dredging area. The additional costs for increased dredge cycle time would be about: (1) $0.11 per cubic yard for LYMAN class dredges; and (2) $0.03 per cubic yard for the MARKHAM.

Photo 22 Stationary Open Lake Disposal by Hopper Dredge

7.3.2.4 Reduced Dredge Loadings

The normal dredging procedure with hopper dredges is to continue loading for a short time after the hoppers are filled initially. As indicated previously, this procedure increases the volume of dredged sediments that can be contained in the dredge, but it also causes some of the dredgings to be discharged back into the waters behind the dredge. It was estimated that the increase in the cost of dredging without overflow would average about $0.05 per cubic yard, but it could be as much as $0.12 per cubic yard for projects where the disposal site is a long distance from the dredging area.

While dredging Saginaw Bay, the pumping speed of the MARKHAM was reduced after the hoppers were filled initially. The solids content of the overflow mixture was reduced from 18 to 12 percent by weight with no appreciable change in the cost of dredging. Similar tests were performed at Buffalo with the dredge LYMAN, but the overflow solids content remained essentially the same as in the normal overflow. Additional tests would be required to determine the effects associated with the reduced pumping speed.

7.3.3 Scow Modification

Recent modifications to dipper and clamshell dredging practices include the requirement that (1) scow pocket doors be fitted tightly to prevent leakage; (2) material spilled on the decks of scows during loading operations be washed off in the dredging area; and (3) free water in the scow pockets be spilled in the dredging area if it approaches the top of the scow pocket. To aid in the measurement of quantities dredged and to prevent spillage while moving to the disposal area, scows were leveled or trimmed before leaving the dredge. The above practices are expected to minimize surface effects from scows.

7.4 Treatment of Dredgings

7.4.1 General

This section of the present report turns to a consideration of the feasibility and economics of treating dredgings by conventional waste treatment methods: (1) on board a dredging plant prior to in-lake discharge of spoil; (2) in local sewage treatment works, after pumping slurries into their sewers; and (3) in separate on-shore treatment plants at or near the harbor. The Metropolitan Sanitary District of Greater Chicago provided information on (2) above by cooperating in a trial injection of dredged materials into available sewer lines. Further, the consulting engineering firm of Nebolsine, Toth, McPhee Associates made feasibility studies and cost estimates for separate treatment facilities. Moreover, a portable 3,000 g.p.h. water treatment plant was borrowed from the Army Mobility Command for trial runs of treating the effluent from diked disposal areas at Cleveland, Ohio, and Buffalo, New York, and a full scale test of flocculation of the effluent from a diked disposal area at Toledo, Ohio, was performed by Dow Chemical Corporation.

7.4.2 Use of Existing Sewage Treatment Facilities

The wastewater flows of separate sewerage systems normally contain less than one percent solids. The concentration of combined wastewater flows and industrial wastewaters may run higher or lower. In order to flow at the common gradients of existing municipal sewerage systems, dredgings would have to be slurried to very thin consistency. Assuming that it might be necessary to slurry dredgings to 0.5 percent solids by weight, even a 100,000 cubic yard operation spread over a year would equal acceptance of the sewage flow from about 70,000 people. Most existing systems do not have that much spare capacity except during off-peak hours at night. Dredging or the discharge of stored dredgings, therefore, would have to be scheduled accordingly. In practice, the Great Lakes harbors are usually dredged at rates ranging up to about 30,000 cubic yards per day, depending on the size and capacity of the assigned dredging equipment. The small hopper dredges of the Corps remove about 10,000 cubic yards of sediments per day. A 0.5 percent slurry of this volume of dredgings equals a sewage flow of about 2.5 million people even when it is discharged throughout the day. It follows that use of existing sewage treatment works would have to be restricted to projects in which small-sized dredging equipment can deliver its loads to exceptionally large sewage systems.

A three-phase trial operation was conducted at Chicago in September 1968. The first phase of the operation was undertaken at the Racine Avenue Pumping Station. A clamshell excavation, operating from the bank, removed approximately 230 cubic yards of sediments from "Bubbly Creek" in the South Fork of the South Branch of the Chicago River. This phase proved inconclusive because the dredgings were not slurried and the volume was insignificant. An eight inch hydraulic dredge was used for the second phase of the operation. A total of 6,788 cubic yards were removed by this means and deposited directly into a manhole in an interceptor sewer southwest of the pumping station. Most of the solids from this phase of the operation were removed in the primary and secondary treatment process of the Southwest Sewage Treatment Plant, very few of them were removed in the grit chamber.

The third phase of the operation utilized dredgings from the North Branch of the Chicago River. Approximately 2,500 cubic yards of sediments were removed by the same hydraulic dredge used before. The dredgings were processed through the West Side Sewage Treatment Plant. Again, no increase in grit production was evident.

The results of the operation showed that: (1) transportation of the dredgings through sewers was feasible; (2) using a hydraulic dredge or introducing the dredgings in the form of a slurry had no adverse effects on the interceptor system; (3) only small amounts of the dredgings were deposited in the grit chambers, with most of them being treated in the other primary and secondary processes; and (4) disposal costs would be very high, varying from $8.90 per cubic yard in phase three to $16.90 per cubic yard in phase two. It was concluded that the acceptance of the dredgings depends upon the weather and the availability of the disposal equipment, which has an estimated surplus capacity of only 150 tons of solids per day. Accordingly, it would be necessary to store the solids from the short-term dredging period for disposal throughout the year.

It appears that dredgings cannot be accepted on a continual basis even at treatment works as large as the Chicago system. Rather, they must be taken only when conditions allow and must be stored at other times. Even then, the over-all costs of disposal by this method would range from $9 to $17 per cubic yard of dredgings. This method is prohibitive in cost compared to other alternate methods investigated, and is not considered further in the present report. The full report on the test at the treatment plant of the Metropolitan Sanitary District of Greater Chicago is contained in Appendix C7.

7.4.3.1 General

During the study of treatment processes for the dredgings, it became evident that the material would have to be stored on dry land for some time prior to treatment. The storage areas would serve as surge basins as the treatment rate would be constant, while the feed from the dredges would be intermittant and at varying rates.

The storage areas and treatment processes raise three problems: (1) reduction of the suspended solids in the water to a minimum; (2) separation of the larger sized particles from the finer particles; and (3) treatment of the finer particles to a form that will make them acceptable for use as a stable fill or for disposal in the open lake. In the first problem, the dredging operations ultimately have to dilute the solids to a 10 to 20% concentration (dry solids by weight). The hopper dredges are required to do this in order to pump the dredgings from their hoppers to the storage areas. The clamshell type dredges would not normally require the dilution of the excavated material, but in order to unload the scows to the storage areas, the only feasible way that will minimize pollution of the adjacent harbor waters is to use a hydraulic dredge taking suction inside the scow. To dilute the dredgings requires a large volume of water. When the slurry is allowed to stand for a period of days, the heavier solids settle and compact. The water remaining contains light suspended particles. To keep the storage area to a minimum size, the water that separates from the solids should be discharged back to the adjacent harbor waters. Before this can be done, the suspended solids in the water will have to be reduced to a minimum.

The solids removed from the harbor bottoms are made up of particles ranging in sizes from 4 to 5 inch pieces of broken concrete to fine clay and silt particles. The larger particles down to fine sand (100 microns) are generally inert and could be used as a clean stable fill or deposited on the lake bottom without causing pollution. The separation of these larger inert particles from the finer particles is the second problem.

After the larger inert particles are removed from the dredgings, the remaining smaller particles will have to be treated before they can be considered acceptable for stable fill or for deposit on the bottom of the Lakes. These smaller particles contain volatile solids, oxygen demanding solids, bio-degradable solids, oils and greases and phosphorus compounds. The treating of these solids to a form that will make them acceptable for use as stable fill or for depositing on the bottom of the Lakes is the third problem.

Each of the three basic aforementioned problems contains the associated factors of storage of dredged materials, rehandling of the materials, pumping of slurries, and handling of treated water and solids.

Five different treatment methods were considered. For each of these, the basic flow pattern was found to be the same. The following assumptions were made: Wherever economically feasible, the large particles would be separated and washed as the dredgings were being pumped from the dredges and scows. The larger, relatively clean, particles would be discharged to scows for hauling to designated disposal sites, while the slurry containing the smaller particles would be discharged to a diked storage area. The water separated from the slurry would be treated for removal of suspended solids in sufficient degree to permit the effluent water to be discharged to the adjacent harbor. Then, the thickened solids would be extracted from the storage area and treated for reduction of contaminants. The treated solids would be handled and transported to scows for hauling to designated disposal areas. The water separated from the treated solids would be treated to remove excess suspended solids and biochemical oxygen demand.

It was convenient to break down the operation into the following units:

(1) Separating and disposing of relatively clean dredged sand, gravel and larger particles from the dredgings during their discharges at the treatment site;

(2) Accumulating and storing the smaller particles;

(3) Rehandling the smaller particles for treatment;

(4) Treating the smaller particles by:

  (a) Aerobic stabilization,

  (b) Anaerobic stabilization,

  (c) Chemical stabilization,

  (d) Wet-oxidization,

  (e) Incineration;

(5) Treating the contaminated water fractions of the dredgings in process (2) above and the waters separated in the course of treatment; and

(6) Dewatering and handling the treated solids up to the point of transporting them to the disposal areas.

By combining (2), (3), (5), and (6) with one of the treatment operations under (4), a complete treatment process can be established.

7.4.3.2 Basic Assumptions

In the absence of full information on the characteristics of the harbor sediments to be treated, the sampling and testing data developed by the University of Wisconsin were assumed to be sufficiently representative for a first study of treatment methods and costs. About 100 samples, therefore, were assumed to represent the millions of cubic yards of maintenance dredgings.

In the unit operations studies, average conditions were assumed to govern the design. Since the purpose of this investigation was to identify workable treatment processes and their capital and operating costs, it may be assumed that, in spite of their recognized limitations, the results obtained do represent feasible solutions. Considered by themselves, the costs shown are good estimates for the assumed conditions. Average conditions were as follows:

(a) A cubic yard of dredgings contains 1,250 pounds of dry solids.

(b) The dry solids contain 15 percent by weight of particles exceeding 70 microns in size.

(c) The volatile solids comprise 10 percent of the weight of the total solids on a dry basis.

(d) After removal of particles larger than 70 microns in size (sand and gravel-sized particles), the dredgings can be thickened by storage to a concentration of 45 percent solids.

(e) Silt- and clay-sized dredgings have a heat value of 1,850 British thermal units per pound of dry solids.

The quality standards that the effluents and slurries must meet are governed by the method of their disposal, which, in turn, governs the selection of the design processes themselves. For the purposes of this investigation, it has been assumed that the sludges or slurries produced must be biologically stable and that, once stabilized, these sludges are acceptable for disposal. At the same time, it is recognized that the treatment processes may produce effluents of different quality. More specifically, it is assumed that: (1) biological treatment will satisfy needed oxygen requirements and destroy bio-degradable volatile solids in sufficient degree to leave an essentially inert residue; (2) chemical treatment will destroy or inactivate the solids reacting with the chemicals applied; (3) wet oxidation will destroy most of the volatile solids but put some biodegradable substances into solution; and (4) incineration will effectively destroy all volatile matter and produce an inert, dry residue or ash. Cost factors must be related not only to the effectiveness of the treatment process, but also to the ease of disposing of the solids produced and the requirements governing their disposal. In the absence of reliable information on ways and means for the removal of inorganic nutrients, such as phosphates, from sludges, slurries, effluents or overflows, the possible need to remove such nutrients was not included in cost estimates.

7.4.3.3 Advantages and Disadvantages of Unit Operations.

(a) Size-separation of Particles.

This unit operation reduces the volume and weight of dredgings to be stored and treated. The associated relative benefit will vary from harbor to harbor depending on the quantity of removable particles sized larger than 70 microns. The cost of separation of specific sludges or slurries must be weighed against the cost of treating the total dredgings.

A disadvantage of size separation may be the inclusion of some volatiles with the larger solids. These solids, too, may therefore have to be treated before discharge. The applicable method of treatment will depend upon the nature and concentration of the volatile matter retained in the solids.

(b) Storing and Handling Dredgings

This essential operation acts as a buffer between a relatively short and possibly erratic cycle time of dredging and an effectively long and relatively stable treatment cycle time. Its advantages are, therefore, accepted as essential for success.

(c) Treatment of Separated Waters

Like the storing and handling of dredgings, this is also an operational step that is essential for success.

(d) Anaerobic Stablilzation

This unit operation can be extended over a full annual cycle of 365 days. However, it requires a relatively large land area and, because it is a biological process, may be upset by toxic substances. Treatment units may take the form of anaerobic stabilization ponds or of digestion tanks. Overflowing liquors must receive suitable treatment before they are discharged to receiving waters.

(e) Aerobic Stabilization

The advantages and disadvantages of this biological treatment process are much like those encountered in anaerobic stabilization. Treatment units, however, normally take the form of shallow diked areas or ponds only. If freezing weather must be avoided, the treatment period may have to be shortened to about eight months in the Great Lakes region, unless it is possible to operate the ponds as aerobic systems during warm weather and anaerobic systems during cold weather.

(f) Chemical Stabilization

The control of chemical treatment processes ordinarily is simpler than that of biological treatment processes. Land requirements are normally less than for biological treatment. The water fraction of chemical slurries may be larger than that of biological sludges. It, too, may have to be treated before discharge.

(g) Wet Oxidation

Fundamentally, this process is not unlike a chemical oxidation process. Separated liquor normally requires biological treatment.

(h) Fluid Bed Incineration

Except for the possible inclusion of phosphates, this process produces an inert residue. For maximum efficiency, the applied solids must be as dry as possible. Solids concentration by mechanical means may be required.

(i) Multi-hearth Incineration

This process is similar to fluid bed incineration.

(j) Disposal of Treated Solids

All of the operations share this requirement, but in degrees varying with the nature of the residues and their water (or solids) content.

7.4.3.4 Estimates of Costs

Capital and operating costs for each treatment process as well as more detailed data on the units are included in the report of the engineering consultants attached to the present report as Appendix C6. Multi-hearth incineration was found to be the most economical treatment process studied, provided the dredged material after removal of its larger particles could be thickened to 45 percent solids as it is fed into the incinerator. Costs increase rapidly with reduction in the percentage of solids. Next in economy appears to be aerobic stabilization.

For 0.5 million cubic yards of dredgings with 45 percent total solids and 10 percent volatile solids, the difference in cost between multi-hearth incineration and aerobic stabilization is estimated to be 10 percent. The accuracy of the cost estimates is not believed to be good enough to remove all doubt that multi-hearth treatment is actually the least expensive treatment system. Pertinent information for annual dredgings of about 100,000 cubic yards up to about 1,500,000 cubic yards is presented in Figure 27.

For the puroses of the present report it is assumed that a 45 percent concentration of solids can be attained. The resulting costs of multi-hearth treatment are then made the basis of comparison with other methods of disposal of dredgings.

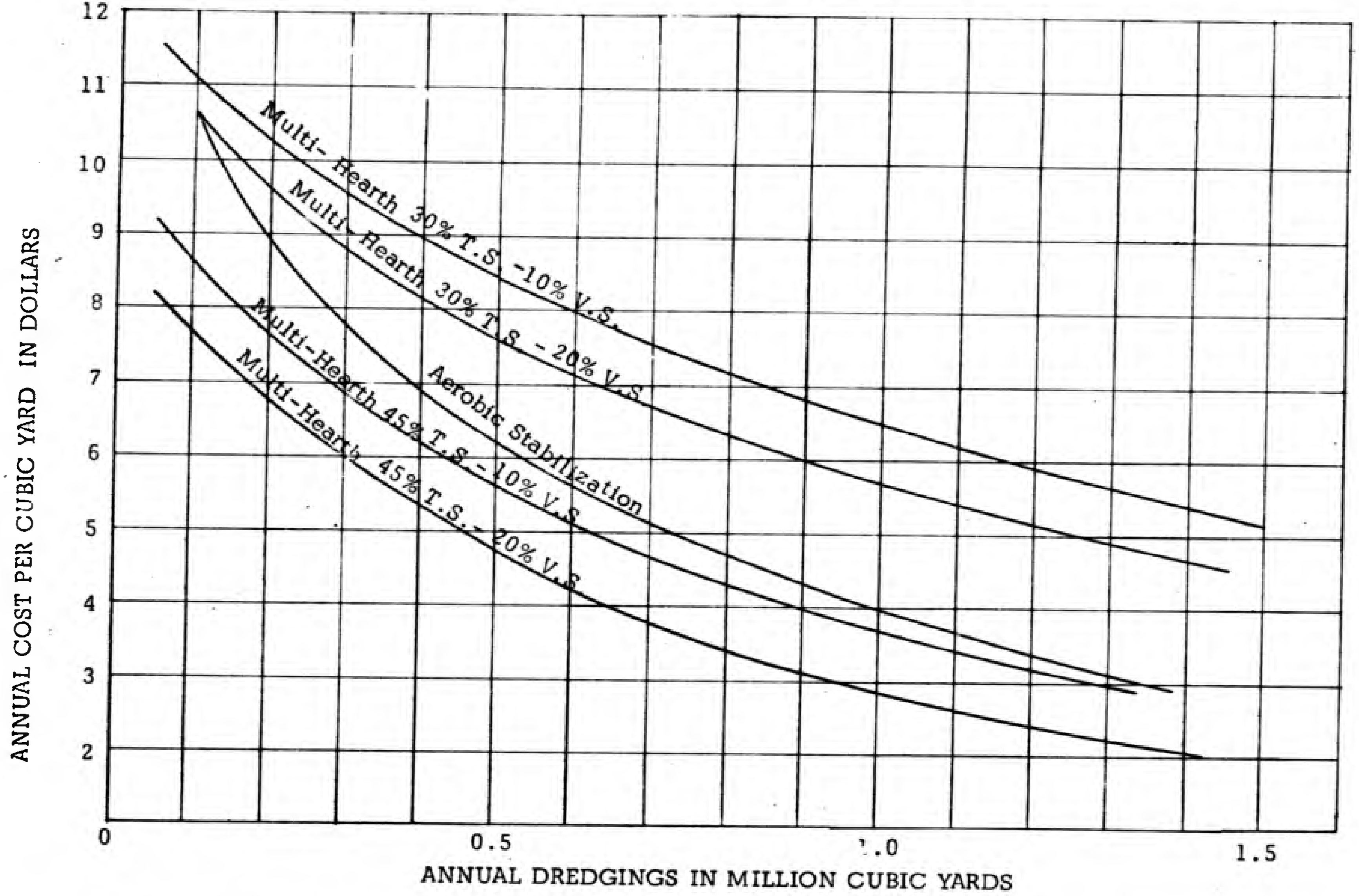

Figure 27 Total Annual Cost Per Cubic Yard for Complete Treatment Using Multi-hearth Incineration & Aerobic Stabilization

7.4.4 Mobile Treatment Unit

A mobile 3,000 g.p.h. water treatment plant was operated at Cleveland and Buffalo to study the feasibility of treating the effluent from diked disposal areas. Only a small fraction of the effluent could be treated by this small unit. Four procedures were employed: (1) coagulation, filtration, and disinfection; (2) coagulation only; (3) coagulation and filtration only; and (4) filtration only. The truck-mounted treatment plant consisted of a combination mixing and sedimentation basin, and a diatomaceous-earth pressure filter. Ferric chloride was the coagulant, lime provided pH control, and calcium hypochlorite was the disinfectant.

The water treatment unit gave good results. Coagulation and sedimentation were most effective in removing turbidity and bacteria. Polishing by filtration and disinfection produced a bacteriologically safe water. The indication was that treatment of effluent, where required, could be limited to coagulation.

No cost estimates were made for this type of equipment. Coagulation, if required, would be by fixed in-place facilities discussed in Section 7.4.6.

7.4.5 On-board Treatment of Dredgings

7.4.5.1 General

Space requirements for complete treatment equipment preclude its on-board use or its assignment to auxiliary accompanying vessels. Among the possibilities of partial treatment methods requiring a limited amount of space, the following were considered for hopper dredges: (1) aeration; (2) flocculation; and (3) chlorination. Hopper dredges normally dispose of dredgings in the open lake, but pumping into diked areas appears to be becoming a more frequent and common practice. Treatment of the pipeline discharge of dredgings into diked areas is discussed in Section 7.4.3 of the present report. The treatment processes listed above are discussed in the following sections.

7.4.5.2 Aeration

During dredging and the transport of dredgings to lake disposal sites, air can be introduced into the dredgings from compressed air outlets in the hoppers. In both instances, the time available was considered too short to be effective. Accordingly, no estimates of capital or operating costs were made.

7.4.5.3 Flocculation

Dow Chemical Corporation was engaged to treat dredgings on board the hopper dredge MARKHAM during maintenance dredging at Saginaw Bay, Michigan. The ability of Dow polyelectrolyte flocculants to induce fines and contaminants in the dredge discharge to settle rapidly was to be tested.

Two Dow chemicals were submitted to field trials. Their introduction into the intake pipes of the dredge prior to their discharge into the hoppers did not result in successful flocculation. Spraying the chemicals directly into the hoppers during filling was also unsatisfactory. However, application of the chemicals from a perforated two-inch pipe above the overflow discharge trough produced flocculation in the outflow pipe and in Saginaw Bay. In eighteen sampling runs on treated and untreated overflows, there was a definite improvement in the settling characteristics of the solids when the Dow polymers were applied. Optimum concentrations of flocculants were estimated at 8 mg/l for Separan AP-273 and 35 mg/l for Purifloc C-31.

After 15 minutes of settling, residual suspended solids and turbidities in Saginaw Bay were as much as five times smaller with flocculation as without it. Improved ortho-phosphate and BOD reductions were also noted. Because the concentration of coliform bacteria in the overflow was small, no measurable reduction could be established.

The cost of chemicals for treating the overflow which contained approximately 10 percent solids lay in the vicinity of 9.0¢ per 1,000 gallons. This corresponds to $0.02 per cubic yard dredged.

Laboratory companies showed that settling rates were higher with polyelectrolytes than with common Fe+3 and Al+3 coagulants. Iron and aluminum salts produced poor flocs unless massive doses were applied.

Flocculation caused the fine particles in the discharge from the dredge to settle rapidly. Nevertheless, the dredges still left a trail - although not as persistent a trail - of turbid water behind. Improvement in the BOD and orthophosphate content of water samples was probably due to a rapid reduction in their suspended solids concentration by sedimentation. The full report on the experimental treatment is contained in Appendix C3.

7.4.5.4 Chlorination

Organic and other unstable substances in dredgings are quickly oxidized by chlorine. Rapid stirring of the chlorinated dredgings can reduce the required detention time substantially. Chlorine is normally applied as 'liquid chlorine." A reactor considered and investigated for a separate shore-based treatment plant produces an improved slurry, but it also produces a water fraction that will require further treatment before it becomes acceptable for discharge. Although partial treatment might be useful, the space requirements of reactors of the type tested, together with their chlorine supply, are too large for use on board a dredge, because, among other things, the dredgings would have to be treated at the rate at which they are pumped. However, storage and use of liquid chlorine in the quantities required would constitute a serious, indeed an unacceptable, hazard. Safer forms of chlorine are available but would require still more storage space and a longer contact or reaction time.

7.4.6 Treatment at Diked Disposal Areas

No treatment of sediments in diked disposal areas has been considered. Treatment of supernatant prior to discharge back into waterways, however, may be necessary. As indicated in Section 7.4.4, treatment of supernatant could be limited to coagulation.

Dow Chemical Corporation was engaged to make a full scale field test at the Maumee River diked disposal area using the same chemicals as for the earlier tests on board the dredge MARKHAM.

The 30-acre Riverside spoil area (see Figure 31) was used for the field test. A two-acre corner was diked off to form a clarification pond. Supernatant from the main area was discharged into the clarification pond through a 250-foot long corrugated metal trough in which the chemicals were added.

Before running the field test, many laboratory tests were run with different coagulants and aids and with a wide range of suspended solids. It was found that the flocculation was most effective with Purifloc C-31 when suspended solids were at a concentration of about 8,000 mg/l and very good at concentrations up to 20,000 mg/l. Above this level, the effectiveness decreased rapidly. Below the 8,000 mg/l level, effectiveness decreased also, but the addition of ferric chloride improved the flocculation. Ferric chloride alone was effective also, but produced a weak, light floc which settled slowly. At low concentrations of suspended solids, a combination of ferric chloride and Purifloc C-31 proved to be best.

The concentration of suspended solids in the water discharged into the coagulation pond was only 60 mg/l during the 48-hour field test at the disposal area. Chemicals used were 33 mg/l of ferric chloride and 7.5 mg/l of Purifloc C-31.

Suspended solids were reduced to as little as 10 mg/l; phosphates decreased from 0.16 to 0.10 mg/l; coliform count dropped from 14,700 to 9,000 per 100 ml; and chemical oxygen demand and dissolved oxygen increased slightly. The cost of chemicals used was $0.01 per cubic yard of dredging.

Dow Chemical Corporation believes that the concentration of suspended solids was too low for an optimum test. Actually, there should be little need for coagulation with so low a level of suspended solids. With higher concentrations, it is probable that the ferric chloride could be eliminated and the same results could be obtained using the same amount of polymer.

The complete report of the Dow tests is given in Appendix C4.

7.5 Diked Disposal Areas

7.5.1 General

Only rarely in the past have dredgings been discharged into diked disposal areas. Where this has been done, it has been confined almost exclusively to new-work dredging and pipeline dredges. Examples of exceptions are: (1) the maintenance dredging of the Maumee River, where the distance to a suitable disposal site in Lake Erie was so great that the dredgings were pumped to a nearby diked area as an economy measure; and (2) the maintenance dredging of the Rouge River where, because of the possible pollution of the Wyandotte water intake by the disposal of Rouge River dredgings into the Detroit River, a diked area was constructed on Grassy Island in the Detroit River for containment of these dredgings.

The hopper dredge HAINS was converted for pump-out of its hoppers and used at Grassy Island for the first time in 1960. The hopper dredge MARKHAM, under construction at that time, was designed with pump-out facilities. The dredge was commissioned in 1960 and used its pump-out facilities for the first time in 1961 on the Maumee River. Since then all maintenance dredgings of the Rouge River have been discharged onto Grassy Island, and the maintenance dredgings of the Maumee River and of a portion of the Maumee Bay channel have been disposed of into diked areas along the Maumee River and in a diked area in Maumee Bay.

In 1966, the City of Green Bay constructed a diked area on shore for industrial development. Both new-work dredgings and maintenance dredgings of the Fox River were deposited in this area in 1967, but the city has reservations about accepting maintenance dredgings in the future.

In studies for the present report and in the interest of (1) acquiring experience in transferring materials from scows to diked areas, and (2) determining the effectiveness of pollutant retention, it was decided to construct experimental diked areas as follows: an on-shore diked area along the Calumet River at Chicago, an along-shore diked area in Cleveland Outer Harbor, and an along-shore diked area in Buffalo Outer Harbor. Also studied was the operation of existing diked areas at Grassy Island, Maumee River and Bay, Green Bay, and Indiana Harbor. The last-named area was owned by Inland Steel Corporation. Results of these operations are reported in Section 6 of the present report.

In addition, the Buffalo, Chicago, and Detroit Districts of the Corps made surveys of as many of the polluted harbors on the Great Lakes as possible within manpower resources with a view to locating all available sites for diked disposal areas. A separate report of each locality surveyed is included as an appendix to the present report. A discussion of the findings of these surveys is given in the sections that follow.

7.5.2 Interim Program for Diked Disposal Areas

Pending completion of the present study and necessary Congressional action to approve and appropriate funds for implementing the resulting program, Congress appropriated a sum of $5,400,000 for an interim program of constructing diked disposal areas for the most polluted dredgings. It was recognized at the time that a procedure other than disposal within diked inclosures might offer a better long-term solution. The interim program, to the extent permitted by the appropriated funds, was to build diked areas to hold two to four years of spoil at harbors the FWPCA considered highly polluted. Under this program, construction of a diked area was started in the fall of 1968 at Cleveland, Ohio, and a diked area was planned for early construction at Buffalo, New York. These areas were in addition to the pilot areas used for testing purposes at those localities in 1967 and 1968. Also, funds were earmarked for further development of diked areas to contain polluted spoil dredged from Indiana Harbor, Indiana; Calumet River and Harbor, Illinois; and Green Bay Harbor, Wisconsin. It was planned to continue the use of existing diked areas for containment of spoil dredged from Toledo Harbor, Ohio, and Rouge River, Michigan, and to enlarge them if necessary. In November, 1968, the Bureau of the Budget took the position that no additional diked disposal areas or enlargements of existing areas should be initiated until the present report became available for review by them. Accordingly, only the diked area at Cleveland, which was started and well under way at the time, will be constructed. A diked area provided by the City of Monroe, Michigan will be used for dredgings from Monroe Harbor.

7.5.3. Surveys of Diked Disposal Areas

7.5.3.1 Scope

To the extent permitted by manpower limitations, surveys were made at most of the harbor and channel projects in the Great Lakes at which dredged materials were classed as polluted by FWPCA. Local officials and planning commissions were expected to provide information on projects that could beneficially use maintenance dredgings as fill and, in the absence of such projects, to assist in locating suitable land areas for spoil in the proximity of projects. Response from local officials and property owners was generally negative because they felt dredgings provided poor construction fill and produced odor nuisances. Promising undeveloped or lightly farmed areas were located, but most of their owners were either not interested or strongly opposed to the use of dredgings for landfills. For the purposes of the surveys, these lands were nevertheless considered possible sites and rough appraisals were made of the cost of acquiring the lands by condemnation.

Estimates of the cost of constructing the needed dikes and transporting the dredgings to the disposal sites were made for the more promising sites. For other possible sites, the reasons for dispensing with cost estimates were noted. All estimates are based on 1968 price levels.

Effluent treatment was not considered even though some reduction of suspended solids in the effluent may be required where and when diked areas can store no more than one or two years of dredings. Treatment probably would be limited to flocculation.

Pipeline transport of dredgings was considered where the volume pumped was sufficient to be more economical than truck and rail haul.

Only low-pressure pumping was considered because the techniques for high-pressure pumping are not yet sufficiently well developed to permit reasonably accurate cost estimates. High-pressure transport of dredgings is being studied by the Bechtel Corporation under a contract with FWPCA, in which it is assumed that dredged materials and other waste products are to be pumped from Cleveland to a distant inland area. The study has not progressed far enough to permit inclusion of its findings in the present report.

Surveys have not considered transport by conveyor belts because dredgings are normally too liquid for use of such equipment.

Each survey considered the specific locality by itself, although there might be savings by joint uses of transportation facilities.

Benefits of filled areas, whether inland or offshore, were not estimated. Maintenance dredgings consist principally of silts and clays interspersed with varying amounts of organic matter. The resulting mixture has a high water-retention capacity and may take many years to consolidate fully. In the Grassy Island and Maumee Bay spoil areas, even materials placed in the early 1960's still held much moisture and had low shear strengths in 1968. In addition, the fills still contain considerable quantities of organic matter and intermittent loose sandy layers of variable thicknesses. For the purposes of the present study, it has been assumed that fills of this kind, while satisfactory for park land or agricultural use, can be stabilized only at much expense either by costly stabilization, excavation and introduction of suitable foundation material under loads, or by driving piles into underlying soils.

Many areas considered for fill are swampy or marshy. Conservation interests would probably object to filling such areas when they lie on known flyways even though the owners of the lands would like to have their present properties filled.

The individual surveys included in the present report compare the various sites only in terms of the cost of their development. For full evaluation, beneficial uses of the filled areas and extinction of conservation values must be included in appraisals.

7.5.3.2 Results of Surveys

Survey reports are included in Appendices K, L, and M. Listed in Table 41 for each project studied are the estimated annual quantities of polluted maintenance dredgings, the costs of dredging and disposal at open lake sites, the estimated costs of disposal in the least costly diked disposal sites available and the estimated increase in costs that would be attributable to disposal into the diked areas. Also shown in the tabulation is the capital investment for lands, dikes, and other facilities that would have to be provided for the diked disposal. Interest on and amortization of the investment are included in the annual cost. Detailed data on diked disposal areas are given in the appendices. There follow descriptions of the most favorable diked disposal systems for each pilot area except Great Sodus Bay.

Table 41

Summary of Diked Disposal Quantities and Costs

		Average annual quantity and cost									
		Polluted maintenance dredging quantity	Cost of dredging with open lake disposal		Cost of dredging with diked disposal		Increase in cost of dredging due to diked disposal				Capital cost for diked disposal
Project	Appendix	(C.Y.)	Total ($)	Unit ($/C.Y.)	Total ($)	Unit ($/C.Y.)	Fixed[a] ($)	Operation & maintenance ($)	Total ($)	Unit ($/C.Y.)	($)
Cleveland Harbor, Ohio	K3	1,220,000	953,000	0.78	2,309,000	1.89	1,347,000	9,000	1,356,000	1.11	11,530,000
Toledo Harbor, Ohio	L13	1,120,000	353,000b	0.32	392,000	0.35	0	39,000	39,000	0.03	c
Detroit River, Mich.	L1	800,000	272,000	0.34	2,846,000	3.56	2,284,000d	290,000	2,574,000	3.22	14,971,000
Buffalo Harbor & B.R.C., N.Y.	K2	625,000	413,000	0.66	1,821,000	2.91	934,000	474,000	1,408,000	2.25	7,870,000
Saginaw Harbor, Mich.	L10	600,000	162,000	0.27	284,000e	0.47	132,000	-10,000	122,000	0.20	1,210,000
Sandusky Harbor, Ohio	K8	600,000	180,000	0.30	1,021,000	1.70	799,000	42,000	841,000	1.40	6,729,000
Fairport Harbor, Ohio	K6	400,000	148,000	0.37	600,000	1.50	240,000	212,000	452,000	1.13	2,723,000
Rochester Harbor, N.Y.	K9	360,000	162,000	0.45	709,000	1.97	277,000	270,000	547,000	1.52	2,440,000
Erie Harbor, Penn.	K5	300,000	114,000	0.38	581,000	1.94	340,000	127,000	467,000	1.56	2,870,000
Lorain Harbor, Ohio	K7	300,000	126,000	0.42	459,000	1.53	224,000	109,000	333,000	1.11	1,965,000
Rouge River, Mich.	L9	300,000	372,000b	1.24	522,000	1.74	150,000	0	150,000	0.50	1,852,000
Ashtabula Harbor, Ohio	K1	220,000	77,000	0.35	518,000	2.36	250,000	191,000	441,000	2.00	2,220,000
Calumet R. & H., Ill & Ind.	M1	200,000	500,000	2.50	785,000	3.93	f	285,000	285,000	1.43	f
Huron Harbor, Ohio	K11	200,000	44,000	0.22	572,000	2.86	362,000	166,000	528,000	2.64	3,134,000
Monroe Harbor, Mich.	L7	176,000	77,000	0.44	170,000	0.96	60,000	33,000	93,000	0.52	550,000
Indiana Harbor, Ind.	M4	151,000	332,000	2.20	422,000	2.80	56,000	34,000	90,000g	0.60	537,000
Green Bay Harbor, Wisc.	M3	137,000	137,000	1.00	555,000	4.05	0	418,000	418,000	3.05	c
Chicago River & Harbor, Ill.	M2	108,000	184,000	1.70	608,000	5.62	f	424,000	424,000	3.92	f
Conneaut Harbor, Ohio	K4	100,000	40,000	0.40	323,000	3.23	239,000	44,000	283,000	2.83	2,075,000
Harbor Beach Harbor, Mich.	L4	95,000h	106,000	1.12	412,000	4.34	272,000	34,000	306,000	3.22	1,460,000
Oswego Harbor, N.Y.	K10	80,000	26,000	0.33	272,000	3.40	197,000	49,000	246,000	3.07	1,730,000
Milwaukee Harbor, Wisc.	M8	70,000	75,000	1.07	423,000	6.05	f	348,000	348,000	4.97	f
Two Rivers, Wisc.	M12	51,000	51,000	1.00	176,000	3.45	f	125,000	125,000	2.45	f
Grand Haven Harbor, Mich.	L3	50,000	31,000	0.62	66,000	1.32	16,000	19,000	35,000	0.70	135,000
Michigan City, Ind.	M7	48,000	48,000	1.00	212,000	4.42	6,000	158,000	164,000	3.42	53,000
Manitowoc Harbor, Wisc.	M6	43,000i	43,000	1.00	199,000	4.60	15,000	141,000	156,000	3.60	108,000
Holland Harbor, Mich.	L5	40,000j	39,000	0.98	65,000	1.63	19,000	7,000	26,000	0.65	132,000
Waukegan Harbor, Ill.	M13	32,000	26,000	0.80	142,000	4.38	f	116,000	116,000	3.58	f
St. Joseph Harbor, Mich.	L12	32,000	22,000	0.68	64,000	2.00	17,000	25,000	42,000	1.31	160,000
Racine Harbor, Wisc.	M10	30,000	30,000	1.00	171,000	5.70	f	141,000	141,000	4.70	f
Kenosha Harbor, Wisc.	M5	29,000	25,000	0.86	132,000	4.55	f	107,000	107,000	3.69	f
Sheboygan Harbor, Wisc.	M11	23,000	23,000	1.00	113,000	4.90	2,000	88,000	90,000	3.90	20,000
South Haven Harbor, Mich.	L11	16,000	16,000	1.00	57,000	3.68	15,000	26,000	41,000	2.68	133,000
Frankfort Harbor, Mich.	L2	10,000k	7,000	0.66	61,000	6.12	46,000	8,000	54,000	5.40	320,000
Menominee Harbor, Mich.	M9	7,000	7,000	1.00	30,000	4.05	4,000	19,000	23,000	3.05	27,000
TOTAL		8,573,000	5,221,000		18,092,000		8,303,000	4,568,000	12,871,000		66,954,000

a Interest and amortization of capital costs.

b Present method is disposal in dike areas.

c Diked disposal area provided in connection with other projects.

d No alternate area can be made available for calendar year 1969, 1970 or 1971. Average annual figures are based on a 7 year period. About 19% of annual cost would be borne by permit dredging.

e Estimates assume lands would be made available at no cost.

f Minor cost included in operations and maintenance.

g All additional costs are in first two years and have been averaged over 10 year period. No additional costs in last 8 years.

h Based upon project restoration in 1973 and continued maintenance through 1978.

i Both harbor and river assumed polluted. Average annual quantities are based on an 8 year maintenance dredging period.

j Average for a period of 8 years. Polluted dredgings are currently being placed in a dike disposal area which has sufficient volume available for 1969 and 1970 dredgings.

k Average for a period of 8 years.

(a) Buffalo Harbor

No land areas suitable for the disposal of dredgings are available in or near Buffalo Harbor. The existing pilot area (Site #9, Figure 28) can accommodate at least one additional year's dredgings from Buffalo River. Plans are being prepared for early construction of an alongshore fill near the mouth of Buffalo River (Site #2). This area, known as "Times Beach," could hold Buffalo River dredgings for a number of years but would have no room for the polluted materials that might have to be dredged from Buffalo Outer Harbor and Black Rock Channel in 1969 and 1970.

A number of sites on the lakeside of the breakwaters (Site #1 for example) could be diked to contain the assumed ten years of maintenance dredgings. The best area (Site # 4) lies in the bay between the south entrance channel breakwater and the filled land of the Bethlehem Steel Corporation. It is part of the much larger inclosure that the corporations proposed to fill with waste slag if New York State authorities approve. A joint project for a diked area for both slag and dredgings offers obvious economies. For separate disposal of dredgings, capital costs for an inclosure holding ten years of maintenance dredgings are placed at $7,870,000. Annual costs for dredging and necessary dike and pump-out facilities are estimated at $1,821,000 or $2.91 per cubic yard against $413,000, or $0.066 per cubic yard, for the 625,000 cubic yards of annual maintenance dredging and open lake disposal.

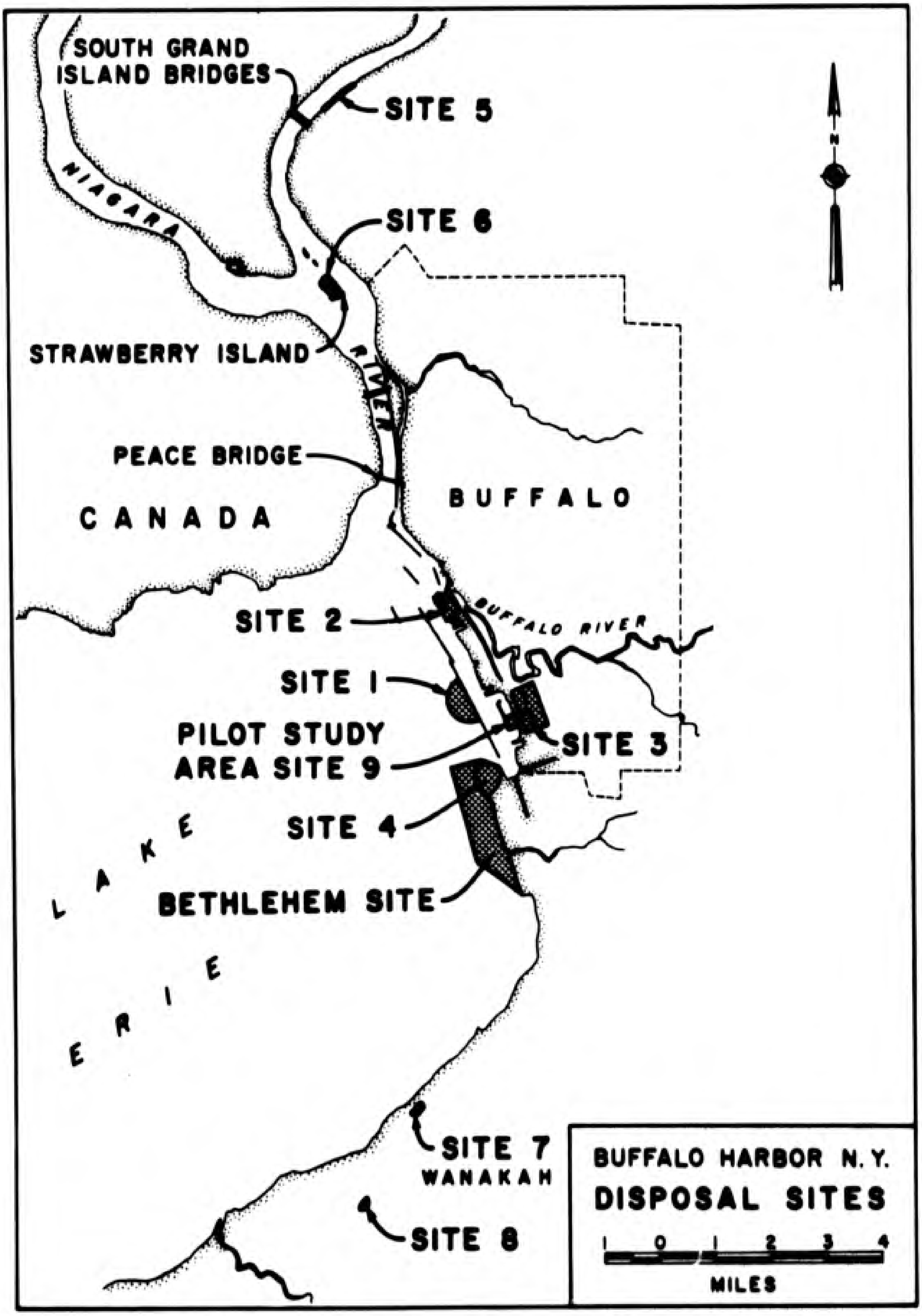

Figure 28. Alternate Disposal Sites at Buffalo Harbor, N.Y.

(b) Cleveland Harbor, Ohio

Numerous land, harbor, and lake sites were investigated at Cleveland, where a diked area (Site #9, Figure 29) is now under construction in the harbor adjacent to the pilot area (Site #13). The new diked area will hold about 2,000,000 cubic yards, an amount sufficient to contain all Cuyahoga River dredgings until other diked disposal areas could be provided.

Land areas considered lie south of Cleveland in the proximity of the river and about eight miles upstream from its mouth. However, the transport of harbor dredgings to these areas presents almost insurmountable difficulties. Consideration, therefore, has been given to excavating a settling basin in the river (Site #8, Figure 30) to trap about 550,000 cubic yards of material annually and reduce dredgings in the harbor by an equivalent amount. This material could be removed from the basin and deposited on nearby land. The spoil would be of substantially better quality than the harbor dredgings and might even provide a desirable fill. Estimated capital costs for land, equipment, and initial excavation of the basin are $3,500,000. Annual cost of $743,000 reduce to $1.35 per cubic yard. This is the least costly disposal plan so far considered, but it can take care of only 45 percent of the annual dredging at the harbor. The remainder of the harbor dredgings could be placed in diked areas of which the following compose the two best systems:

(1) Diked areas adjacent to Burke Lakefront Airport (Site #10 and #12, Figure 29). These would be extensions of the existing pilot area and the diked area now under construction. When filled, the entire system would provide the land area required for planned expansion of the airport. Because the fill would not be suitable for runway foundations, the airport administration has proposed to substitute satisfactory foundation material under runway pavements. Capital costs are placed at $7,780,000 for dikes and pump-out facilities. Annual costs of $1,566,000 reduce to $2.34 per cubic yard for the 760,000 cubic yards of

residual dredging after removing 550,000 cubic yards at the upstream settling basin.

(2) Diked area adjacent to and lakeward of the western outer breakwater, extending from the harbor entrance to the planned city sewage disposal plant (Site #2). The area will be connected to land by the construction of the disposal plant. The completed fill would provide a desirable recreation area and a start on a long-planned highway bypass around Cleveland. Capital investment is estimated at $9,950,000 for dikes and pump-out facilities; and annual costs at $1,824,000, or $2.72 per cubic yard for the estimated quantity of 670,000 cubic yards of annual dredging.

The combination of the upstream settling basin and disposal system (1) is calculated to require a capital investment of $11,530,000 and result in an average annual cost of $2,309,000 for the 1,220,000 cubic yards of annual maintenance dredging, or an average of $1.89 per cubic yard, as compared to the average annual cost of $953,000, or $0.78 per cubic yard, for disposal in the open lake.

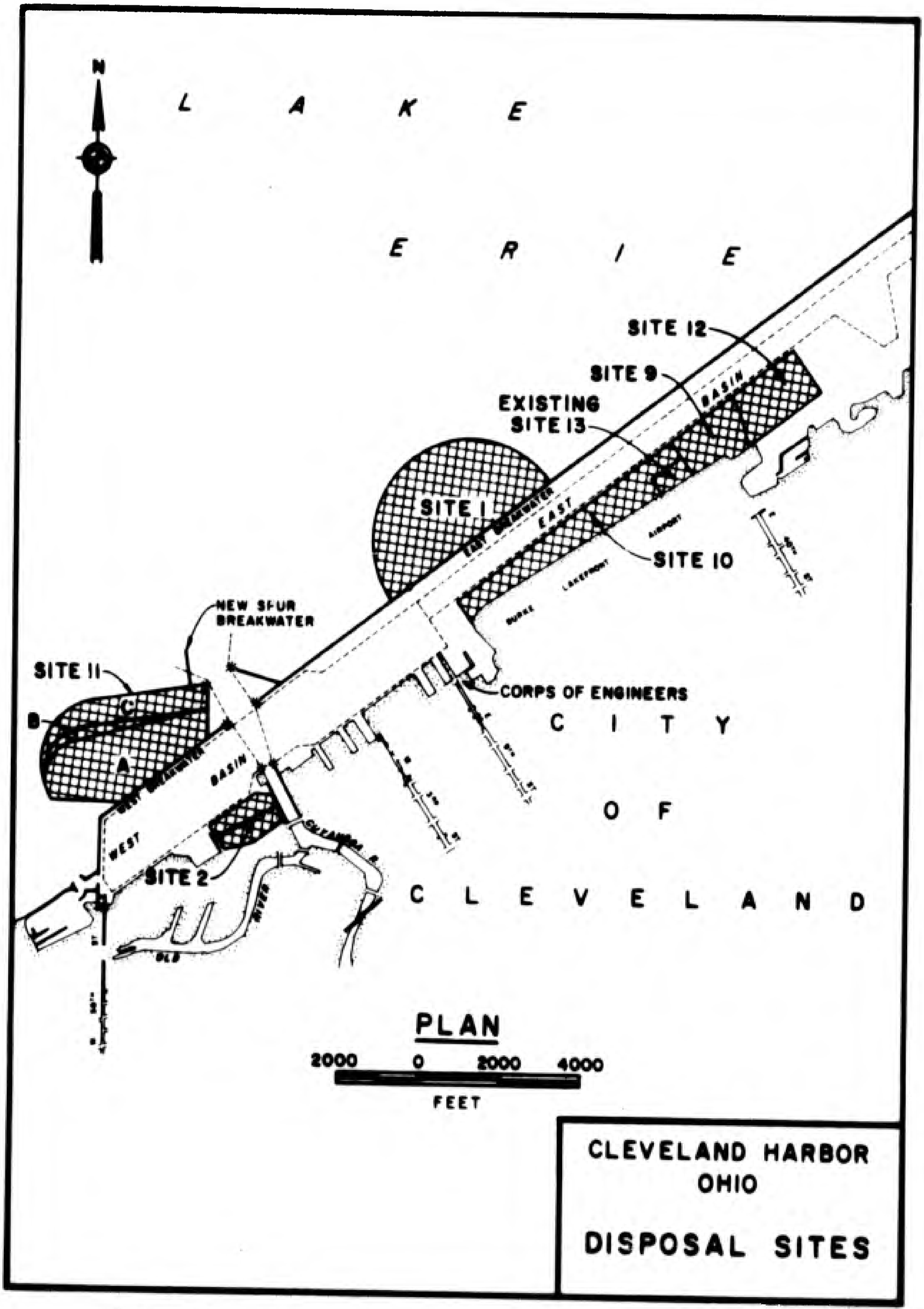

Figure 29. Alternate Disposal Sites at Cleveland Harbor, Ohio (Harbor Areas)

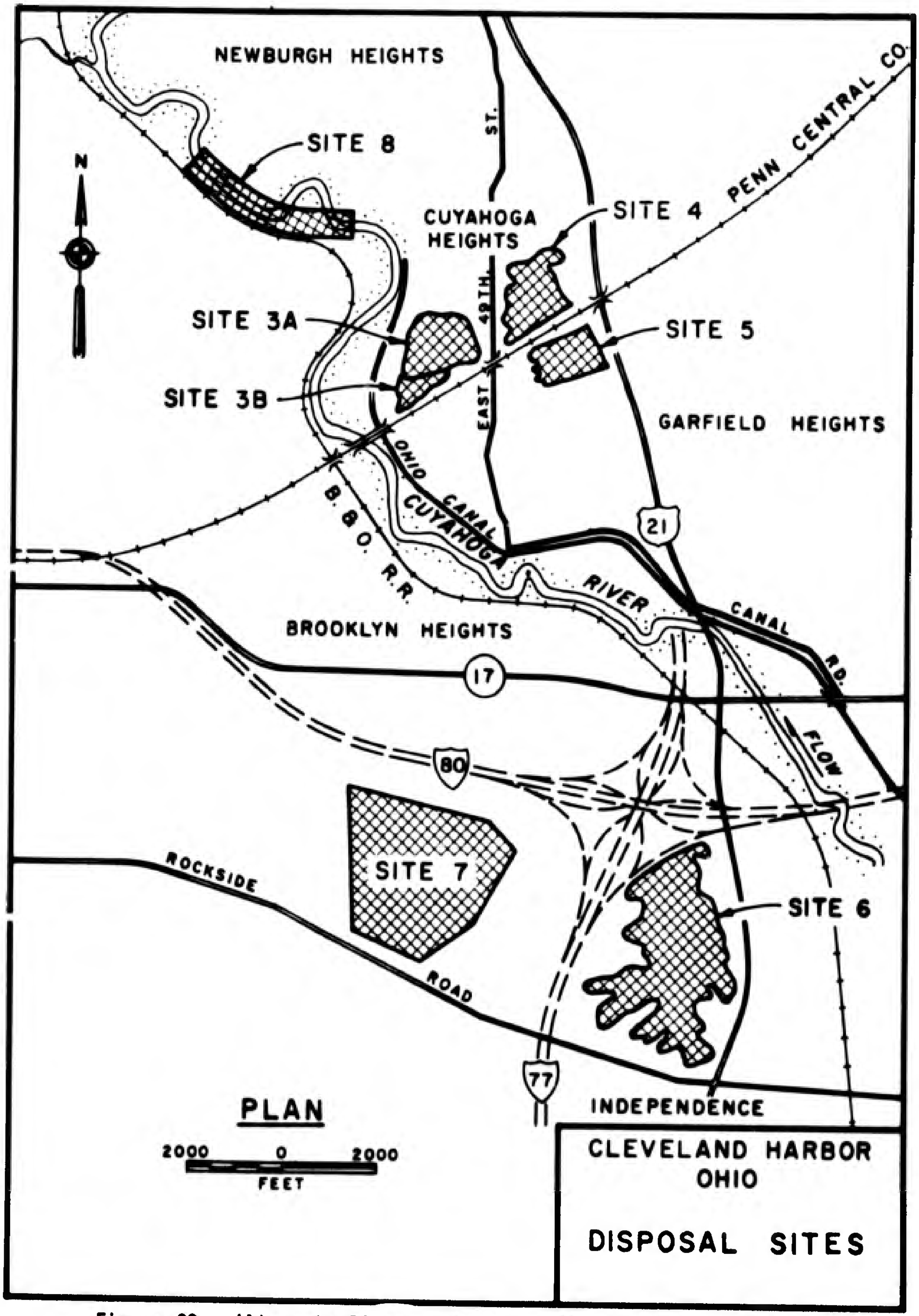

Figure 30. Alternate Disposal Sites at Cleveland Harbor, Ohio (River Areas)

(c) Toledo Harbor, Ohio

Since 1961, a major portion of the dredgings has been placed in diked disposal areas at greater economy than disposal in Lake Erie. No change is, therefore, contemplated. The harbor was surveyed merely for additional disposal areas.

Five disposal sites were investigated for disposal of dredgings from Maumee River and Bay channel projects. Existing sites were found to be best. They are large enough to contain sediments to be dredged through 1970. The two sites in current use are: (1) Riverside Park (Figure 31), and (2) the diked disposal site in Maumee Bay built in 1961-1962 (Figure 32). An additional river site (Figure 31) is to be diked at Federal expense by 1970. Also being considered is a site in connection with additional dock facilities that are going to be constructed by the Toledo-Lucas County Port Authority (Figure 32). Needed dikes will be provided by the Port Authority and the inclosed area will be made available for disposal of maintenance dredgings from Federal projects during 1971-1978.

Aside from the two diked areas presently in use, about a fifth of the dredgings are currently deposited in an open-water disposal site in Lake Erie. The average annual cost of the present dredging and disposal methods is about $0.315 per cubic yard, or $0.27 per cubic yard for dredging and $0.045 for disposal. From 1969 to 1978, unit dredging costs will remain about the same, but the cost of disposal will rise to $0.08 per cubic yard or an increase of $39,000 annually.

Costs for developing the additional diked disposal area in conjunction with the Toledo-Lucas County Port Authority and existing and proposed sites

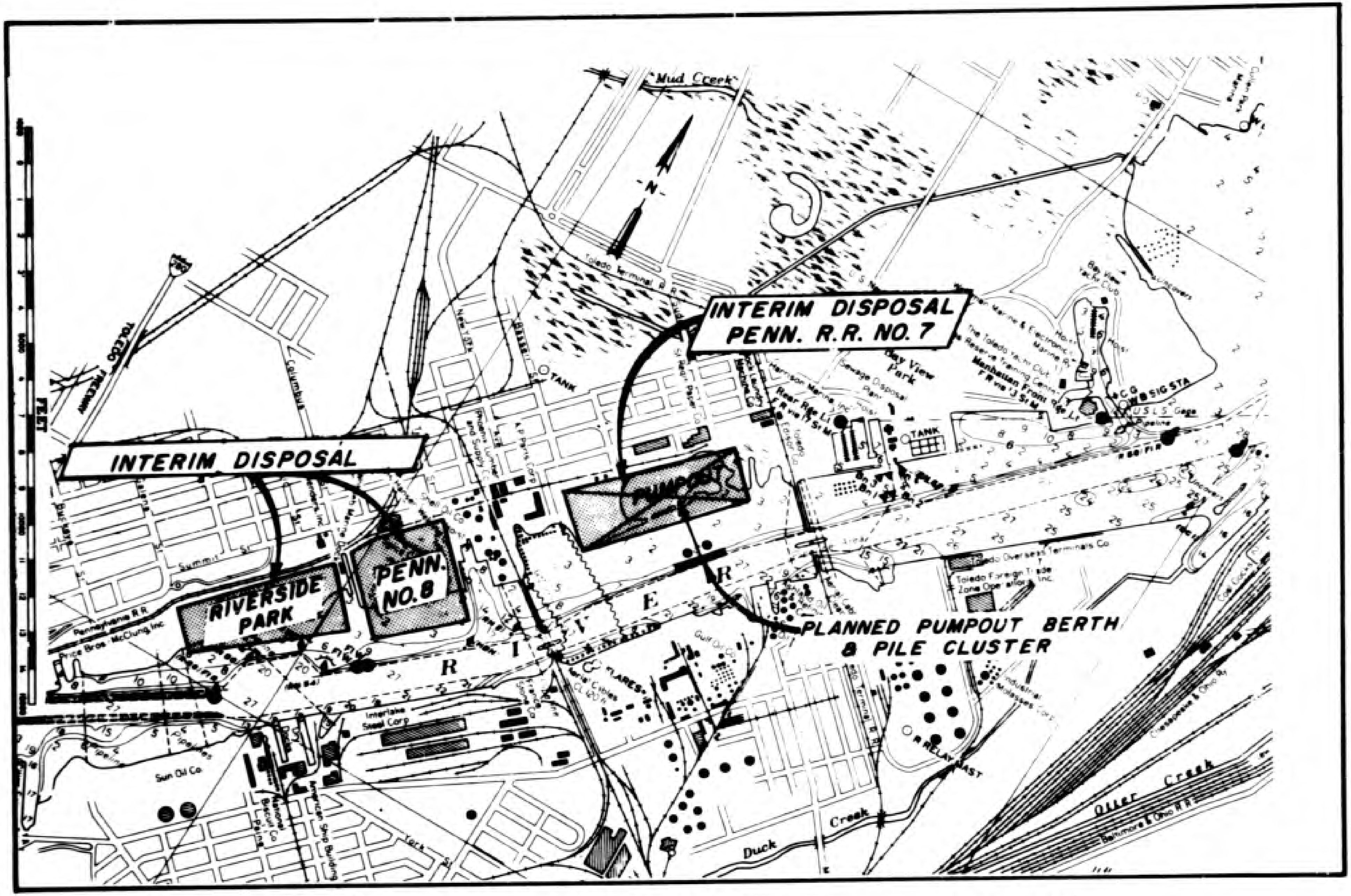

Figure 31. Alternate Disposal Areas at Toledo Harbor, Ohio (River Areas)

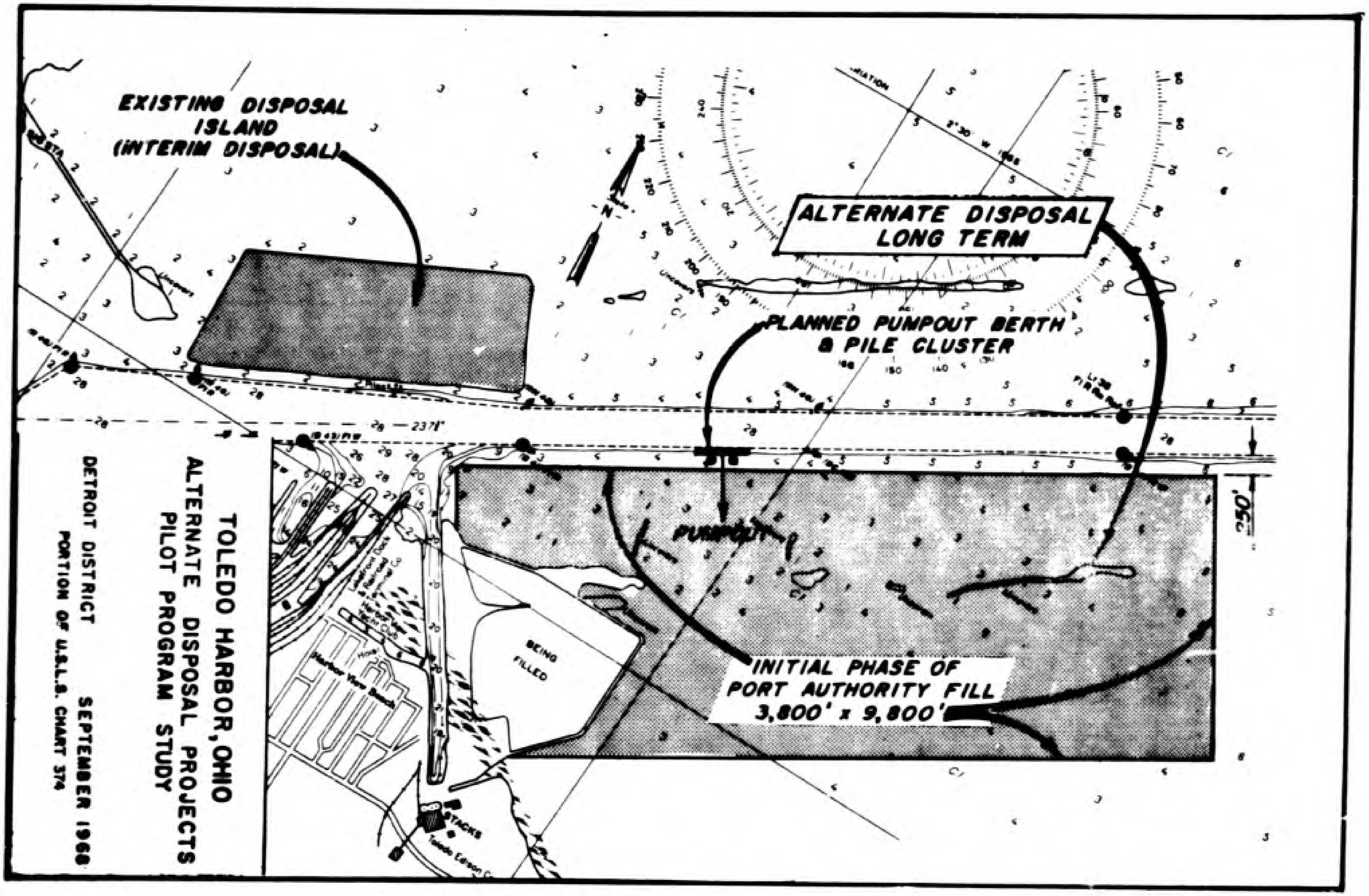

Figure 32. Alternate Disposal Areas at Toledo, Ohio (Harbor Areas)

in Maumee River are expected to be about the same as for similar items in connection with existing disposal areas. Operation and maintenance costs are expected to increase slightly as indicated above.

(d) Rouge River, Michigan

All maintenance dredgings have been disposed of in diked disposal areas since 1960 in order to avoid pollution of downstream reaches of the Detroit River. No change is contemplated at the present time. This locality was surveyed for additional disposal areas.

Of the two sites for Rouge River dredgings, the present diked disposal area at Grassy Island (Figure 33) was found to be the better. Consideration was given to an increase in dike elevation and construction of a new dike to inclose 36 acres westward of and adjacent to the present diked area.

The average annual cost of current dredging and disposal operations is $1.24 per cubic yard, or $0.86 per cubic yard for dredging and $0.38 per cubic yard for disposal. Raising the existing dikes is expected to cost $1,140,000. Investment costs for the new dikes for the 36-acre addition are estimated to be $712,400. Both developments are essential for containment of dredgings through 1978.

Annual costs to raise the existing dikes and add the new area are estimated to be $264,000. This is $150,000 higher than present annual costs for diked disposal. The resulting increase in cost of disposal is $0.50 per cubic yard, making the average annual cost of dredging and disposal $1.74 per cubic yard.

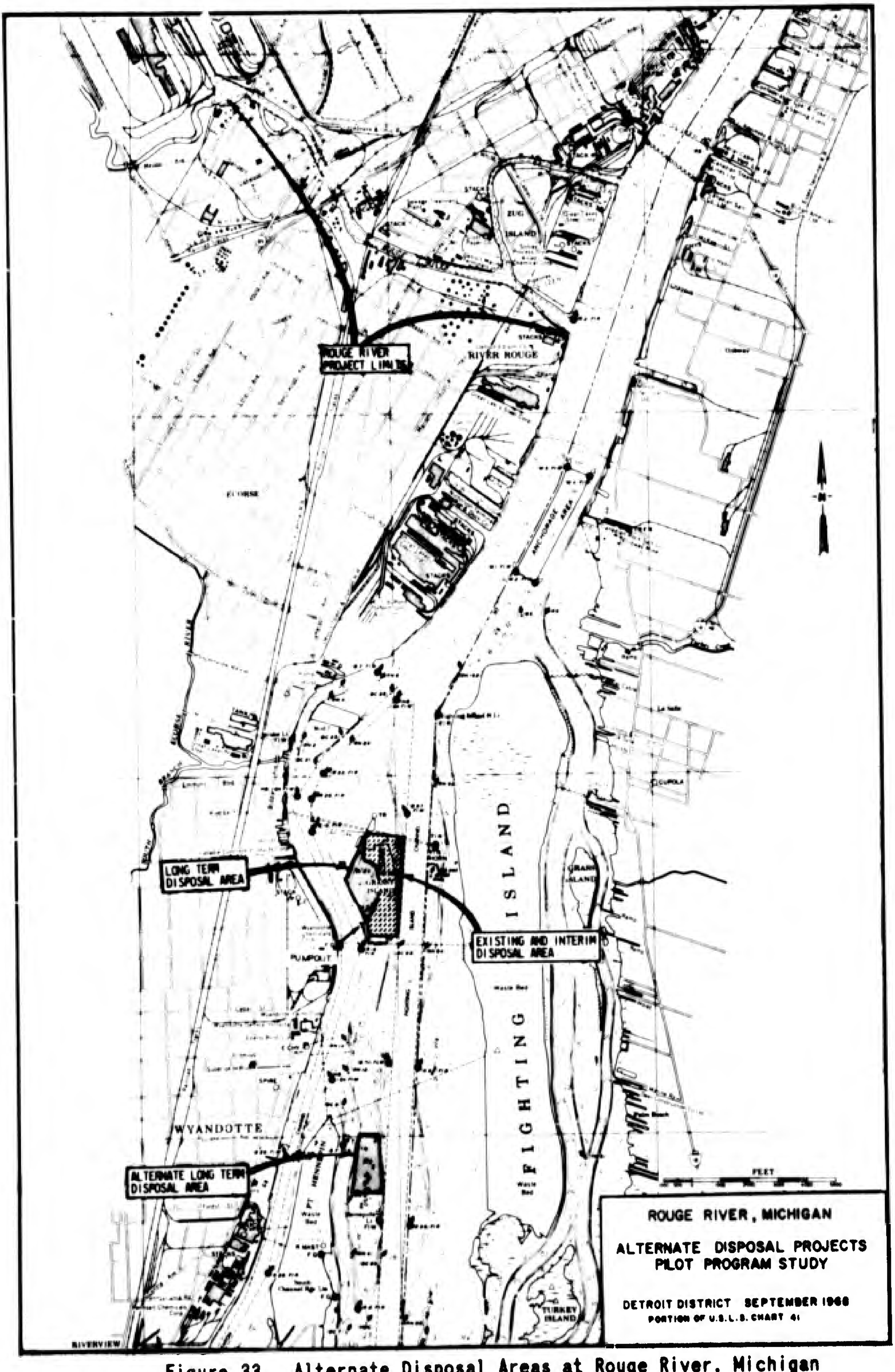

Figure 33. Alternate Disposal Areas at Rouge River, Michigan

(e) Indiana Harbor, Indiana

Fourteen sites were investigated for disposal of Indiana Harbor dredgings. It was assumed that disposal in a diked area with an opening to the lake for passage of scows, as was done in 1967 on a trial basis, will provide a disposal system acceptable to the regulatory agencies. Best of the disposal sites are the existing Inland Steel diked area (Site #13 Figure 34) and the planned extension of the area to the northeast (Site #14) expected to be completed in 1970. Site #13 is currently being filled with slag and should be completed in 5 to 6 years. Opportunity to float scows into the area and the acceptability of dredgings at the present stage of filling are in doubt and another site along the Lake George Branch of the Indiana Harbor Canal (Site #10) will most probably be used until Site #14 becomes available.

Use of Site #10 would involve hauling scows to an unloading dock where a land-based crane would transfer material to trucks for haul to the disposal site. Costs are estimated to be $1,615,000 higher than the $664,000 cost for open lake disposal for the two years before Site #14 becomes available. Included in these costs are $620,000 for land acquisition and minor diking costs. No additional costs would be involved in disposal at Site #14.

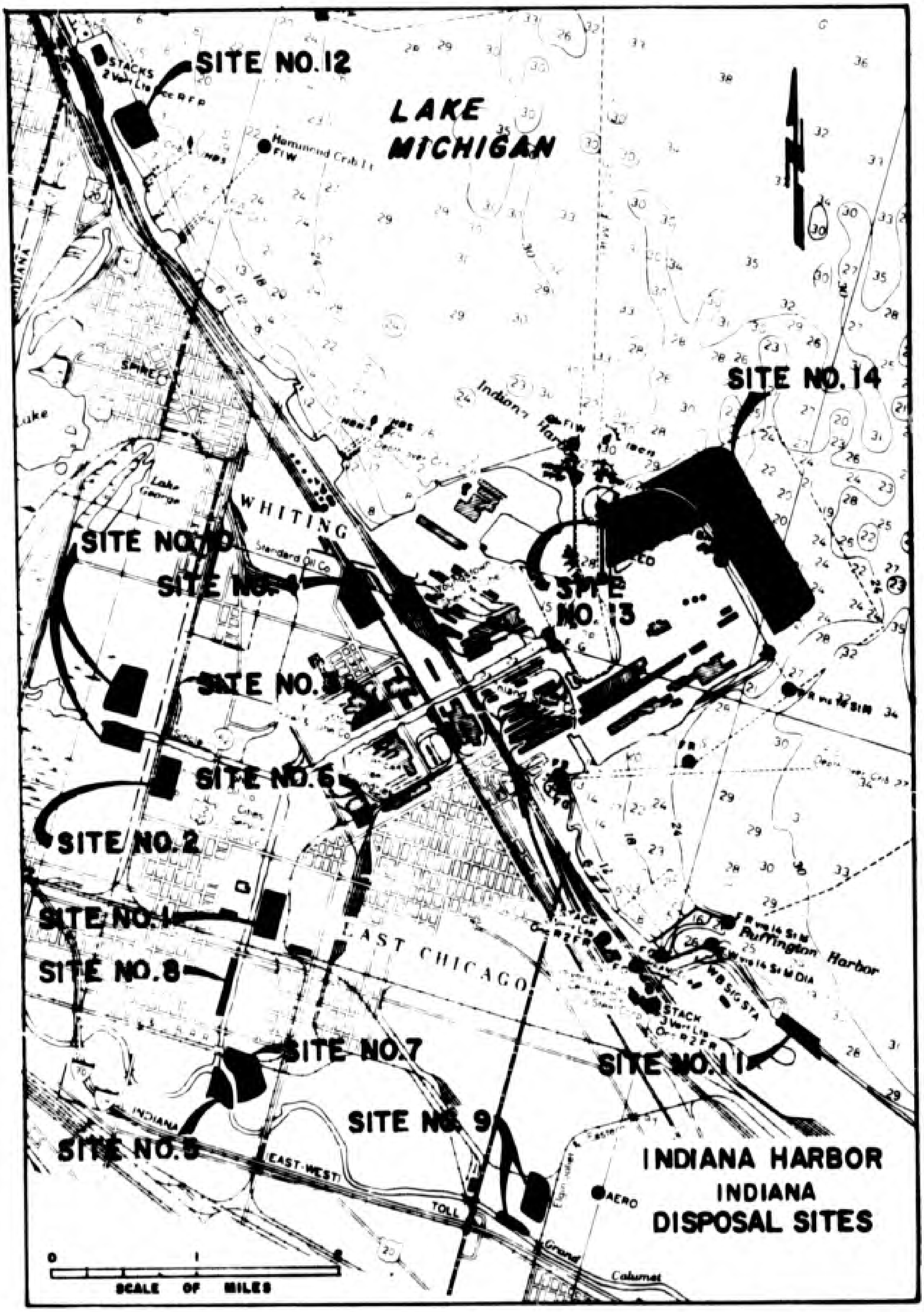

Figure 34. Alternate Disposal Areas at Indiana Harbor, Indiana

(f) Calumet Harbor and River, Illinois and Indiana

Eleven inland sites were studied for disposal of dredgings from Calumet Harbor and River. The best sites were, referring to Figure 35:

Site #1, a low-lying swampy area of approximately 53 acres adjacent to Lake Calumet and north of the area used for disposal of 1967 and 1968 dredgings. The associated capacity will be 1,800,000 cubic yards after the owner has removed about 900,000 cubic yards of sand.

Site #2, a 40-acre low-lying area to the east of the 1967 and 1968 disposal area with a capacity of 450,000 cubic yards.

Site #8, an area of about 350 acres of low marshy land lying in a horseshoe bend of Calumet River, near the Thomas J. O'Brien Lock and Dam, with a capacity of 3,500,000 cubic yards.

Dredging would be by clamshell dredge, and scows would be unloaded by land-based crane at a convenient unloading dock. The dredgings would then be truck-hauled to the disposal sites. Costs of disposal in these areas are estimated to be $1.45, $1.20, and $1.46 per cubic yards in excess of the $2.50 per cubic yard for open lake disposal at Sites #1, 2, and 8 respectively. Site #1 will not be available until 1970.

It would be best to use Site #2 for the first two years and either Site #1 or #8 for the remainder of the period required for alternative disposal methods. Additional costs for the assumed 10-year period are estimated at $2,850,000 for maintenance dredging. Capital costs would be minor and are included in the dredging costs.

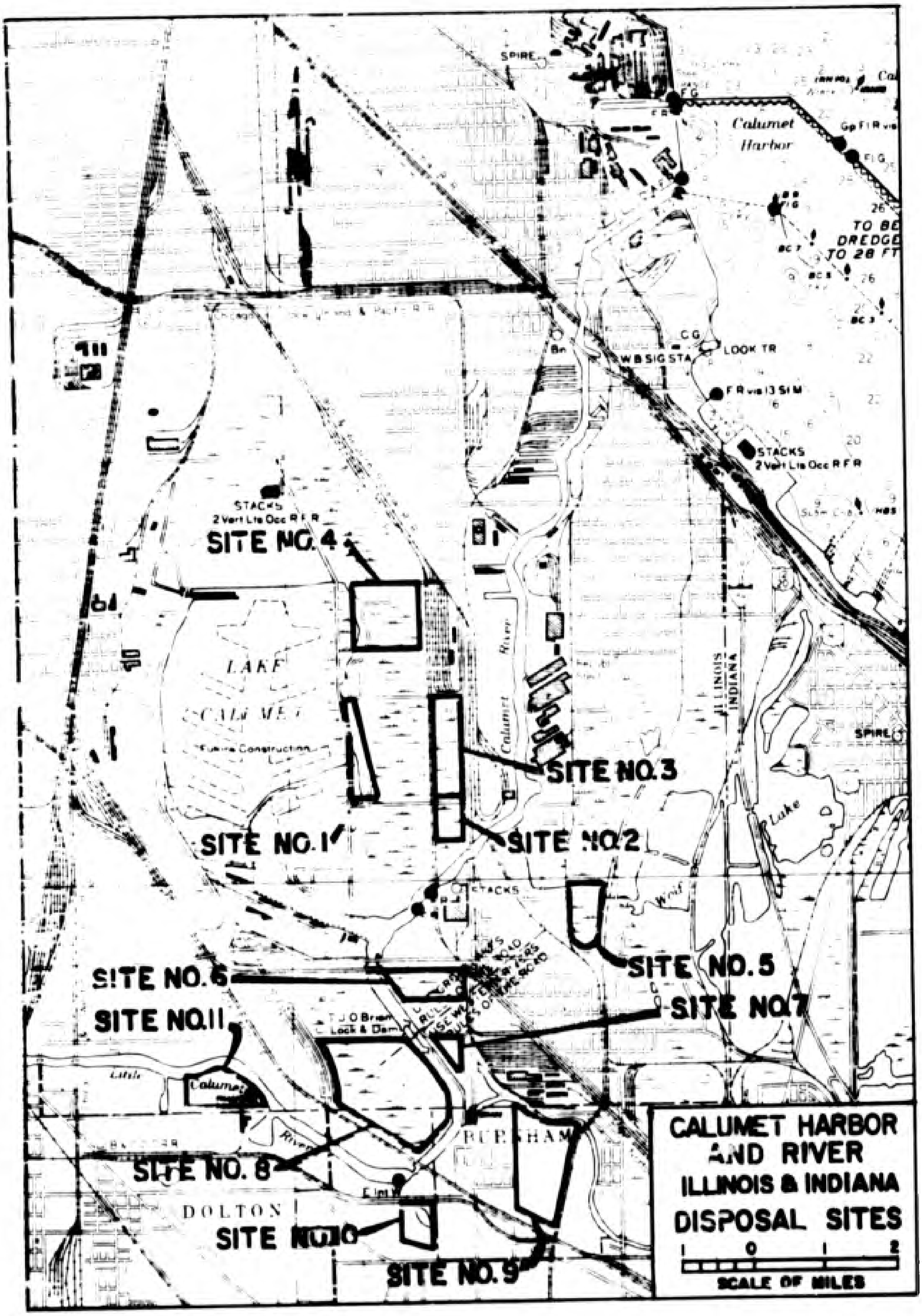

Figure 35. Alternate Disposal Areas at Calumet Harbor, Illinois

(g) Green Bay Harbor, Wisconsin

Five disposal sites were studied: three-low-lying marshy areas along the shore of the bay, on an area in the bay formed by clay dikes constructed with material excavated in new-work dredging of the bay channel in 1967, and a water area along the shore of Fox River. The sites are shown on Figure 36.

Site #1 lies in the bay area and is scheduled to be used for some of the remaining work to complete the improvement of the bay channel. The remaining capacity will suffice for only three years of maintenance dredging. The area could be enlarged with the help of new-work dredgings to inclose enough space to contain maintenance dredgings for the entire 10-year period.

Site #5, a low-lying marshy area, is being developed by the City of Green Bay in local cooperation with the improvement of the bay channel. It has served as the disposal area for the new-work dredging performed in 1967. The city does not wish to add maintenance dredgings to this area beyond 1968 and 1969. In 1967, the Fox River was dredged by clamshell. The dredgings were deposited in an excavated sump in the bay close to the diked area for re-excavation by hydraulic dredge and pumping into the diked area. The 1968 maintenance dredgings were also deposited in the sump, but they will not be transferred to the disposal area until the dredgings for 1969 can be added.

Site #2 is a marshy area lying northwest of Site #5, and could be developed by diking to a capacity of 1,300,000 cubic yards. Site #3 is a marshy depression about two miles east of the mouth of the Fox River and could contain 1,500,000 cubic yards without needing retaining dikes.

For each of these disposal areas it was assumed that regulatory agencies will be satisfied if, as was done in 1967, scows are dumped into a sump in the bay close to the disposal site and dredgings are later reexcavated by

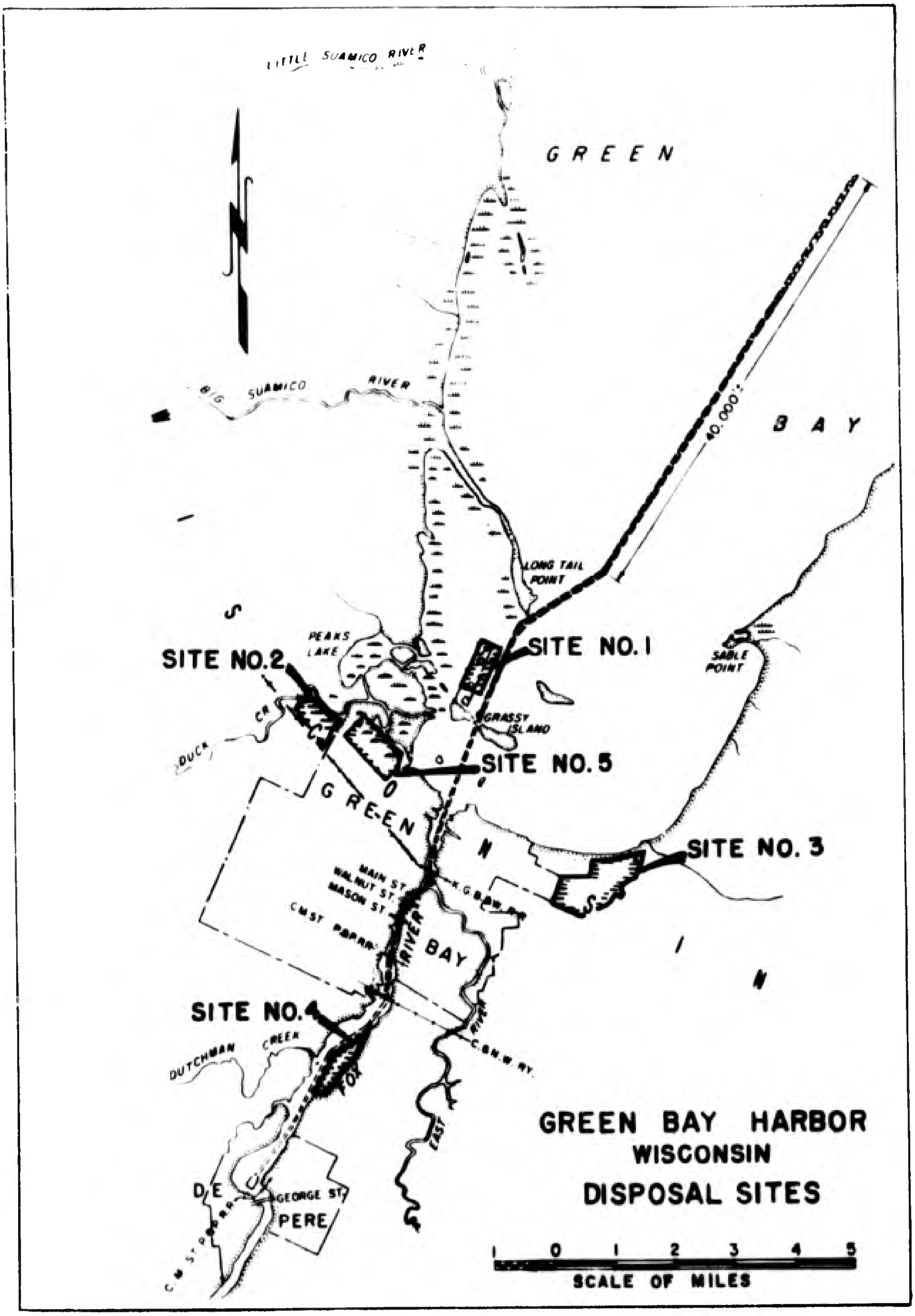

Figure 36. Alternate Disposal Areas at Green Bay Harbor, Wisconsin

hydraulic dredge for pumping into the disposal area. On this basis, Site #1 would be best except that it could not be made ready to receive maintenance dredging until 1970. Accordingly, Site #5 would be used in 1969. Cost of disposal for a 10-year period would be $4,178,000 in excess of the cost of $1,370,000 for disposal in the open waters of Green Bay. These values reduce to an additional cost of $3.05 per cubic yard for alternate disposal.

Further study of these sites is indicated. The bay disposal area has degraded substantially and riprap protection of the bay side slope is necessary if the area is used for retention of polluted maintenance dredgings. Consideration should be given to performing the dredging with hopper dredges or to unloading scows by direct pump out rather than dumping in a sump in the same manner as in the experimental work at Buffalo and Cleveland Harbors.

Section 8

BENEFITS

8.1 Introduction

In the past, economic justification of a river and harbor project has been based upon the benefit-cost ratio for the proposed project. Following previous precedents, the Corps has estimated the costs for the most promising alternate methods of disposal of dredgings from Great Lakes harbors and channels. These estimates are discussed in Section 7. The purpose of this section is to discuss and evaluate the benefits that might accrue if an alternate disposal method was employed in lieu of open lake disposal.

8.2 Background Discussion

In 1966, the Corps of Engineers submitted feasibility reports on alternate disposal areas for the 15 most critically polluted harbors on Lake Erie and for one or more harbors on each of the other Greak Lakes. The reports were essentially cost studies of diked inclosures at each harbor. At the same time, a request was made of FWPCA, Department of Interior, to evaluate the benefits that would accrue from the alternate disposal procedures. An exchange of correspondence indicated that FWPCA felt the disposal of dredged material in the Great Lakes was contributing to pollution, and it should be discontinued in accordance with the requirements of Executive Order 11288, "Prevention, Control, and Abatement of Water Pollution by Federal Activities." Further, they felt that benefit evaluation was not a controlling factor.

The feasibility report was reviewed by the Bureau of the Budget. They requested the Corps to investigate alternatives to its current disposal methods. They also proposed that FWPCA assist the Corps by: (1) establishing guidelines designating when, where, and under what conditions current disposal methods should be modified; and (2) formulating a technique for calculating the economic benefits attributable to abatement of any effects caused by open lake disposal. The Bureau of the Budget felt such a study was imperative because alternate disposal practices could have far-reaching implications for the future allocation of funds among water resources programs throughout the nation.

FWPCA agreed to assist the Corps with point one, but objected to the calculation of economic benefits for alternate disposal. They were concerned over precedents that would be set if alternate disposal methods were to be evaluated on a benefit-cost basis. If favorable benefit-cost ratios were required for justification of Federal pollution-control projects, they felt that every industry and municipality in the Great Lakes Basin or elsewhere could reasonably insist that their pollution control projects proceed only where similar justification can be shown.

Before benefits can be evaluated, the effects of open lake disposal must be measured. Quantities of dredgings are small in relation to the overall volume of the Great Lakes, and their effects on water quality are difficult to determine fully with available technology.

The Bureau of the Budget realized that there were complexities in the evaluation of these benefits, but that there were circumstances where benefit calculations possibly could be made. They felt that an attempt should be made in connection with studies for the present report. By their emphasis on benefit evaluation, the Bureau did not intend to imply a prejudgment of the alternatives for dredgings disposal, but that the best possible evaluation of benefits is an essential part of the relevant factual data for decisions regarding water resource projects. They agree that the Federal Government should provide leadership in the control of pollution; however, they also feel it must be a wise investor of its resources.

8.3 Water Use Benefits

8.3.1 General

In view of FWPCA reluctance to study the determination of benefits of alternate means of dredgings disposal, and in an effort to comply with the desires of the Bureau of the Budget for formulation of a technique for calculation of such benefits, the Corps of Engineers initiated a benefits study.

The Water Resources Center, University of Illinois, was engaged to study the feasibility of evaluation of benefits that might accrue from improved Great Lakes water quality if dredgings were not disposed of in the open waters of the Lakes. They submitted a report on their findings on 31 May 1968. Their report is attached as Appendix C8.

The report was prepared by an interdisciplinary staff of experts. The study was considered to be the first phase of a possible two-phase program to evaluate economic benefits. The goal of their report on the first phase of the study was to determine, for each beneficial use of water, whether the benefits resulting from improved water quality could be evaluated in monetary terms; if so, how; and if not, why. Hopefully, methodologies could be developed for use at any given site to determine the dollar-value of the benefits involved.

A summary of the methodologies developed to evaluate water use benefits follows. Specific attempts to evaluate benefits at a given site are also discussed.

8.3.2 Municipal Water Supply

The Great Lakes are the source of municipal water supply for most of their surrounding municipalities. Prior to use, the water is treated to meet established water quality standards. In general, the cost of treatment decreases with improved water quality at the intake point. If the water quality of the Great Lakes would be improved by considered alternate disposal methods for dredged material, and if these improvements are measureable at the water supply intakes, the benefits from reduced treatment costs could be evaluated. The benefits would be in the form of savings in chemical costs and other associated costs in the treatment process. The difficult part of this methodology is estimating the changes in water quality after the use of alternate disposal methods. The changes are expected to be extremely small. The distance between water supply intakes and open lake disposal areas is expected to be a factor and would vary from harbor to harbor. In order to evaluate the possible magnitude of these benefits, Greeley and Hansen Associates, consulting engineers, were engaged to evaluate the benefits for a municipal water treatment plant on Lake Michigan. Their studies, discussed in the next paragraph, were based on hypothetical changes, provided by the Corps, in water quality parameters during the use of alternate disposal methods.

The report, shown in Appendix C9, discussed possible water supply benefits from a cessation of open lake disposal of polluted harbor dredgings in the vicinity of Chicago, Illinois. Treatment cost data was obtained from the city's water filtration plants. The results of the investigation indicated that benefits in the form of reduced treatment costs at Chicago might approach a maximum value of $7,500 annually. Benefits of this magnitude are comparatively insignificant; in 1967, the total cost of chemicals for treatment of the Chicago water supply was $2,466,347. Since they represent benefits for the largest treated municipal water supply in the Great Lakes, no attempts were made to evaluate water supply benefits at other harbors.

8.3.3 Industrial Water Supply

Evaluation of industrial water supply benefits would be very similar to the methodology employed for municipal water supply. Industrial waters are used in three principal ways: as cooling water; as process water; and as boiler feed water. Quality requirements are greatest for the small volume used for boiler feed, and least for the large volume for cooling. Reduced treatment costs would again be the only feasible means of evaluating benefits from water quality improvement as a result of use of alternate disposal methods. Benefit evaluation would require an identification of the industries that use water from the Great Lakes directly rather than a municipal supply, and a determination of the uses of the water, the quantities involved, and the required quality standards after treatment. Thus, the changes in water quality expected after use of alternate disposal methods would have to be estimated for each industrial intake. Studies by Greeley and Hansen Associates were expected to include the evaluation of water supply benefits at typical industrial plants. However, their studies were terminated after it was determined that municipal water supply benefits at Chicago would be insignificant. It was assumed that industrial water supply benefits would be of the same magnitude.

8.3.4 Recreation

All water-oriented recreational activities are either directly or indirectly affected by the water quality of the Great Lakes. The extent to which these activities are deleteriously affected by pollution, in general, and dredgings disposal, in particular, has not been well defined because of many variables which are difficult to measure. That recreational use of water results in economic benefit is an unquestionable fact. It is also a virtual certainty that improved water quality in the Great Lakes will increase associated benefits. The problem lies not in the lack of economic benefits, but in the measurement of them.

Intensive research is needed on water quality parameters, particularly with respect to how various levels of important parameters affect the public's participation in recreational activities. Even if this information were available, it would be necessary to determine the net change in the levels of each of the parameters as the polluted dredgings were disposed of in an alternate manner in each case. This is the same difficult question that needs to be answered to evaluate benefits for other water uses as well as for recreation. Only very slight changes in water quality are expected in the central lake areas as a result of cessation of disposal of polluted dredgings in the open waters of the Lakes. These changes may be more noticeable along shorelines where alternate disposal practices are implemented. However, even slight changes in the value of a recreation day, if multiplied by all the water-oriented recreation days that are experienced each year on the Great Lakes, could result in sizeable benefits.

For those recreational activities that would be enhanced or increased with alternate disposal practices implemented, it would be necessary to estimate the monetary value of a recreation-day under existing and alternate conditions. It would also be necessary to estimate the number of users under existing and alternate conditions. The benefits from any resulting increased recreational activity and possible enhancement of existing activity could then be calculated.

8.3.5 Commercial Fishing

The economic benefits attributable to commercial fishing as a result of changes in dredging operations are also difficult to evaluate. Studies have shown that a gradual decline in the numbers of desirable commercial fish species in the Great Lakes can be attributed to pollution. The methodology proposed in the University of Illinois report for estimating benefits consists of:

(1) Estimating the effect of change in quality of lake water resulting from use of alternate disposal methods on the number of fish of each species;

(2) Assuming that a percentage change in the catch equals the percentage change in population of each species; and

(3) Multipling the change in catch by the weighted-average market price less the cost of catching the additional fish.

The Illinois report concludes that commercial fishing benefits cannot be calculated until much more is known about the ecology of the Great Lakes.

8.3.6 Intangible Benefits

Improvements that reduce the amount of polluted material getting into the Great Lakes would be of significant value to the 30 million people who live in the Great Lakes Basin. Prior discussions of water use benefits indicate that, in most cases, a very considerable amount of additional data collection and research will be required before it becomes possible to evaluate these benefits in monetary terms. There are other intangible benefits that should be discussed. The University of Illinois study discussed aesthetic responses to variations in the water quality of the lakes. The university proposed a methodology for gathering and analyzing data concerning the relation of aesthetic responses to both perceptual and symbolic contact with water quality variables. Such a study would be useful, but the results would probably still be in the form of intangible benefits.

Variations in water quality are known to have substantial effects on the market value of waterfront property abutting lakes and streams. Improvements in the water quality of the Great Lakes would undoubtedly increase the value of adjacent public and private lands. Although it is recognized that considered improvements in this report would provide some value to the property owners involved, the benefits must be classified as intangible at the present time.

In recent years, publicity dealing with the pollution of the Great Lakes has affected attendance and associated spending in the communities bordering the Lakes, particularly Lake Erie. In some instances the publicity has exaggerated the pollution problems. For example, the public beaches along the Presque Isle peninsula are considered safe for swimming and other outdoor recreational activities. A public official from the State of Pennsylvania has made the statement that the national publicity about Lake Erie being "dead"cost the recreation and tourist industry in the Pennsylvania portion of the Lake Erie approximately $13 million in 1967. From the national viewpoint, such losses may not be significant because the money probably was spent elsewhere for other recreational opportunities. It is recognized that it is sometimes necessary to overemphasize an issue to create public interest so that corrective measures will be taken. However, it is also recognized that there is a growing demand for water oriented recreation, and limited resources are available. If people are persuaded to forego the enjoyment of available facilities, this must be considered an intangible loss. Improvements considered in the present report would help to reduce these losses in the future and to create intangible benefits, such as enhancement of the general welfare and security of the people, improvements in sanitation and added protection against epidemics.

8.3.7 Summary

The difficulties involved in evaluating tangible water use benefits for specific purposes have been discussed in previous sections. Most of the problems center around the unknown condition that would result at the points of use if alternate dredging practices were implemented. Despite the rather extensive sampling data that was obtained for the present report, the results are inconclusive. The extent to which the water quality of the Lakes would be improved after a ten-year period of alternate disposal practices cannot be predicted. It is believed that significant inprovement in water quality during this period is possible if widespread pollution abatement practices are implemented at the sources of pollutants concurrently with the use of alternate disposal practices. In the present report, however, credit can be taken only for benefits attributable to alternate disposal of polluted dredgings. It must be concluded that such benefits are largely intangible because they cannot be measured in monetary terms at the present time.

8.4 Land Use Benefits

Studies of alternate disposal areas that would contain maintenance dredging spoil for at least ten years were conducted at thirty-seven harbors in the Great Lakes Basin. In most cases, disposal on an undeveloped land site, if such were available within a few miles of the harbor, would be the least costly alternative. In some cases, though, the only feasible alternate means of disposal is use of a more expensive alongshore or offshore diked area.

Possible benefits from future use of the landfill areas and created land areas were not calculated because of the poor strength characteristics of maintenance dredgings. Recent tests performed on cores taken from Grassy Island and the diked disposal area in Maumee Bay, both of which have been used since the early 1960's, showed that the fills have low shear strength and should not be used for structural purposes without modifications.

It was assumed that the filled areas eventually could be used for recreational or agricultural purposes, but it would probably require at least ten years and possibly much longer, following the termination of disposal operations, before most of the areas would drain and compact enough to be developed for even recreational purposes. The increase in value of the property, if any, when converted to present worth probably would be insignificant. Understandably, poor quality fill material is not a valuable commodity. In fact, landfill sites for waste materials are in short supply near the larger cities of the Great Lakes region.

It has been assumed that benefits from land created or filled by dredgings disposal would be negligible, except in a few cases, such as the disposal area adjacent to the Burke Lakefront Airport at Cleveland. Even in these cases, though, the fill values must take into consideration costs required to make the area suitable for occupancy.

During the investigations for alternate disposal areas at specific harbors, public officials and some property owners were contacted to determine the availability of various sites. In a few cases, owners offered to provide sites for spoil disposal without cost in order to enhance the site for future development. Some owners offered to provide their sites for a fee that ranged up to $0.50 per cubic yard of spoil, although the Chicago District, Corps of Engineers, actually negotiated a contract for disposal rights in the Lake Calumet area for $0.05 per cubic yard. There were no offers to pay the Federal Government for the material deposited on a given site.

If alternate disposal on landfill sites is advertised at harbors in the Great Lakes, there is the possibility that competition for the material might develop. Many owners of property that could be so used were not contacted during the intitial investigations. The least costly alternative at each harbor must be reevaluated during detailed design studies. Willingness to pay for the spoil would have to be investigated in an attempt to develop more economical plans for alternate disposal. In effect, possible land enhancement benefits could be evaluated in a realistic manner. Individual owners could speculate on the future value of their properties after spoil disposal and offer to pay or be reimbursed for the material. In each case where the least costly alternative would include payments to the property owners, the alternative of acquiring the property at a fair market value would have to be considered.

It is assumed that the procedures discussed above would provide a satisfactory evaluation of possible land use benefits.

Additional studies are needed to determine the feasibility of stabilization methods to increase the strength characteristics and enhance the future value of filled spoil areas. These studies could be conducted on lands currently being used by the Federal Government for alternate disposal of dredged materials. Stabilization methods that could be investigated include aeration of the spoil material to decompose organic materials and supplementing the spoil with solid wastes.

Section 9

VIEWS OF THE BOARD OF CONSULTANTS

9.1 Introduction

To assist in the overall development of the present study, the Corps engaged the services of a Board of Consultants. The composition of the Board encompassed several academic disciplines. The Board members, each well-known in his field, were: Dr. Gordon M. Fair, Harvard University, sanitary engineering; Dr. Gerard A. Rohlich, University of Wisconsin at Madison, sanitary engineering; Dr. Alfred M. Beeton, University of Wisconsin at Milwaukee, biology; Dr. C. Fred Gurnham, Cyrus Wm Rice and Co., chemical engineering; and Professor Sanford S. Farness, Michigan State University, urban planning.

By contract, the Board was charged to "serve in advisory capacity in connection with planning, operating, and testing, alternate pilot disposal areas for materials dredged from rivers and harbors in the Great Lakes Region."[1] The most important contract service was for the Board to "prepare independent report or reports on (their) findings, touching on: the character of the materials dredged; the effect of the various type of disposal areas on the adjacent community and on the quality of the water in the Great Lakes; and recommendations as to the method of disposal to use in the various localities with due regard to the costs of disposal and water quality improvements which could be attained."[2]

The following sections consist of the views of the Board of Consultants as expressed by them. However, the Board members assisted, too, in providing much of the material in other sections of the report. Moreover, they have given advice and counsel on the report and have reviewed it in its entirety. From the standpoint

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[1] DACW 49 67 C 0038, Article 1., p. 2

[2] Ibid

of their individual disciplines and collectively as a body of experts, they support the judgments and conclusions of the overall report including those of the reporting officer as being technically and scientifically sound.

9.2 The Board's Task

The Board of Consultants was appointed in 1967 and, following its organizational meeting in March of that year, was convened at monthly or bimonthly intervals for conferences and field inspections at the pleasure of the Corps of Engineers. From time to time, moreover, the Board was authorized to meet *in camera* for the review of available information and for the drafting of programs of special studies to be pursued in furtherance of the Corps' program. Individual members of the Board were also authorized to report on work in related fields of study of the Great Lakes and on specific aspects of the Corps' program.

As interpreted by the Board, the charge of the Corps to the Board was (1) to advise in the effective development of the Pilot Program of Disposal of Dredgings initiated in 1966 by the Corps of Engineers in cooperation with the Federal Water Pollution Control Administration; (2) to evaluate the results of studies conducted during the dredging seasons of 1967 and 1968; (3) to study new approaches to spoil disposal without neglecting the possible modification of existing measures of pollution abatement that might permit continued dredging under prevailing disposal procedures; and (4) to identify and, where possible, to quantify benefits of promising disposal practices such as the creation and development of land and lake disposal areas for recreation and for the protection of fish and game as well as wildlife in general.

In meeting these obligations, the Board of Consultants was free to advise the cooperating agencies on ways and means for gathering basic information on the pollutional character and effect of dredgings, not only in terms of analyses, but also as *ad hoc* methods in terms of the functional behavior of river and harbor sediments as such and as dredgings in the lake environment. Most important, perhaps, among the resulting investigations of the cooperating agencies were those directed to filling the gap in present-day knowledge of the impact of dredgings on the ecology of lakes and harbors and thus, in turn, on the eutrophication of these bodies of water. Growing out of these studies, moreover, was the possibility of identifying the value and assessing the cost of treating dredgings at fixed and floating installations prior to their return to the lake waters or their removal to diked or land disposal sites.

9.3 The Board's Concept of Dredging Problems in Relation to Lake Environment

The dredging of channels and harbors of the Great Lakes was assigned to the Corps of Engineers for the purpose of (1) accommodating the depth of draft of Great Lakes vessels by "maintenance dredging" for the removal of bottom deposits washed into these channels and harbors by entering streams, soil erosion of lands bordering these waters, and by harbor pollution from municipalities, reparian industries, and lake vessels; and (2) permitting the passage of vessels of greater depth of draft into or through given waterways by increasing channel dimensions. The usual practice has been to discharge the spoil from dredging operations at offshore sites in the Great Lakes themselves. The design of existing dredging vessels and the in-lake disposal of dredgings met this obligation both technologically and economically. However, the possible pollution of the Great Lakes waters by in-lake disposal of harbor and channel sediments called for a study of future obligations of the Corps in preserving the quality of Great Lakes waters.

If future discharges of spoil into the Great Lakes were to be restricted to only clean dredgings, equipment and methods presently employed in the collection and transport of polluted sediments might need modification, and a radical departure from traditional spoil disposal practices connected with the maintenance dredging of polluted channels and harbors might have to be instituted. However, the anticipated pollution abatement program for streams entering Great Lakes harbors is expected to cut back the present degree of pollution of maintenance dredgings in the course of time. In view of this, decisions with regard to the interim treatment and disposal of dredgings must involve both long- and short-range local planning at individual harbors.

The Board's concept of the impact of these developments on future obligations of the Corps of Engineers, in the performance of this public service function without interruption and with due regard to economic constraints, is presented in the succeeding paragraphs of this section of the present report. Of special concern to the Board has been the need for reliable information on the extent of possible pollution produced by dredgings. Accordingly, the Board requested that studies of the harbor and lake environments be scheduled as part of the program of investigations for the years 1967 and 1968. Both field and laboratory studies were required.

9.4 The Social Setting of Dredging Activities

9.4.1 The Great Lakes Basin as a Component of the Social System

The Great Lakes Basin, as the geographic site of human activities, is an integral part of the cultural and social systems superimposed upon the basin by man. This fact makes it necessary in evaluating dredging activities to consider not only physical, chemical, and biological elements but also the cultural and social components of the basin.

Natural environments are greatly modified by man in the course of historical and cultural evolution. Through interaction with nature, man objectifies and socializes various cultural meanings, values, and norms. The cultural meanings and purposes actualized by man appropriate the physical, biological, time, and space elements of nature and reshape them into cultural and social forms and relationships that are not present in merely natural environments.

Comparison of the components of social systems with natural physical and biological systems, as indicated below, serves to indicate their many differences.

Physical Systems	Biological Systems	Social Systems
Physical components	Biological components	Man
Physical time and space	Physical components	Cultural meaning components
	Biological time and space	Institutional components (Economic, political, etc.)
		Cultural biological components
		Cultural physical components
		Cultural times and spaces

9.4.2 Illustrations of Social Structuring of the Great Lakes Basin

The Great Lakes Basin has been thoroughly incorporated over recent history into the cultural and social systems of the United States and Canada as a biophysical cultural component. In this process it has been greatly modified and reshaped. Utilizing the constitutive powers of law, governments have been created by man and a pattern of political spaces and boundaries has been formed. This political space pattern is composed of the local, state, and national boundaries permeating the basin. Other laws have progressively shaped a network of public rights-of-way in the environment. This process of environmental design has appropriated land, water, and air components as physical cultural components of transportation institutions in establishing trafficways for land, water, and air transportation.

Further constitutive legal acts have classified and divided physical, biological, and human components of the basin into economic and non-economic categories. This is an important cultural determination which shapes the economic subsystem of a society. Commercial and non-commercial categories of fish and wildlife, for example, have thus been defined as components of the biological culture of the basin. Other regulative functions have been extended to biophysical, cultural components such as forests, water, air, and minerals to control rates and intensities of use in the interests of preservation and pollution control. Even time as a natural component does not escape cultural transformation by man. Various social times, as defined by the legal component of the cultural system now regulate human activities in the Great Lakes Basin.

The foregoing illustrations present a few instances of the numerous and continuing ways by which man culturally appropriates physical and biological components of the environment as content for the forms of his social systems.

The resulting physical, biological, institutional, cultural, and human components of the social system are closely interrelated. Both natural events and human actions have radiating, multiple effects upon various components over time. For example, political actions such as dredging may have biological, esthetic, and economic consequences affecting various components. Natural biological events such as the invasion of destructive species may generate political, economic, and technological consequences. Economic actions may have physical, ethical, esthetic, and political consequences.

Such combinations of actions and consequences can be viewed positively as value, negatively as disvalue, or also as mixed outcomes, depending upon whether they make for functional conditions and the value orientation and perspective of the evaluator. The foregoing discussion serves to point out that dredging activities are social-technical actions occurring in a social system. Because of the interrelated nature of the social components of the Great Lakes Basin, these actions necessarily have effects upon various other components.

9.5 Functional and Dysfunctional Concepts of Great Lakes Basin Components

9.5.1 Cultural Criteria and Natural Properties of Functional Components

As a framework for considering dredging operations it is helpful to review the normative, structural characteristics and requirements of physical, biological, and institutional components related to dredging. The various component subsystems all have characteristic forms, functional capacities, and, in the case of the more complex components, environmental requirements that must be met if normal states and functions are to be maintained. Impaired or defective states and capacities appear as dysfunctions in varying degrees. Cultural values including costs and benefits, whether economic, political, biological, ethical, or esthetic, are derived from these relationships.

In the case of physical components, such as chemical and energy elements, one becomes aware of consistent properties, processes, and relationships through the laws or norms of the physical sciences. Machines and artifacts performing technical functions derive their normative concepts from the ideas embodied in them by their designers. Functional and dysfunctional states of machines are quite easy to recognize as indicated when they operate normally or when they break down as their operating requirements are not met. Biological components such as plants and animals present a more complex concept of normative functioning. Cycles of biolcgical growth, development stages, survival, aging, and ranges of normality appear as normative criteria. Disease, deformation, and pathologies in various forms become criteria defining dysfunctional states. Biological species, including man, also have definite environmental requirements relating to nutrition, light, air, water, and temperature which constitute additional criteria for normative biological functions.

Similar structural and functional characteristics define the normative concepts of complex biophysical components of the environment such as lakes and rivers. Natural geological and evolutionary processes of change operating on a vast time scale induce gradual structural and functional modifications. Such changes, however, do not destroy the reality of functional lakes and streams and the validity of normative concepts based upon their characteristics for shorter time periods.

Mans' knowledge and technical capabilities give him the power to modify processes of natural geological and biological change within fairly wide limits. Social policies and institutional programs can, therefore, be alternatively designed to have different effects upon the biophysical elements of the environment. Public and private goals may be aimed at merely maintaining present conditions and functional values. Alternatively, objectives and standards may be framed to increase functional characteristics and values above natural levels. Selective breeding and management of fish and wildlife and the control of natural erosion are examples of such policies. Lastly, social policies and practices can be framed so as to deteriorate progressively and destroy the functional capabilities and values of land, water, air, and biological communities. The latter alternative has generally been in force in the Great Lakes Basin up to the present and is the primary source of current environmental dysfunctions.

Institutions organized by man acquire functional and dysfunctional characteristics from the central purposes they are organized to achieve as social functions. Here the normative criteria are developed primarily from concepts of effectiveness and efficiency. Institutions appear and disappear in the social environment and have widely varying life cycles. Some governmental and religious institutions endure for centuries. Many smaller institutions such as small businesses are disbanded after only a year or two of existence.

The structures, functions, and technologies of institutions are relevant in the highest degree since the entire biophysical environment, while geographically continuous, is parceled out among institutions as property, equipment, and jurisdictional areas. Institutions, both public and private, are thus the collective managers of the environment.

Institutions have two main types of dysfunctional characteristics. The first is failure in the achievement of their primary functions. Economic organizations may fail to be productive. Educational institutions may fail to effectively educate. The second type of dysfunction involves destructive effects upon the biophysical base, both internal and external to the institution. A city or factory may, for example, pollute the air inside its environs as well as in the external environment. A farm may lose its own topsoil through erosion and thereby also pollute adjacent streams. Most of these dysfunctions arise out of inadequate or defective technologies. Since these effects occur in social systems they take on many forms and are culturally perceived as economic, esthetic, biological, physical, ethical, or political dysfunctions.

9.5.2 Dysfunctional Cultural, Institutional, and Technological Conditions Creating Water, Soil, and Sediment Pollution, Dredging Problems and Social Costs

The qualities and normative functional characteristics of rivers, lakes, aquatic and terrestial plants, fish and wildlife, and land in the Great Lakes Basin are interdependent. Every institutional use by man of land in the basin involves a water use as well with resultant modifications of both components. Among the biotic factors that influence the qualities of land and water environment, vegetation is one of the most important. However, the kinds and densities of aquatic and terrestial plants that can exist in the region are determined by the physicochemical qualities of water, soil, and sediment components and by climatic factors. The plants in turn influence the types, distribution, and qualities of fish and wildlife. These relationships reveal a close correlation between institutional, physicochemical, and biological conditions in the environment. It thus becomes evident that the quality of water and the general environment in the Great Lakes Basin and its subregions are primarily dependent upon the scale and location of urban, industrial, and agricultural land use, regional governmental structure and policy, and the technologies of production and waste treatment utilized by these institutions.

The Corps of Engineers, with its responsibility for improvement and maintenance of harbor and channel projects for navigation purposes, operates throughout the social space of the Great Lakes in an institutional environment. Review and analysis of the land and water use structure and interrelated activities of those institutions within the sphere of dredging operations indicate that a major portion of the Corps' dredging activity is in fact performing the function of regional wastes management and disposal rather than its assigned function of improving and maintaining navigation channels.

This situation obtains to the degree that dredged spoil is composed of wastes produced by social institutions rather than material produced by natural erosion, littoral drifting, or shoaling. To the extent that the Corps of Engineers is disposing of the wastes and pollutants produced by industrial, municipal, and agricultural operations its dredging functions represent a transfer of the physical performance and monetary costs of wastes management and disposal from these institutions to Corps operations. The relative proportions of these two public service functions performed by the Corps of Engineers has significance for more logical classification of dredging purposes, funding, and allocation of costs and benefits at the Federal level.

The apparent contradiction of a public agency financed to perform navigation functions but actually devoting a major share of its resources to regional wastesdisposal functions can be more clearly understood when related to the cultural, institutional, and technological dysfunctions in the various river basins tributary to the Great Lakes. The qualities of water, soil, and sediment in the Great Lakes Basin as a whole are the sum of the qualities present in each lake and tributary watershed. Whereas the tributary watersheds vary widely in size and land use, those rivers and harbors that require dredging have typical patterns of institutions, land, water, soil, and sediment relationships.

The environmental components that form the usual setting of dredging operations are arranged geographically in a sequence: first a bay, then a harbor navigation channel, a port city, an upstream river, tributary streams, dispersed cities and industries along streams, with surrounding farm land and sparse forests extending up to the headwater boundaries of the watershed. Superimposed upon these elements are diversified patterns of state and local government jurisdictions, land use regulations, and a network of transportation facilities.

During the historical establishment of these man-made components, most of the natural conditions that had retarded water run-off and maintained the natural velocity and biochemical characteristics of streams were disturbed. Original forests and grass were removed while agricultural drainage, urban development, and highway construction substantially modified run-off coefficients and water quality. The power of water to erode and transport sediment depends upon its velocity. However, when the velocity of water is doubled its sediment transporting function is not doubled but increased more or less fourfold. Hence, even small changes in run-off rates modify the pattern of erosion and sediment desposition. These relationships indicate that only a minor proportion of present environmental processes and relationships can be said to be natural rather than cultural in developed watersheds tributary to the Great Lakes. Practical determination of the relative proportions of natural versus culturally induced processes requires detailed study of individual watersheds along with synthetic reconstruction of original, natural conditions with which to compare present conditions. Such information is obviously necessary as a rational framework for establishing and allocating various social costs and benefits for governmental decision-making and programming.

Cultural, institutional, and technological dysfunctions that deteriorate environmental and human conditions are causally interrelated. The avoidable damages, depletion, and qualitative deterioration created by man as a result of the production and use of various goods and services are experienced as disvalues and may be termed social costs. These negative effects take forms such as the impairment of human health; pollution of water, soil, and air; flooding; loss of biological productivity and quality; and the destruction of property values.

Some social costs arise out of complex interactions among a series of institutions as is true in the case of the deterioration of the Great Lakes and their drainage basin components. Others are identified with specific industries or businesses. Some social costs affect large groups of people as in the case of the Great Lakes and metropolitan air pollution. Social costs can also remain concealed for long periods of time and become apparent only at a later date. These conditions often characterize dysfunctions such as soil erosion, flooding, and wildlife depletion.

Cultural dysfunctions operating historically in watersheds tributary to the Great Lakes have necessitated dredging. The main form of this process has been the undue dominance given to economic perception of the environment and reasoning and planning only in such value terms.

Non-economic environmental components and values have been thus disregarded to a large extent. In modern urban and agricultural environments around the Great Lakes where economic rationality has been dominant, we now find the paradox of rising economic standards of living, measured in dollar income, and declining standards of living, measured in ecological, biological, health, esthetic, and interpersonal terms.

During the period of original pioneer settlement in the Great lakes Basin the economically efficient rectangular system of the public land survey was the basic design principle creating the social landscape. This non-adaptive, rigid method of site planning for vast agricultural and urban areas, which is basically unrelated to topography and natural ecosystems, has been widely recognized by ecologists, soil scientists, and hydrologists as a primary institutional generator of social costs in the form of induced flooding, erosion, sedimentation, and biological disbalances. In addition, the economic emphasis upon private gain and individual institutional efficiency by upstream cities, farms, and industries resulted in efforts to minimize the personal and institutional costs of production.

Such economically motivated efforts have taken the form of widespread failure to treat wastes, control erosion and sedimentation, and maintain the social environment. Technologies for the production of industrial, municipal and agricultural goods and services and for the management of their solid, liquid, and gaseous wastes have remained inefficient and dysfunctional. From the standpoint of conventional economic theory, processes that may be technologically inefficient and dysfunctional may still be economically efficient because the social costs thereby created can be shifted to other persons or institutions or to environmental components such as rivers and lakes. Economic reasoning in the past has therefore tended to maximize social costs and minimize private costs, thus leading to widespread environmental dysfunctions.

The social system in each watershed tributary to the Great Lakes now generates downstream flows of solid, liquid, and other wastes from upstream and harbor institutions which have only recently begun to be recognized as phases of public and private economic processes. Solid and sedimentary wastes from industrial, municipal, and agricultural sources plus induced streambank and streambed erosion are quantitatively the most significant and contribute most to the need for dredging and the deterioration of harbor, bay, and lake environments. The Corps of Engineers functions in this context in each watershed as a downstream unit at the mouth of the river for performing regional wastes management and treatment. The environmental and monetary costs of dealing with culturally produced wastes in this manner are largely avoidable if society, through government, takes the necessary steps to modify private and public institutional rules of accounting to include social costs of operations as far as possible and to improve the technologies utilized in each watershed. It should be noted that the foregoing discussion applies equally to sediment wastes, whether they are classified as polluted or unpolluted, contaminated or clean. Cultural erosion and sedimentation create a series of important social costs in the form of sediment pollution. From a social viewpoint, wastes management is generally more efficient when on-site treatment and wastes-reduction practices can be utilized. These practices raise the subject of upstream wastes controls and are discussed in Section 9.7.2 of the present report.

9.6 Description and Evaluation of Corps Activities

9.6.1 Magnitude of the Problem

In accordance with Section 4, the volumes of present and expected future dredgings amount to almost 11 million cubic yards annually. As noted previously in Section 6, furthermore, the present character of dredgings ranges from relatively clean sand and gravel to sediments that contain considerable concentrations of pollutants or potentially pollutional components. Accordingly, a number of the harbors are tentatively classified as "polluted" or "unpolluted" (See Table 19, Section 6). However, although 84 percent of the total material dredged comes from harbors classified as "polluted", in conformance with Table 16, Section 4, and the classification in Section 6, more than half the total amount of "polluted" dredgings comes from only six of the 39 Great Lakes harbors that are presently classed as "polluted."

Two basic factors enter into an evaluation of the impact of dredgings and dredgings disposal on harbor, lake, and land environments: (1) the amount and composition of the dredgings, and (2) the ecological responses that are evoked by them. Because both vary widely in different places, it is not possible to identify a generally optimal disposal method. Instead, the most suitable disposal program must be designed for each individual harbor, with due consideration of its impact on the environment, costs, and practicality.

9.6.2 Means Used to Assess the Problem

Early in the study it was recognized that little information was available on the physical, chemical, and biological characteristics of the harbor and lake disposal environments. Such information is critical for (1) determination of the nature of the environments in terms of existing water quality criteria, (2) evaluation of the effects of dredging on the harbors, and (3) identification of the effects of disposal on the lake environments. Furthermore, the physical and chemical nature of the sediments had to be known before studies and recommendations could be made on alternative methods of treatment and disposal.

The data needed to realize these objectives could be obtained only by combining field studies of the harbors and lake disposal sites with laboratory analyses of the treatability of harbor sediments and effects on biota.

Accordingly, the Board of Consultants recommended that existing data on harbors and adjacent lake areas be compiled and analyzed and that field studies be undertaken to fill in gaps in existing knowledge. To this purpose, a sampling program was developed to obtain information on conditions in the dredging project areas. It was recommended, too, that, if possible, the sediments should be examined for some unique characteristics that would be useful in identifying harbor sediments after they had been disposed of in the lake.

The effects of dredging were studied in some harbors by sampling during dredging, upstream and in the vicinity of the dredging operation, and after dredging. Sampling proceeded before, during, and after disposal to determine the effects on the lake environment.

In general, the means used to evaluate the environments and effects of dredging and disposal produced useful information for all but open-lake disposal areas. What happens to harbor sediments disposed of in the lakes, however, remains an unsolved question. Complete data that would provide definitive answers to this question probably cannot be obtained at the present time. On the other hand, bioassays of various harbor sediments proved to be useful indicators of possible effects of disposing of these sediments in the open lake. Although the extent to which the results of the laboratory studies made can be applied to the natural situation is not known, functional testing did, indeed, provide valuable data to evaluate the feasibility of using different treatment methods for the sediments.

9.6.3 Evaluation of Harbor Surveys

One of the major problems in interpreting harbor reports has been the lack of uniformity in sampling and laboratory procedures, in the analysis of the data obtained, and especially in the presentation of the results obtained. The selection of sampling sites and sampling equipment and procedures had direct bearing on the information made available about the harbors and lake disposal areas. In most instances, a single sample was taken at a given station and the data obtained were treated as being representative in spite of variations in sediments between mid-channel and channel banks. Furthermore, the kind of sediment obtained is a function of the sampling device. Thus, the Ekman grab will collect a sample of fine sediment without disturbing it greatly but is too light to collect a representative sample of coarse or hard-packed sediment. To the contrary, the heavier grabs, such as the Petersen and Shipek grabs, will collect representative samples of coarse sediments but not of fine sediments because of the disturbance they produce as they descend.

Despite these obvious sampling, analytical, and reporting problems, a substantial amount of useful data has been made available, and some of the data have been used by FWPCA to establish certain preliminary empirical criteria for the degree of pollution of harbor sediments. While field observations of the color, odor, physical nature of sediments, and fauna appear to be useful, objective analyses for ammonia, COD, oil and grease, total phosphorus, and volatile solids would be more valuable for determining the degree of pollution of harbor sediments. An evaluation of the results of the bioassays of the sediments conducted at the University of Wisconsin suggests a relationship between the chemical nature of the sediments and their toxic and algal-growth-promoting potentials. The sediments were categorized in the University of Wisconsin report as falling into one of five groups. Sediments in category 5 were toxic and limited algal growth; sediments in category 1, the "cleanest" sediments, were non-toxic and stimulated algal growth. Ammonia, chemical oxygen demand, volatile solids and phosphate content of the sediments progressively increased from category 1 through category 5 (see Fig. 37). Consequently, by combining FWPCA and University of Wisconsin results, it appears that visual observations of sediments, while useful, should be supplemented by objective criteria for ammonia, chemical oxygen demand, oil and grease, total phosphorus, and volatile solids in order to determine the degree of pollution of sediments.

The data obtained indicate that dredging exerted little influence on harbor-water quality, especially in harbors where the waters were "heavily polluted," i.e., where they possessed a high background of turbidity, total suspended solids, volatile solids, ammonia, and phosphorus. In harbors where some effect of dredging was detected, at Rouge River and Great Sodus Bay, for example, it was found to be temporary. At Buffalo, Cleveland, and Great Sodus Bay, dredging was shown to improve the harbor environment through removal of polluted sediments.

The results of the various surveys and studies suggest that sediments from many harbors would be considered "polluted," toxic to some animals, and would stimulate growth of phytoplankton and Cladophora. It is also evident that sediments vary considerably in their degree of pollution, not only among harbors, but also within a given harbor.

Evidently, the studies undertaken and the sampling done in open-lake disposal sites could not yield wanted information, and considerable doubt remains about what happens to the dredged material after it has been dumped in a lake, and about the effect the material exerts on lake-water quality and biota.

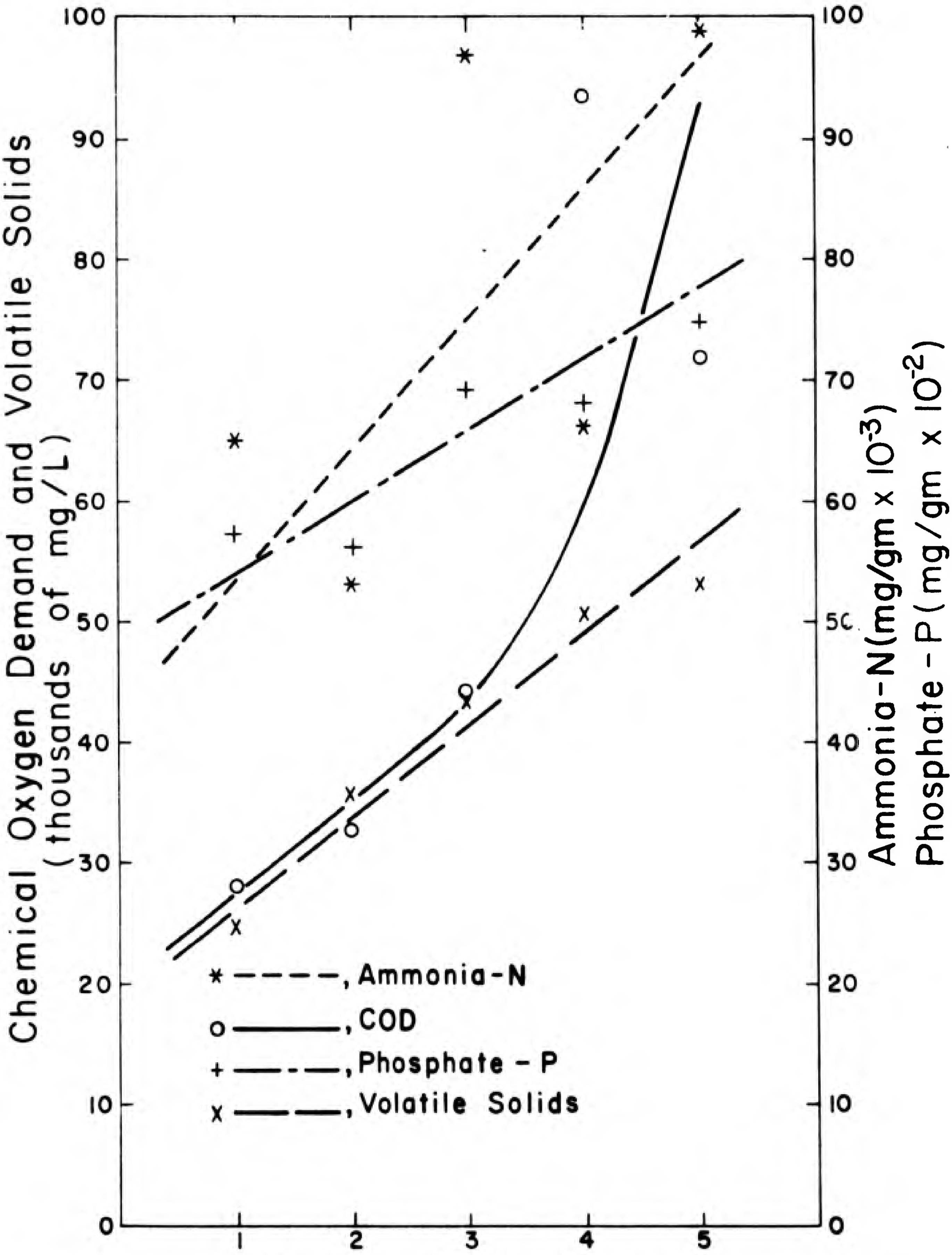

Figure 37 Harbor Sediment Analysis by University of Wisconsin

Open-lake disposal of "lightly polluted" sediments apparently has not brought about a disappearance of "clean-water" organisms. An example is the open-lake disposal site for Great Sodus Bay sediments. The lack of organisms or the dominance of pollution-tolerant organisms in disposal areas may be due to "highly polluted" sediments, or it may indicate a previously deteriorated environment. Nevertheless, the results of the bioassays at the University of Wisconsin did show that harbor sediments, in very low concentrations, were toxic to planktonic and bottom animals and stimulated growth of phytoplankton and *Cladophora* under laboratory conditions. Possible effects of dredgings are not necessarily limited to the disposal site, especially if the sediments are dispersed over a much greater area by wave and current action. The effect on water quality, while not showing up in some gross measurements such as that of turbidity may yet be sufficient to stimulate the growth of phytoplankton and *Cladophora* at considerable distances from the disposal area. As pointed out in Appendix C2, "Deposition of (harbor) sediments in the lakes...injects the spoil material into a medium with which it is not in equilibrium."[1]

The Board's detailed comments on the harbor surveys at the eight pilot areas are incorporated into the Corps analyses presented in Section 6. In addition, the Board evaluated a number of other harbor surveys and their comments are attached as Appendix C1, which also includes specific recommendations and conclusions about some of the following harbors:

Alpena, Michigan
Ashtabula, Ohio
Au Sable, Michigan
Bayport, Michigan
Black River, Michigan
Bolles, Michigan
Caseville, Michigan
Charlevoix, Michigan
Cheboygan, Michigan
Clinton River, Michigan
Conneaut, Ohio
Detroit River, Michigan
Erie, Pennsylvania
Fairport, Ohio
Frankfort, Michigan
Grand Haven, Michigan
Grand Marais, Michigan
Hammond Bay, Michigan

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[1] FWPCA, Appendix C2, p. 23.

Harbor Beach, Michigan
Harrisville, Michigan
Holland, Michigan
Inland Route, Michigan
Kenosha, Wisconsin
Kewaunee, Wisconsin
Leland, Michigan
Little Lake, Michigan
Lorain, Ohio
Ludington, Michigan
Manistee, Michigan
Manistique, Michigan
Manitowoc, Wisconsin
Milwaukee, Wisconsin
Monroe, Michigan
Muskegon, Michigan
New Buffalo, Michigan
Oconto, Wisconsin
Oswego, New York
Pensaukee, Wisconsin
Pentwater, Michigan
Portage Lake, Michigan
Port Austin, Michigan
Port Clinton, Michigan
Port Sanilac, Michigan
Port Washington, Wisconsin
Racine, Wisconsin
Saginaw, Michigan
Sandusky, Ohio
Saugatuck, Michigan
Sebewaing River, Michigan
Sheboygan, Wisconsin
South Haven, Michigan
St. Joseph, Michigan
Sturgeon Bay Ship Canal, Michigan
Traverse City, Michigan
Two Rivers, Wisconsin
Waukegan, Illinois
White Fish Point, Michigan
White Lake, Michigan

9.7 Evaluation of Control Measures

9.7.1 General

Operationally, dredgings are removed from channels and harbors during sequences of a relatively few 24-hour days within a given dredging season. Depending upon (1) the rate of shoaling by incoming sediments, (2) the expansion and modification of shipping and harbor facilities, and (3) the intensity of harbor traffic, channels and harbors are usually dredged annually, occasionally more often, and in some instances at longer intervals of time. The accumulated sediments differ in quantity and quality from place to place and from season to season. Within a given harbor system, likewise, they differ from area to area and from time to time with the locality that is being dredged.

In view of the techniques and vessels that have been developed for the present methods of dredging and lake disposal, it is likely that the system now in use is a least-cost operation. This is not to say that other methods of disposal would not yield benefits that would offset the additional costs that might be incurred by use of alternate methods.

In the absence of offsetting benefits, though, economic restraints on the disposal of dredgings point back to the lake as the recipient of dredgings until more is known about the long-range possibilities of managing the Great Lakes water resource in its manifold aspects. Of exemplary importance is an integral evaluation of possible effects of plans (1) of FWPCA and other agencies of government - local, state, national, and international - to control the pollution of all waters tributary to the Great Lakes, (2) of the Soil Conservation Service to mitigate the erosion of agricultural and forest lands; and (3) of the Fish and Wildlife Service and other government agencies to protect spawning areas for fish, to provide sanctuaries for birds and game, and to develop recreational areas for the regional population. Indeed, the problem of disposing of Great Lakes dredgings is surrounded by so many uncertainties that whatever is done must be accepted as at best an <u>ad hoc</u> and temporary solution that should remain open for reexamination from time to time and place to place.

9.7.2 Control of Upstream Areas

9.7.2.1 Upstream Sources of Wastes and Their Effects

The discharge of wastes does not in itself create environmental pollution. Pollutional effects come into being only when discharges are of such intensity and duration that they impair the normal functioning of biological and physical components of the environment or create detrimental consequences for human users of the environment.

It has been indicated previously that a substantial portion of the dredging operations of the Corps of Engineers is devoted to the function of regional wastesmanagement and disposal for the various river basins tributary to the Great Lakes. Waterborne wastes are discharged from a multitude of upstream sites by industrial, agricultural, municipal, and other governmental institutions.

Upstream institutions produce two basic forms of wastes affecting the dredging operations of the Corps of Engineers. Liquid wastes, functioning as chemical nutrients and toxicants, originate from cities, industries, farms, and government agencies such as highway departments during highway de-icing operations. A variety of solid wastes, which may be chemically active or inert, are also produced by these institutions. When excessive amounts of such wastes are discharged into watercourses and harbors they have detrimental consequences for selected components of the environment. Three important types of dysfunctional effects may be distinguished as follows: (1) pollution of water by chemicals; (2) pollution of soils and sediments by chemicals; (3) pollution of watercourses, harbors, and lakes by sediments.

Pollution of streams, harbors, and lakes by sedimentation warrants far greater attention than it has received to date in pollution abatement programs. Silt, derived largely from agricultural, urban, and accelerated stream channel erosion, is by far the most important solid waste produced in terms of quantity.

The basic sources of sediment are similar in the various river basins. The relative importance of each source varies widely, however, depending upon the proportions of urban, agricultural,and forested lands. In heavily urbanized river basins construction activity produces a significant share of total sediment output.

Although erosion is a natural geological process, its natural rate has been greatly accelerated by urban and industrial development, forestry and agricultural operations, and the construction of highways and drainage systems. In agricultural areas,continuing operations such as deforestation, agricultural drainage, land forming, fertilization and cultivation have greatly modified the natural characteristics of soils, topography, and hydrological relationships. It is such man-induced erosion that is largely open to control by modification of the technologies and the cost accounting methods utilized by the various institutions in each river basin.

9.7.2.2 Need for Comprehensive Wastes Management Programs for River Basins

The need for adequate upstream wastes management in order to attain the objective of improving the quality of the biophysical environment of the Great Lakes Basin raises the question of the adequacy of current pollution abatement programs. Because of greatly increased social complexity, modern society is in a period when complete environments, as distinguished from the separate components of water, land, cities, and agriculture, are becoming the focus of legislation and the administration of public services. This new ecological approach to public administration of environments is based upon a growing consensus regarding human rights in a healthy environment as such, where environment is viewed as a necessary basis for human existence and as fundamental to human values.

If the ecology of the Great Lakes is to be maintained and improved, programs for wastes management must be implemented for each of the major institutional classes whose operations generate wastes. Resolution of the specific problems presented by polluted dredgings requires recognition of the pollution of rivers, harbors, and lakes by sediments as a major form of pollution. It would then be accorded equal emphasis with pollution by municipal and industrial wastewaters and other types of wastes in public programs for pollution abatement.

Municipal and industrial wastewaters are progressively receiving higher levels of treatment under recent Federal and state pollution abatement programs. However, even with the improved handling of these wastes, there remain the sediments generated by urban, agricultural, and construction runoff. If unabated, these persisting wastes will reduce the efficiency of municipal and industrial investments for wastewater treatment, retard the improvement of water quality, and continue to generate polluted sediments in rivers and harbors, thus perpetuating the spoil disposal problem of the Corps of Engineers. Uncontrolled erosion and resulting sedimentation will intensify its adverse effects on tributary streams, harbors, and shorelines during summer low-flow periods by degrading water quality in the vicinity of heavily populated areas precisely when the demand for high-quality water is greatest. Disproportionately high social costs will result.

The foregoing considerations suggest that to be effective, regional programs for wastes management must be addressed simultaneously to all of the main forms of wastes and concerned institutions. Where this situation does not obtain, as in the case of land erosion and runoff, the value and marginal efficiency of investments for higher levels of treatment of one single type of waste may be canceled by the consequences of other uncontrolled wastes in the environment.

Agricultural runoff is known to be a significant source of nutrients, as well as sediments and toxic biocides. Farm-land erosion, together with induced stream-bank and -bed erosion, generally produces the largest volume of sediment. Even with adequate future management of municipal and industrial wastes, uncontrolled surface runoff will accelerate the deterioration of water quality in tributaries and harbors. The effects of high levels of wastes treatment by the Corps of Engineers, industries, and municipalities may then be canceled out.

Long-term trends in agriculture indicate more intensive use of fertilizers and biocides and the production of greater amounts of animal and crop wastes, all of which suggest increasing pollution of sediments reaching rivers and harbors in the future. At the same time, public programs for upstream erosion control may continue to be focused upon the actions of individual land owners outside an environmental context. As the history of the soil conservation movement indicates, erosion control measures have not yet been granted the necessary river basin prespective.

The Soil Conservation Act of 1935 was the first recognition of soil erosion as a national problem requiring a permanent program of action. It was the reaction to continuing indifferences to soil erosion throughout the country and pointed up the need for improved methods of reducing erosion. The program was implemented through a voluntary system of grants-in-aid to farmers who agreed to install particular soil and water conservation practices on their lands.

It is administered locally by soil conservation districts which are official units of government created under state law and generally coterminous with county boundaries. Soil conservation districts have had to operate with farms as they exist. Hence, they normally develop erosion control plans within the rectangular configurations created by the land survey system of the U. S. This lack of relationship to topographic and ecological patterns has limited the effectiveness of control measures when they have been applied.

During the 1930's soil conservation was a major social and political movement equivalent in strength and public involvement to the contemporary movement for pollution abatement and enhancement of environmental quality. The early emphasis in the program was upon erosion control. It is of interest to note that one of the objectives stated in the Soil Conservation Act of 1935 is that of protecting rivers and harbors from the adverse effects of erosion, which apparently reflected Congressional intent. In later decades the focus of the program gradually shifted from the multiple-purpose control of soil erosion to individual farm management for greater economic productivity.

Government subsidy has been a widely used incentive throughout agriculture, and a major motive for soil conservation is increased private income. However, the installation of soil conservation facilities does not generally increase the market value of farm properties by an equivalent amount. Soil erosion control measures also do not promise large operating profit margins for farm operation. Only selected conservation practices promise to be highly profitable under normal market conditions while many involve potential losses.

Few farmers therefore, are compelled to use land and water so as to minimize the social costs of land erosion and runoff to river basins. Farmers have remained subject to the principle of encouragement by subsidy, and soil erosion control is still largely oriented, as a program, to individual farms for maximizing private returns. Land use regulations that compel conservation practices on farms are included in the powers of most of the standard soil conservation districts in addition to the power to assist farm operators in controlling erosion on a voluntary basis. Reliance, however, has been placed primarily on voluntary cooperation. Only a very few districts have enacted land use regulations. These rare instances have (1) required practices to prevent wind erosion, (2) regulated grazing of open-range land, and (3) prohibited the plowing of sod land and the like.

This approach to agricultural erosion and runoff stands in sharp contrast to the compulsory Federal and state legislation directed to municipal and industrial pollution abatement. Considering the voluntary and fragmented status of agricultural wastes management, this represents a major discrepancy among the principal social institutions generating environmental wastes. This gap in pollution abatement seriously qualifies the national program for improving water quality.

Present pollution abatement controls for upstream areas do not, therefore, provide adequate wastes management programs for river basins in the Great Lakes Region. Under these circumstances the Corps of Engineers is asked to fulfill its responsibilities in the absence of basin-wide pollution abatement plans and of time perspectives composing necessary frameworks within which to program and evaluate alternative methods of disposing of polluted dredging spoil.

It is well known that sharply increased marginal costs are involved in attaining progressive degrees of wastes reduction. Marginal costs for units of wastes reduction will vary widely among the various institutions generating different types, quantities, and geographic distributions of wastes in the various river basins. The further existence of uncontrolled wastes production by agriculture and land runoff destroys the possibility of scheduling and predicting definite improvements in water quality in rivers and harbors. Given these conditions the problem of planning efficient investments for treatment of spoil and evaluating their results in terms of contribution to water quality becomes an almost impossible task.

Upstream controls, therefore, need to be established as a necessary and meaningful framework both for rational planning in the disposition of dredgings and for achieving public water-quality objectives. To this end, the objectives of the soil conservation program need to be expanded to include the reduction of the social costs of agriculture and the improvement of the quality of the environment. The program should be made more complimentary to other environmental management needs such as protecting rivers and harbors, controlling urban runoff, and improving water quality.

9.7.3 Modification of Dredging Practices

9.7.3.1 General

The Board has suggested that the present dredging and disposal practices of the Corps of Engineers should be evaluated with the aim of determining if modifications are needed. The choice of dredge types is limited to the available equipment that will accomplish the work. As pointed out in Section 4, the Corps normally uses the hopper dredge for maintenance dredging on the Great Lakes when the work is accomplished with Government-owned equipment and the clamshell dredge when the work is performed by contractor-owned equipment. At present, adequate data are not available on which to base a comparison of the several types of dredges as to their effects on lake ecology when handling polluted sediments. The modifications considered in the following sections relate to measures that can be applied in the interest of reducing pollutional effects.

9.7.3.2 Selective Dredging

Selective dredging from the point of view of separating polluted sediments from relatively clean sediments, for separate disposal, could be adopted in some locations. To do so would require a more elaborate sampling program and evaluation of samples prior to dredging. The extent of such sampling would vary with the pollutional characteristics. Selective dredging is not necessary for either a thoroughly polluted or a thoroughly clean harbor, but has merit for a channel where clean and polluted sediments occur unmixed. This is corroborated by the harbor reports discussed in Section 6 and Appendix C1. Selective dredging in respect to depth is not feasible. Tests have shown that the sediments at any single point are relatively uniform to the depth of usual maintenance dredging.

The season or time of year may possibly have an effect on the nature of dredged sediments, but this has not been thoroughly documented. If the results of further investigations show merit, dredging could be scheduled to clear certai harbors, e.g., those predominantly silt-laden in constrast to those polluted by municipal or industrial wastes, at times when the sediments are clean.

Related to selective dredging is the consideration to dispose of hopper-dredge overflow separately, e.g., to an impoundment or to a municipal sewer. Thus, the cleaner and coarser material retained in the hopper might be suitable for deep water disposal or for washing or treatment followed by lake disposal.

9.7.3.3 Control of Leaks and Other Losses

Scows and hopper dredges enroute from dredging site to disposal area frequently leave behind a trail of discolored lake water because of leaks or spills. Proper maintenance of equipment and operating procedures for prevention of leaks and overflows could avoid this.

In some harbors, notably Indiana Harbor, Buffalo, and Cleveland, floating oily wastes are a problem throughout the harbor area. There is flotation of additional oily wastes when bottom sediments are disturbed during dredging operations. Where dredging is performed by hopper dredge, the oil slicks can be minimized by avoiding overflows during dredging. Oil should not be a problem during transport of dredgings if proper preventive measures are taken, although it may become troublesome at the disposal area. The weighted gate on the MARKHAM class dredge or the weir gate on the LYMAN class should be installed on all Great Lakes dredges.

9.7.3.4 Stationary Dumping

The standard practice for discharging a scow or hopper dredge in the open lake, or a scow in an enclosed lagoon, is to make a sweep of the area while the dredgings are being dumped. This leaves a large area of turbid water which would not be created if the vessel were brought to a halt before dumping. However, stationary dumping would be more costly because of the increased time required, and the possible improvement would probably not be great enough to warrant the expense.

Almost nothing is known of the ultimate fate of dredgings dumped in the open lake. It is probable that stationary dumping would blanket a smaller area to a greater thickness of deposit, although water depth would have a major effect on both area and thickness. Stationary dumping should also provide decreased opportunity for washing and leaching pollutional materials from the heavier components as they sink through the water, and so should result in less deterioration of lake-water quality. In the absence of quantitative data on these aspects of dredging, either short- or long-term, the Board nevertheless recommends that further study be made of stationary dumping.

9.7.3.5 Dumping at Lake Bottom

It has been suggested that dredgings disposed of by open lake dumping be deposited in or near the bottom, instead of being dropped to the bottom after release near the surface. Tha aims are similar to those of stationary dumping: decreased surface (visible) pollution; decreased area of bottom covered; and decreased washing and leaching into lake water.

Studies by the Philadelphia District of the Corps of Engineers indicate that deep disposal could be accomplished, but that operating costs would be increased by $0.06 per cubic yard (see Section 7.3.2.2).

Discharge into the hypolimnion is a special refinement of the deep discharge concept, but it appears to have no particular merit and would add to cost because of the associated increase in travel distances for dredging vessels. Municipal water intakes frequently draw water from the hypolimnion, to take advantage of the colder water found there; hence disposal in this region may have to be avoided. In Lake Erie, in particular, dissolved oxygen in the hypolimnetic water is often critically low and additional organic pollution can then not be tolerated.

The Board encourages the Corps of Engineers to further investigate and evaluate deep-water disposal to determine whether or not there are decreased surface pollution, decreased area of bottom coverage, and decreased washing and leaching into lake water. In addition, studies should be continued on reduced dredge-loadings and reduced pumping speeds as a means to control surface pollution in dredging areas.

9.7.4 Treatment of Dredged Materials

9.7.4.1 General

Within limits, the dredgings from channels and harbors can be categorized as either clean or polluted. The amount and character of unwanted substances determine their classification as one or the other. Unwanted substances are those affecting the ecology of the lake waters unfavorably. Added in sufficient amounts over a long enough time, they result in the eutrophication of lake waters in varying degree. However, some types of dredgings may also poison the waters or render them otherwise objectionable without eutrophication being the determining factor.

There are two major ways of managing the quality of dredgings and their disposal with or without treatment: (1) selective dredging of clean and polluted dredgings with treatment of the polluted dredgings only, and (2) integral collection, treatment, and disposal of all the dredgings from a given channel and harbor system. Each way presents its own difficulties.

For purposes of conserving the size of treatment units, dredged sediments must be accumulated at the treatment site during dredging operations and stored for the period between dredging cycles. Where this is an annual cycle, storage must probably be for as much as a year.

As part of quantity management, accumulation may be reduced by size-separation of incoming dredgings, more or less immediate disposal of large-sized, relatively clean fractions, and storage of fines and other relatively polluted fractions.

9.7.4.2 Use of Existing Sewage Treatment Facilities

As pointed out in Section 7.4.2, the use of existing municipal treatment and disposal plants has been considered, and a trial operation has been conducted in cooperation with the Greater Chicago Metropolitan Sanitary District.

In considering this approach, it was recognized that the method would be applicable only to locations where exceptionally large systems were available. However, even at Chicago the results indicate that only a relatively small proportion of dredgings can be handled practically because of (1) the great dilution needed to reduce the solids concentrations of the dredgings for transport and (2) the limited excess capacity of treatment units available at most treatment works.

9.7.4.3 Separate Treatment Processes

It is natural, but not necessarily ultimately satisfactory, to draw upon engineering knowledge of established methods of wastewater treatment and, in particular, of the treatment of wastewater sludges and slurries in a first analysis of the presumable effectiveness and economy of the treatment of dredgings. This has been done by Nebolsine, Toth, McPhee Associates (Appendix C6) with due consideration of the data provided by the study conducted at the University of Wisconsin (Appendix C5).

The conclusion in Appendix C6 is that multi-hearth incineration is probably the most immediately economical method of treating dredgings at an on-shore installation not far from the source of dredgings. Whereas it may be assumed that this type of incineration will consume the combustible fraction of the dredgings, the fate of the phosphates in the dredgings is not stated. Presumably, however, the ash would retain much of this mineral. If the ash is to be disposed of in the lake, studies of the effects of this material on the lake environment and of possible methods of removing phosphates before discharge must be conducted.

A close competitor with multi-hearth incineration is aerobic stabilization, which can draw upon the advantage of a diked enclosure serving both as a storage and a treatment unit. Whether such stabilization ponds could be operated successfully as anaerobic units during cold weather will have to be determined.

In comparing annual costs for alternate diked disposal areas with treatment by multiple-hearth incineration or aerobic stabilization, indications are that at certain locations one or both of the treatment methods may be competitive from the cost point of view. Thus, where disposal other than to the open lake is necessary, a careful evaluation to determine least cost among the alternatives should be made.

Other treatment methods included in Appendix C6 were: anaerobic digestion, aerobic treatment in aeration tanks, chemical oxidation with chlorine, wet oxidation and fluid-bed incineration. None of these seemed to compete economically and operationally with aerobic stabilization ponds and multi-hearth incineration.

9.7.4.4 Treatment on Board Dredges

Various methods were considered and some tests conducted for treatment of dredgings on board vessels. These fall into three main categories: flocculation with coagulating chemicals and polyelectrolytes; aeration; and chlorination.

Because of short contact time, the benefits derived from aeration are not significant. Although flocculation and chlorination are technologically possible, the problems of implementation as well as the costs are prohibitive.

A characteristic of the hopper dredge is to wash and sort the material. Consideration should be given to additional washing on the dredge and disposal of the wash water to a diked area for treatment.

9.7.5 Diked Disposal Areas

Diked disposal areas for dredgings can be developed (1) on land not too distant from the dredging area to be reached with economy (Example: Green Bay, Wisconsin); (2) along shore adjacent to or within the harbor dredged (Example: Cleveland, Ohio); or (3) within the lake in close vicinity of the channels and harbors dredged (Example: Toledo, Ohio).

9.7.5.1 Construction of Diked Enclosures

The primary purpose of placing dredgings on low-lying land is to dispose of the dredgings. A secondary purpose is to bring a well-located area up to grade at reasonable expense in order that it may serve as a useful recreational, commercial, or industrial site. On the Great Lakes, the spoil used so far for this purpose has been derived largely from new-work hydraulic dredging. Maintenance dredgings - not unlike the core materials of hydraulic-fill dams such as those in the Miami Conservancy District - cannot be expected to consolidate enough to bear the loads of sizable structures directly. Necessary support will have to be provided by piles or excavation to solid base. Sand drains would probably not perform satisfactorily. On-shore and in-lake sites can normally be filled with materials conveyed to them by most of the dredging methods presently employed on the Great Lakes. On-shore sites in harbors and channels, by straightening harbor lines, may aid in the development of harbor facilities and provide useful commercial or industrial sites. Other on-shore sites as well as in-lake sites might be transformed into recreational areas.

Dikes are normally constructed of locally available materials, including new-material dredgings in some instances. The factors governing the movement of water and included pollutants into and out of diked enclosures are considered in detail in the report by R. C. Scott, "Geochemical Summary of Polluted Sediments in Great Lakes Dredging Areas" (Appendix C2).

9.7.5.2 Filling Diked Enclosures

For diked areas situated in a harbor or in the open lake, monitored tests at Buffalo, New York, in 1968 have shown that dredgings are best discharged by pumping directly from scows to the diked area, necessary carrying waters being drawn from the enclosure. Similar hydraulic arrangements can be made for unloading hopper dredges.

Intermediate release of dredgings into a slip or similar partial enclosure, followed by hydraulic pick-up of the discharged dredgings for transfer to the diked area, cannot be considered useful unless it can be shown that curtains of air bubbles or some other protective system can prevent the escape into lake or harbor of dredgings or washings from temporarily deposited dredgings.

9.7.5.3 Management of Enclosures

As yet, the implications of fully managing diked disposal areas to stabilize organic materials have not been explored adequately. That they deserve to be is demonstrated by the experiences at Cleveland, Ohio, in the summer of 1968. Aeration of sediments in stabilization ponds has been investigated by Nebolsine, Toth, McPhee Associates (Appendix C6). The Board recommends further exploration of this operation, including its testing in a pilot plant. In addition, other experimental management procedures should be investigated including the nature and degree of nuisance that may be associated with degradable diked spoil.

9.7.5.4 Further Studies of Spoil Enclosures

In the opinion of the Board, the large-scale experimental enclosures that have been built to serve selected harbors should (1) be kept under surveillance for a number of years and (2) further laboratory and field investigations of specific properties of the sediments in these enclosures should be continued in order that their response to a variety of environmental conditions can be ascertained. The information developed should then be put to use in the construction and management of all types of disposal areas.

Clearly, it should be possible to find areas of lake bottom with environmental exposures that are not too different from those possessed by diked enclosures. To be sure, for a given volume of sediment the area of contact is different. Nevertheless, it may be possible so to discharge spoil into the open lake as to minimize the interfacial contact between sediments and water. It may be possible to prepare in-lake disposal sites by suitable excavation-and-fill for storage of sediments under optimum conditions. The development of deep cut-and-fill operations can be envisioned to this purpose.

9.8 Alternate Sites and Methods

9.8.1 Summary of Alternate Locations and Methods Constituting the Potential Technology of Navigational Maintenance

The major technologies presently available for maintaining and potecting navigational waterways in the Great Lakes together with means for handling and treating associated solid and liquid wastes are summarized below. Alternate sites for sediment removal are basically divided into downstream harbor locations and upstream sites. Similarly, alternate sites for disposal are either harbor related or inland sites. The alternate means for dredging, transporting and treating spoil have been previously described in the present report. The role of alternate methods for sediment reduction and control are of great significance and are discussed in the following sections.

Alternate Locations For Sediment Removal and Disposal

Alternate Sites for Sediment Removal	Alternate Sites For Sediment Disposal
Harbor-Channel Sites	In-Lake Open Sites
Upstream Sites	In-Lake Diked Sites
	On-Shore Diked Sites
	Wetland Sites for Landfill
	Upland Sites for Land Contouring

Alternate Methods For Handling Sediments

Sediment Removal Methods	Sediment Transportation Methods	Sediment Treatment Methods
Dipper Dredge	Scow	Incineration
Clamshell Dredge	Hopper Dredge	Municipal Treatment
Pipeline Dredge	Pipeline	Stabilization Pond
Hopper Dredge	Truck	Flocculation
Dragline Excavator	Belt Convevor	Aeration
Multi-Bucket Excavator	Railroad	Chlorination

Alternate Methods For Sediment Reduction & Control

Institutional Sediment Reduction Methods

- Agricultural Erosion Control Measures
- Urban Erosion Control Measures
- Industrial Wastes Reduction
- Municipal Wastes Reduction

River and Sediment Regulation Methods

- Bank and Shoreline Stabilization
- Upstream Sedimentation Basins
- Bedload Traps
- Spur Dikes
- Training Dikes

9.8.2 Need for Evaluation of the Comparative Efficiency of Conventional Maintenance Dredging and Disposal Methods

Maintenance dredging has been carried on by the Corps of Engineers at Federal projects for over a century. At present about fifty larger commercial harbors require annual maintenance dredging while the remaining smaller harbors require such dredging every two to five years. Existing harbor developments require about ten million yards of annual maintenance dredging.

Conventional dredging equipment and methods have evolved in a historical period when the objectives of government programs were frequently single purpose and emphasis was placed upon minimizing direct monetary outlays by the public for environmental maintenance. Continuing growth of population and industry, together with recent concern for pollution abatement, improved water quality, and the ecology of the Great Lakes, have served to broaden the required framework for designing and evaluating dredging operations to consideration of the river basins surrounding the Great Lakes.

When maintenance dredging is viewed in an expanded river basin context as a downstream waste management function, abating the navigational damages created by upstream sediments, it can no longer be assumed without further analysis that conventional dredging and disposal methods represent least cost operations.

Culturally produced sediments constitute the bulk of maintenance dredgings. Land erosion and sedimentation in river basins are environmental dysfunctions which generate a wide range of social costs. Public and private investments and facilities of various kinds including dredging, are necessary to control such dysfunctions. In this context, however, conventional maintenance dredging and disposal operations represent only one of various feasible control methods, all of which require evaluation as to their technological, social, and economic efficiencies.

The principle of economic efficiency involves comparative evaluation of the flow of benefits and costs resulting from different control and abatement methods. Efficient expenditure decisions therefore require identification of sediment control measures that will be most effective. To illustrate, for any given river basin how would the application of selected river regulation and sediment control methods, as outlined previously, compare with maintenance dredging for cost effectiveness? How would land treatment methods compare? In which stream reaches or sub-basins would various sediment controls be most effective? How would such costs compare with maintenance dredging costs over a fifty year time horizon?

The problem of maintenance dredging is analogous to the case of a highway department having a highway facility that is periodically damaged by high-water floods arising in the watershed which it traverses. The highway agency is confronted with various choices. It may annually remove silt and reconstruct the roadbed to abate flood damages or it may, after comparative cost studies, arrange to share in the costs of upstream flood control facilities to protect the highway. The relative efficiencies of the two types of expenditures cannot be determined without a general analysis of the situation.

In regard to maintenance dredging, as a method of restoring damaged transportation facilities, surveys of individual river basins are equally required to provide answers to such questions. In the absence of such studies it appears unreasonable to assume or conclude that conventional dredging and disposal methods are the most economical solutions. A few river basins, with unique settlement patterns, may represent exceptions to this general conclusion.

9.8.3 Harbor Versus Upstream Removal and Disposal of Sediments as Location Alternates

The present study of alternate methods of dredging and disposal to improve the ecology of the Great Lakes has, for the most part, given emphasis to alternate methods and locations for the disposal of the sediment with lesser attention being given to alternate methods and locations for the removal of the sediments. One of the few exceptions to this orientation is the study of alternate disposal methods at Cleveland Harbor, Ohio, as described in Section 7.5 of the present report, which resulted in a scheme for an upstream settling basin to collect sediments. The estimated cost of $1.35 per cubic yard is within the normal cost range of conventional dredging and disposal practices, even though under this plan the spoil is disposed of by trucking to rather distant landfill sites. However, as designed it will accommodate only about 45 per cent of the volume of annual maintenance dredging.

The various downstream, harbor-related sites in the Great Lakes available for disposal include in-lake dumping areas, in-lake diked areas, and on-shore diked areas. A major disadvantage of water-related diked enclosures is the high cost of dikes capable of preventing lake pollution and protecting enclosures from destructive wave action. In addition, the limited load bearing capacities of consolidated dredgings limits the future utility and value of filled enclosures to recreational or wildlife habitat purposes, unless additional investments are made to improve their structural characteristics.

Upstream sites available for disposal fall into two categories, the first being wetland, low-lying sites and the second comprising upland sites. Wetland sites generally possess significant disadvantages for long-term sediment disposal. In many urbanized and developed river basins, wetlands are in short supply, having been extensively utilized in the past for sanitary landfills and industrial expansion. Secondly, because of extensive human settlement, they are highly valued as scarce resources for wildlife habitat. Thirdly, because wetlands are usually integral components of natural water systems performing useful functions in man's habitat such as flood retention, ground water recharge, and drainage, any conversion of these areas destroys such intrinsic functions, creating thereby additional social costs which must then be assumed by the public.

Upland, well-drained sites in most upstream areas are in relatively abundant supply and such sites adjacent to streams possess potentials for disposal of sediments that have not been adequately evaluated in the search for alternate disposal sites. Also, there are numerous sediment control and river regulation devices such as spur dikes, training dikes, and settling basins of various kinds for sediment control and removal which need to be evaluated for application to different types of streams.

Disposal sites close to stream channels and situated in anticipated or existing stream valley recreation or conservation areas would present optimum conditions. In any case, well-selected sites could be built up in height through land contouring with the advice of landscape architects to enhance the scenic and recreation values of the environment. Thus, limited areas could contain very large amounts of sediments without destroying drainage functions and be adapted to progressive development of natural ground cover in harmony with local vegetation. With imagination there are few limits to the varieties of beneficial uses of sediments. For example, Chicago has created a sledding hill from solid wastes. Other cities have used expressway spoil for similar land contouring and sculpturing purposes.

Depending upon local conditions a variety of holding areas, lagoons and limited earth dikes might be associated with such upstream operations. In some instances relatively small-scale installations might prove to be the most efficient. Sediments are a high-weight and low-value product and in such cases the economies of increased scale of operations are quickly canceled by increased transportation costs.

In summary, upstream removal and disposal gives promise of having significant potential advantages, compared with the costs and environmental effects of conventional dredging and disposal operations in inner harbors and channels. It is recognized that hydrologic, topographic, and land use patterns of river basins vary greatly and that upstream methods would not be feasible for some basins. However, it appears that upstream methods are adaptable to the majority of river basins in the Great Lakes and that the following potential benefits of such alternate methods are significant enough to warrant study and evaluation:

a. Minimize or eliminate diking costs.

b. Reduce distances from removal sites to disposal sites, thus reducing the transportation cost component.

c. Improve water quality, stream ecology, and generate multiple economic and social benefits along downstream reaches of rivers and in harbors.

d. Reduce stream transport loads of sediments, pollutants, and nutrients thus retarding eutrophication processes at critical harbor, bay, and shoreline points in the Great Lakes.

e. Possibilities of using dry or nearly dry operations and a large range of mobile, land-based equipment.

f. Possible future economies resulting from integration with evolving metropolitan and regional solid wastes management programs.

g. Enable the conservation of wastes for potential processing and recycling into productive use by future generations.

h. Enhance scenic and recreation values of the landscape.

i. Monetary costs equal to or lower than alternate inner harbor operations.

j. Possible benefits arising from integration with evolving river renewal programs.

9.9 Conclusions and Recommendations

Probably the most important point the Board can make at this juncture in the cooperative study of workable means for the safe disposal of dredgings from the harbors, rivers, and channels of the Great Lakes is that the study so well begun be continued with vigor in the coming years.

9.9.1 General Considerations

The sediments laid down in the harbors, rivers, and channels of the Great Lakes are derived from sources far and near and contain both natural and cultural pollutants in varying amount and concentration. By far the largest volumes of sediment have their origin in soil erosion and the sediments constitute in this sense hydraulically selected samples of the surface materials from the catchment area of the Great Lakes. The pollutional constituents of these sediments come principally from the associated natural flora and fauna and the related decaying organic matter and products of decay.

Generally smaller in amount, but in some instances of considerable local magnitude, are the sediments flushed into the natural drainage channels of the region by runoff from agricultural and cultivated lands. Normally least in amount but often of prime importance in connection with the disposal of dredgings are the sediments contained in the runoff from municipal and industrial areas and in the discharges from municipal and industrial wastewater systems.

Because the catchment area of the Great Lakes is large and the shorelines of the Great Lakes are long, because the harbors are many yet widely scattered, and because the harbors differ in their natural setting and the activities and uses of the resource by man, the harbors and their sediments are basically different, although not necessarily totally dissimilar, in many of their aspects. Moreover, because some harbors serve major urban and industrial areas and are open to commercial shipping, whereas other harbors are small and serve primarily for recreation, the character and degree of pollution of their sediments differ appreciably. Finally, the hydrology of the region and consequent relationships of harbor to lake influence the flushing rates and exchanges of harbor and lake waters.

It follows that full cognizance should be taken in studies of Great Lakes dredgings that each harbor system is unique and that by imaginative local planning alone can workable means for the disposal of dredgings be implemented.

At the planning level, moreover, it is necessary to foresee and determine with whom the responsibility should rest to devdlop and maintain harbors, to provide efficient disposal sites, and to abate pollution.

9.9.2 Impact of Present Dredging and Disposal Methods on Water Quality

Up to the present time the usual method of disposal of dredgings from harbors, rivers, and channels is their discharge from dredges or scows into the Great Lakes at prescribed sites, situated normally at suitable depths, in the open lake at convenient distance from harbor entrances. Just what the long-term impact of this practice will be on lake eutrophication and useful water quality cannot yet be stated unequivocally, in the opinion of the Board, even though it must be acknowledged that in-lake disposal of heavily polluted dredgings must be considered presumptively undesirable because of its long-term adverse effects on the ecology of the Great Lakes. This is evidenced among other things by the results of bio-assay tests that have been made at the Board's request.

In view of this conclusion, the Board recommends that all harbors being dredged should be studied intensively to ascertain the causes and degree of their pollution and their response to dredging and extensively to assay the magnitude and variance of associated lake pollution and of environmental pollution produced by necessary disposal of their dredgings. Investigations of this kind can, furthermore, provide the basis for priorities for pollution abatement in Great Lakes harbors by indentifying the most critical situations and the order of their attack. A correctional campaign based on inadequate evidence may be self-defeating.

9.9.3 Effects of Maintenance Dredging on the Harbor Environment

The effects of maintenance dredging on the harbor environment are generally limited to temporary increases in turbidity and suspended solids. Oil slicks can occur also, but they do not appear to be indigenous to dredging alone. For the most part, no significant lasting changes were noted; and in some cases the effects were masked by existing heavy pollution.

In reference to effects downstream from the dredging area, the following statements are of note for (1) Calumet and (2) Indiana Harbor: (1) "The results of the four samples taken 1000 feet above and below the dredge on the Calumet River reveal no significant differences in water quality due to dredging activity, although downstream from the dredge there was a slight increase in suspended and dissolved solids and turbidity"; (2) "In Summary, there is a short-term aeration of water during the dredging operations (at Indiana Harbor)."[1]

Limited data from Buffalo, Cleveland, Great Sodus Bay, and Green Bay indicate that removal of dredge spoil improves the sedimentary environment. However, there is no information on presumably associated improvement in water quality.

Oil slicks in entire harbor areas as well as at dredging sites can be contained and removed by several types of commercial equipment. An oil-film control project was begun in July, 1968, by the City of Buffalo and Erie County with the assistance of a Federal grant from FWPCA. The project is to encompass: (1) pneumatic and mechanical barriers; (2) development of instruments for monitoring oil in sewerage systems; (3) providing means for trapping oil in sewerage systems; (4) development of oil sampling devices; and (5) an analysis of costs and economic evaluation of methods derived. This study will help in solving oil slick problems at other harbors.

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[1] The principal references for this and preceding statements are: Appendices A3, A8 and A25.

The assistance of aeration in suppressing anaerobic conditions and resulting unsightly blackening of harbor areas was studied by the Corps as early as 1911.[1] Since then, powerful mobile aeration units have been employed both to keep harbors from icing over in winter and to aerate them in summer.[2] Mechanical and pneumatic devices of this kind might be used to advantage in avoiding or remedying unsightly and malodorous conditions in harbors, rivers, and channels. Indeed they might serve the purpose of converting harbor systems into aerated basins in which incoming sediments are stabilized before they are removed by dredging. Therefore, the Board recommends a broad study of the effectiveness and economy of the aeration of harbor systems by such means. The Board also recommends experimental use of a hopper dredge as an aerator and classifer of sediments in advance of the dredging operation.

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[1] W. M. Black and E. B. Phelps, Report to the Board of Estimate and Apportionment, New York, 1911.

[2] E. L. Thackston and R. C. Speece, Supplemental Reaeration of Lakes and Reservoirs, J. Am. Water Works Association, 58, 1317 (1966).

9.9.4 Limitation of In-Lake Spoil Disposal

Viewed against the total background of natural and uncontrolled cultural pollution, the task of establishing allowable limits for the amounts of specific pollutants introduced into a given lake at a given in-lake spoil-disposal site assumes large proportions. Much remains to be learned before this can be done. Precise information is needed on factors such as the following: (1) dispersion of specific types of sediments and critical components of sediments during and after disposal both in time and area; (2) effect of depth of deposition and accumulation of sediments on water quality and lake ecology; (3) release of nutrients such as phosphorus to lake waters in relation to their pH as well as other properties; and (4) effects of temperature, stratification, currents, and wave action. The full diluting capacity of a lake is not called into action. The dilution effected is governed instead by more nearly local conditions. Thus it has been demonstrated that along-shore water quality may extend 5 to 10 miles from shore and differ appreciably from open-lake water quality onshore and offshore winds as well as shore features exert highly variable influences. Magnitudes and rates of flushing and exchange differ greatly and must receive consideration in evaluating the magnitude and nature of the pollutional load imposed in a given place and the capacity of the water to accept the load. Pollutional effects are determined not only by the lake environment as a whole but thence progressively in greater intensity by more specific local environments eventually down to the microenvironment of individual particulates of sediments during and after they are unloaded from dredges.

In spite of careful planning, much sampling, and extensive analytical work, the studies so far conducted on the fate of dredgings discharged into the Great Lakes have been disappointingly meager in their yield of fundamental information. Because of this, the Board recommended resorting to functional testing of benthal deposits, including their bioassay. Although only a limited amount of this kind of work could be done at the University of Wisconsin in 1968, it has been remarkably fruitful, and the Board recommends that this approach continue to be pursued by the Corps on as broad a scale and front as feasible.

9.9.5 Selection of Open-Lake Disposal Sites

From what has been said in 9.9.4, it follows that practical considerations entering into the selection of open-lake disposal sites are many and wide-ranging. Examples are (1) physical factors such as (a) the nature of the lake bottom, (b) accessibility to dredges, (c) depth in relation to the navigation of small craft, (d) thermal stratification, (e) winds, waves, seiches, and currents, (f) flushing rates and other exchange of water through the disposal area and its surroundings; and (2) ecological factors such as (a) nature of the biota and the biota's use of the lake bottom, (b) existing water quality and pollution, and (c) major uses of the lake water within effective ranges from the disposal area. In relation to ecology, moreover, it should be kept in mind (1) that some areas may be essential spawning grounds for desirable fish species and (2) that the disposal of dredgings may interfere with important water uses, notably municipal and industrial water intakes, bathing beaches, and yacht harbors.

Objectionable open-lake effects are not limited narrowly to disposal sites and dispersal of sediments over wide areas may not be registered only by gross measurements. Additions of substances in trace amounts may produce odors and tastes in lake waters either directly or through the stimulation of growths of phytoplankton at considerable distances from the disposal area.

Hazards of sampling during storms may preclude evaluating the effects of storms on disposal areas unless suitable sampling techniques such as the use of radioactive tracers can be systematized. Feasibility studies of this nature are now being pursued by the Buffalo District. They are commended by the Board.

9.9.6 Future of Open-Lake Disposal

Economic restraints on the storage and transport of dredgings will continue to point back to the Lake as the recipient of unpolluted dredgings until more is known about the long-range possibilities of managing the Great Lakes water resource in its manifold aspects. Hence disposal methods and effects should remain under examination in time and place. For effectiveness and efficiency of operation, the Board recommends that future work of this kind be assigned to one or more well equipped and adequately staffed harbor survey units. These units should be established (1) to sample harbors; (2) to determine the degree of required dredging; (3) to supply information on possible selective dredging and disposal; and (4) to become deeply involved in special studies and the searching out of the most effective and economic means for managing the Great Lakes water resource.

At the same time, the studies of FWPCA seeking to establish meaningful criteria for the degree of pollution of lake and harbor sediments should be continued with the addition of bioassays and other functional tests of sediments and their confirmation by field observation as well as laboratory analyses.

9.9.7 Treatment of Sediments

The expected wide variation in place and time of the composition, concentration, and condition of harbor dredgings, as well as the expected decrease in harbor pollution as the Great Lakes regional FWPCA program of water pollution abatement nears its objectives, suggests that the treatment of dredged sediments be kept as simple and elastic as possible. Only in this way can available treatment be fitted to changes and differences in composition of the dredgings actually collected and disposed of.

As of the present time, multi-hearth incineration appears to be the least costly method of treatment. If further studies confirm the cost figures provided by Nebolsine, Toth, McPhee Associates (Appendix C6), and if the availability of phosphorus in multi-hearth ash is or can be reduced to an allowable value without significant added expense, multi-hearth incineration might be sufficiently promising to be submitted to pilot-plant testing at a suitable location or to full-scale experimental study at an existing treatment plant. The Board recommends that arrangements to this effect be kept in mind if treatment measures as an alternate disposal method later prove to be economical or are selected despite economic considerations.

Although aerobic stabilization has received favorable support in the findings of Nebolsine, Toth, McPhee Associates, the toxicity of some sediments may operate against their being treated by this method. This aspect of biological treatment is worthy of further investigation. The favorable pH of most Great Lakes waters is of interest in connection with the possible containment of phosphorus in the sediments.

The settling properties of most Great Lakes sediments is poor. Only rarely is the rate of settling fast enough to be employed for the differential separation of mineral sediments from their organic fractions and subsequent treatment of the organic concentrates. However, the bulk rate of settling can be enhanced by flocculation with or without the aid of coagulants.

Biological stabilization of dredgings in diked or similar enclosures with or without aeration, coagulation, pH adjustment, or other chemical conditioning of incoming dredgings and purification of effluents in special reference to phosphate removal is promising and, in the opinion of the Board, should receive further study.

9.9.8 Containment and Consolidation in Diked Enclosures

Properly constructed, maintained, and operated diked areas can perform a number of useful functions in dredgings disposal. Their operation as stabilization units is referred to in 9.9.7 and their use for the permanent isolation of harbor dredgings from Great Lakes harbors is of long standing. However, their ultimate serviceability should continue to be investigated.

The properties of the resulting structures and soils need to be known more fully. Moisture content, liquid limit, permeability, rate of consolidation, and shear and bearing capacity are examples. Determination of physical, chemical, and electro-chemical methods for stabilizing these materials to make them more acceptable as fill are also needed.

The useful disposal of dredgings in shore-line waters for the formation of marshes and other shallow-water refuges for fish and wildlife should also be investigated. Areas of this kind could be enclosed by low dikes and filled with enough spoil to adjust the depth of water to the needs of marsh or emergent aquatic plants. Cultivation of useful species should be studied.

9.9.9 Ancillary Laboratory Investigations

The need for fundamental laboratory studies of the properties of dredgings and for bench-scale testing of their response to different environmental conditions has been suggested in many of the preceding sections and are reaffirmed here. Additional laboratory stuides should be undertaken for the functional identification of significant properties not only of dredgings, but also of associated lake and harbor waters as well as effluents from dredging operations, including the treatment of dredgings. Examples are the treatment of effluents from diked enclosures, and the removal of phosphates and other nutrients from effluents, slurries, and ashes created in the course of handling, storing, treating, or disposing of dredgings.

9.9.10 Recommended Disposal at Pilot Areas

The eight pilot areas were analyzed in depth in Section 6. This section presents the Board's conclusions for those harbors. In addition, a number of other harbors were analyzed by the Board. Those analyses are attached as Appendix C1.

Great Sodus Bay Harbor, New York:

Present data do not demonstrate an adverse effect on Lake Ontario by present dredging and disposal practices. The harbor environment could be improved by reducing the total solids, COD, and phosphorus in the overflow water from hopper dredges. The importance of taking remedial action is uncertain in view of the light pollution level of harbor sediments. The bioassays at the University of Wisconsin show that the sediments are not toxic to benthic and planktonic animals.

Buffalo Harbor, New York:

Until the discharge of pollutants into Buffalo River is controlled, its sediments will continue to be badly polluted and large in volume. Needed are (1) upstream control of soil erosion and (2) more intensive treatment of municipal and industrial wastewaters.

Selective treatment of heavily polluted clamshell dredgings and selective open-lake disposal of hopper dredgings from well-aerated portions of the harbor should also be studied.

The possibility of working with Bethlethem Steel Corporation in the development of a diked area for disposal of dredging spoil and slag should be encouraged.

Cleveland Harbor, Ohio:

Reclamation of the Cuyahoga River through abatement of industrial and municipal pollution in the Cuyahoga Valley appear to be the keys to the Cleveland situation: Improved wastewater collection systems and treatment plants at Akron and Cleveland; control and treatment of their stormwater overflows and discharges; identification, separation, and treatment of industrial effluents that are polluting the river and its tributaries as well as the outer harbor.

In addition, studies of feasible treatment and disposal methods should be pursued at the pilot dredgings enclosure in cooperation with Cleveland and Akron educational institutions and the sewer authorities of these major communities. A regional effort would seem to be called for.

An upstream settling basin to trap and reduce the sediment load downstream (see Appendix K3) and construction of along-shore dikes at Sites #3 and #4 (see figure 30) have merit for handling sediments over the next ten years. Two matters should receive further study, namely, (1) the possibility of some cost-sharing by Cleveland if along-shore diked disposal areas are used for further development of Burke Lakefront Airport and (2) improvement of ways and means to transfer dredgings from scows to enclosures.

Toledo Harbor, Ohio:

If dredged materials continue to be contained in diked disposal areas, sufficient detention time must be provided to allow the fines to settle. The present and proposed program of using diked areas for most of the spoil should be continued, but the quality of the overflow water should be monitored to detect possible pollution which would require remedial measures.

Rouge River, Michigan·

The sediments are seriously polluted and represent a suitable environment for only the most pollution-tolerant organisms. This is shown by the great abundance of pollution-tolerant aquatic oligochaetes. The bioassays at the University of Wisconsin indicate that the sediments are toxic to amphipods and midges. The quality of Rouge River water might be improved by limiting or treating the overflow water from the hopper dredge.

Some of the sediments produce relatively large quantities of gas when they are digested anaerobically. This response might interfere with plans to raise the diked enclosure on Grassy Island to the planned height because the gases released per unit area may accumulate in disruptive amounts and endanger the intended uses of the island.

Available information indicates a seriously degraded environment. Selective dredging and disposal cannot be considered for this harbor, becuase all of the sediments are of poor quality. The present method of disposal, i.e., pumping the dredged material into a diked enclosure on Grassy Island, appears satisfactory and should be continued.

The Corps of Engineers has identified additional disposal areas that could fulfill site requirements for many years to come (Appendix L9). Two of them are part of the Wyandotte National Wildlife Refuge. Their joint management should be studied and consideration should be given to increasing the aesthetic appeal of the relatively high bluffs to be created at Grassy Island if that site is continued in use.

Indiana Harbor, Indiana:

The substitution of dredged spoil for other materials in filling suitable landfills would be an effective use of the waste material. However, economic considerations, i.e., hauling costs, available sites, and other available materials, will seriously affect the use of spoil for land fills.

Although surveys of the lake disposal area did not demonstrate lasting effects of disposal, the sediments are polluted and contain high concentrations of oil and grease. Consequently, in-lake disposal will always present the possibility of release of oil slicks as well as contributing to pollution of the lake. The continued use of the Inland Steel enclosure and extension of this area appears to offer a reasonable solution. If escape of pollutants through the entrance to the enclosure becomes a problem coagulants could be considered as a control measure.

Calumet Harbor, Illinois:

The bottom sediments in the Calumet River contain high concentrations of polluted materials. The removal of sediment would have a beneficial effect on the river if local waste discharges were controlled.

The operation of dredges has no significant effect on changing the river-water quality in the vicinity of the dredges.

Because the Calumet River flows away from Lake Michigan, waters entering the system and disposal of dredgings on land will prevent the dredging of the area from affecting the lake. Land disposal would direct the leachings and solids from the spoil away from the lake through the river system. Dredgings should not be dumped in the open lake. The use of Alternate Disposal Site #2 and then Site #1, (see figure 35), as suggested offers a workable solution at reasonable cost.

Green Bay Harbor, Wisconsin:

The sediments were seriously polluted and would not offer a suitable environment for benthic organisms. The river and bay can be improved by removal of these sediments. Dumping in a sump area may deteriorate water quality and explain the poor quality at BM1 during the sampling in 1967. This is not known, though, because of the influence of the municipal sewerage outfall near the river mouth. Sampling was not extensive enough to determine the relative importance of each source of pollution. Sampling was not continued as recommended by the Board earlier. Consequently, it is not possible to (1) determine the effects of dredging on water quality, (2) describe the influence of open lake disposal on adjacent lake areas in terms of existing water-quality criteria, and (3) determine the effects of open lake disposal on the lake itself.

The diked disposal area constructed in the bay by hydraulic dredge in 1967 did not with stand the waves and currents and had been breached in several places by the spring of 1968. Evidently construction of a dike by this means is not satisfactory with the type of sediments in Green Bay.

In general, the on-land diked area offered an effective means for reducing pollution from the disposal of dredgings. Turbidity in the overflow pipe was reduced to the level of the minimum turbidity of the bay. Total phosphorus and suspended solids were within the range reported for the channel. Soluble phosphorus was slightly higher in the overflow, and nitrates, ammonia, and dissolved-solids concentrations were significantly higher than in the bay. Little, if any, seepage took place through the dike.

According to the Corps of Engineers report on alternate disposal areas (Appendix M3), new work would be undertaken in 1969 and approximately 1,600,000 cubic yards would be deposited at Sites #1 or #5 (see figure 36) because these sediments are thought to be polluted. These sediments are far enough out in the bay for their classification as polluted to be doubtful and for disposal in the bay not to be objectionable. Sites #1 and #5 should be used for the polluted sediments from the Fox River and the channel out to Grassy Island. The dikes of Site #1 will have to be repaired to prevent breaching by waves.

Site #1 should be expanded for future disposal of maintenance dredging spoil. If one of the land sites (#2 or #3) must be used, Site #2 should be avoided because of its possible development as a conservation area. New work material would be disposed of best at Site #3.

9.9.11 A Long-Term View of Harbor Pollution

The present report has been concerned primarily with ways and means for the safe disposal of dredgings from Great Lakes Harbors during the next ten years of the Federal Water Pollution Control Act of 1965. It has been assumed that during this decade water pollution management within the catchment area of the Great Lakes will have progressed to a point where harbor sediments will no longer be polluted by degradable municipal and industrial wastes and where nutrient phosphates and other chemicals will no longer enter the Great Lakes in sufficient amounts to influence the trophic nature of the Lakes.

However, the experience of the first years following passage of the Act suggests that the time table for pollution control may not be fully met and that anticipated population and industrial growth of the Great Lakes region as well as changes in land-use practices may not bring the pollutional loading of the receiving bodies of water to the vanishing point. In the circumstances, the Board recommends that the cooperating agencies lift their sights and increase the horizon of their enquiry to include not only the solution of existing problems in the satisfactory disposal of harbor dredgings but also of associated area-wide problems that may develop within and following the assumed ten-year period.

Examples of possible problems to be solved are:

a. Present and future availability of along-shore, in-lake, and on-land disposal sites for both polluted and unpolluted dredging, unpolluted sediments being included because they too, reduce the volume of the Great Lakes.

b. Present and future effects of soil erosion on the quality and volume of harbor dredgings as functions of intensive and extensive soil erosion control within the catchment area of the Great Lakes system.

c. Present and future economy of dredging and dredgings disposal in comparison with the transfer of harbor installations from river mouths that are bound to shoal, to deep-water sites.

d. Long-range forecasting of sediment encroachment on the Great Lakes and long-range anticipation of lake eutrophication.

e. Consideration of area-wide inter-relationships between dredging disposal and possible enhancement of the Great Lakes environment by the promotion of recreation through on-shore and in-lake parklands constructed on dredged fills, the creation of wet lands for the protection of fish and wildlife, and the adaptation of the regional economy to dredging problems in general.

f. Upstream control of sediments derived from cultural as well as natural erosion of stream banks; cultivated as well as uncultivated fields; excavations for roadways and other constructions; and urban as well as rural runoff.

g. Upstream control of pollutants in the form of degradable organics and algal nutrients including the study of bottom cores taken from the Lakes to establish the present rate of accretion of organic residues in the form of algal cells and of precipitated carbonates and other sediments.

h. Study of using aerator-mixer in harbors to stabilize and flocculate sediments.

Section 10

DISCUSSION

10.1 Introduction:

The preceding sections of the present report have been concerned primarily with background data and the findings of the current study. The purpose of this section is to present the views of the reporting officer, namely the District Engineer, Buffalo District, Corps of Engineers. Several key topics will be discussed: (1) does the disposal of dredgings in open lake water areas affect lake ecology, (2) how can dredging and disposal practices be altered to improve lake ecology, (3) what are the economic costs and justification for alternate disposal practices, (4) how should costs of alternate disposal practices be allocated, and (5) how should an alternate disposal program be administered. These items are not independent of one another but the discussion follows generally in the order of the topics as listed.

10.2 The Sedimentary Process

In order to evaluate the effects of dredging and disposal in the open lake on harbor and lake environments compared with the effects of natural transport of sediments into the lake it is necessary to review briefly the geomorphological framework within which sedimentation and dredging take place.

Solids eroded from upland areas of a stream basin and from stream banks and beds together with solid wastes from agricultural, industrial, and municipal sources when introduced into a stream are carried by it either in suspension or by bed movement. The carrying capacity of the stream is governed by its velocity. Wherever the stream enters an enlarged cross-sectional area, a reduction in velocity and deposition of solids occurs. Such deposition continues until the enlargement is eliminated and the velocity becomes constant. Material is then carried further downstream until another enlarged area is encountered. The process continues and proceeds downstream to the lake shore.

At the lake shore the same sedimentary process takes place but there is a significant difference in conditions. The velocity differential is extreme and deposition is very rapid.

Studies of shore processes on the Great Lakes concerned with the erosion, accretion and movement of material in the littoral zone, shoreward of about the 20-foot depth, have been made in connection with navigation and beach erosion control studies.[1] On Lake Erie, the entire shoreline of the State of Ohio and much of the shorelines of the Commonwealth of Pennsylvania and the State of New York have been studied in detail.

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[1] House Documents 220, 79th Congress, 1st Session; 502 and 596, 81st Cong., 2nd Session; 350 and 351, 82nd Cong., 2nd Sess.; 32, 126, 127, 229, 231, and 324, 83rd Cong., 1st Session; 414, 87th Cong., 2nd Session; and 97, 90th Cong., 1st Sess.

These studies are consistent in their findings. Shoreward of the 10-foot depth, except where littoral material is impounded by natural embayments or shore structures, there is progressive and continual erosion of the bluffs, beach, and lake bottom. Between the 10-foot and 20-foot depths there is less consistency; some areas show erosion and others show accretion with the amount of accretion generally increasing with depth. In a few areas where investigation has extended to depths of 30 feet, this condition is further confirmed by comparison of bluff, beach, and lake bottom profiles obtained from periodic surveys.

Only the coarse sand and gravel fraction of materials that are eroded from the bluffs or discharged at the mouths of unimproved streams remains on the beach or within the breaker zone. The breaker zone is the reach from shore to the depth (about 10 feet) at which most storm waves break and inside which turbulence and littoral currents sort out and remove fine materials. Eventually, the fines are carried offshore and deposited on the lake bottom. Bottom materials out to the 20-foot depth are sampled and tested and a decrease in grain size at increasing depths generally occurs.

Extensive deposits do not accumulate at the mouths of tributary streams. During normal flows the sediment load of the streams is quite small. Most of the deposition at the stream mouths occurs during periods of high flows, primarily during the spring runoff of melting snow and following periods of heavy precipitation. Between these periods of supply and deposition, the energy in the waves and littoral currents along the lake shore is sufficient to remove all but the coarsest material. Even the coarse material, though, tends to move away from the stream mouth in the direction of predominant littoral drift.

Unlike waves in the ocean, wave characteristics on the Great Lakes are such that once material is eroded from a beach area into depths of 6 to 10 feet or more it is not returned to the beach. In the ocean, however, long-period waves frequently occur between storms and return material shoreward to restore eroded beaches. Such action does not occur on the Great Lakes owing to insufficient fetch distances and depths to generate the necessary wave characteristics.

Accordingly, sediments carried down to the lake shore by streams are sorted and classified by natural lake forces so that the coarse sands and gravels remain in the along-shore area and the finer lighter materials are distributed over the lake bottom. This is confirmed by the data for Lake Erie presented in Section 2.5, which show a progressively greater concentration of the light-weight volatile solids with lake depth.

Thus, it is seen that sediments brought to the lake by streams at which there are no harbor improvements are deposited over vast expanses of the lake bottom with the lighter particles farthest away from the stream mouth. Transport of sediments out into the lake is primarily by bed movement. The particles at the mud-water interface sort of bounce along carried by water currents. As a result, polluted silt and clay particles and organic matter are exposed to water contact during their entire periods of travel from the stream mouth to far out in the lake. This exposure is, of course, to the water environment present at or near the lake bottom.

10.3 Artificially-Induced Sedimentation

The preceding section describes the process by which sediments are deposited in the Lakes. Now it is necessary to consider how the process has been altered at places where the Corps has developed harbors.

Harbor developments can be classified into two general types as follows: (1) Harbors consisting essentially of a widened and deepened section of a stream, and (2) harbors consisting substantially of a portion of the lake inclosed within breakwaters, but including the improved lower portion of a stream. In the first type, where cultural development of the lower portion of a stream permits sufficient space, the harbors are formed by excavating the stream to provide the width and depth needed by commercial ships. It is also generally necessary to excavate a portion of the lake bottom to provide a commensurate channel extending out from the stream. Frequently, it is necessary to construct piers out from shore along each side of the lake channel to keep it from being filled with material washing in from the adjacent lake bottom. This type of harbor, in effect, forms an embayment into the lake shore causing the change in stream velocity to take place at the upstream end of the improved section of the river instead of at the lake shore. Thus, the receiving body of water for the stream is its enlarged lower protion. The bulk of the sediments are deposited in the harbor portion. There, the sediments are protected from lake waves and currents, and only the finest and lightest particles, capable of being carried in suspension by the low velocities in the harbor, reach the lake. Until a natural gradient has been reestablished, the materials deposited accumulate in the harbor and are not moved out into the lake as would be the case for the unimproved stream. Accordingly, it is necessary to pick up and dispose of the deposited material periodically in order to maintain the harbor dimensions. A typical example of this type of harbor is shown in Photo 23.

The second type of harbor has been formed where cultural developments did not permit space on the stream banks for all the facilities needed to accomodate the growing shipping requirements. In effect, this type of development has moved the shoreline toward the lake leaving behind a large body of water with space along the original shoreline for the needed commercial establishments. Stream velocities at this type of harbor undergo two large changes. The first occurs at the upstream end of the improved river channel, and the second takes place where the river channel joins the quiescent waters inclosed by the breakwaters. Most of the stream sediments are deposited during the first velocity change, but the light material, capable of being carried by the low stream velocities, is deposited during the second velocity change. Usually, there is some residual of extremely small and light particles that remain in suspension and are carried out into the lake. As in the previous type of harbor, the sedimentary area is protected from lake forces, and the deposited sediments must be picked up and removed from the harbor by artificial means. An example of the second type of harbor is shown in Photo 3.

There are many variations of these two types, but only one which needs special mention. This is a variation of the first type where the receiving body of water is an existing large shallow bay. Because of the shallow water, the channel in the lake outward from the stream mouth must extend for several miles to reach a natural depth equal to the improved harbor depth. Construction of piers for such long channels is not practical. Consequently, material washed in from the adjacent lake bottom areas constitutes the major portion of the required maintenance dredging. The materials deposited in the outer portions of

Photo 23 Aerial View of Rochester Harbor, New York

these channels are not the new sediments recently brought down by the stream, but generally are materials deposited in the lake during older times, which have been sorted and washed by lake action and are representative of the lake bottom in the area. The channels in Maumee Bay, in Green Bay, and in the Lower Detroit River are examples of this variation.

10.4 Effects of Dredging at the Dredging Site

The FWPCA, in Appendix C2, states that "dredging operations themselves and the type of dredging do not appreciably contribute to the rates or the quantities of nutrients transported by the rivers to the Great Lakes."[1] At most, there is a temporary increase in suspended material, and, in some instances, an oil slick appears on the water surface. These same effects appear to a lesser degree after passage of every large vessel.

FWPCA, in its analysis of Cleveland Harbor, and the Board of Consultants, in its analyses of Calumet, Indiana Harbor, Buffalo, and Great Sodus Bay Harbors, indicate that dredging may be beneficial by improving the sedimentary environment or creating a short-term aeration of the harbor waters. Thus, dredging operations themselves cause little significant effect on the harbor environment and may occasionally be beneficial to the bottom environment.

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[1] R.C. Scott, "Geochemical Summary of Polluted Sediments in Great Lakes Dredging Area," FWPCA, 1968, p. 11.

10.5 Effects of Disposal

The dredgings generally are transported to a selected point in a lake where they can be deposited with a minimal interference with beneficial water uses. As they are deposited, the sediments settle down through the lake waters at the disposal site and come to rest over a limited portion of the lake bottom. There they are subjected to the normal lake forces which tend to distribute them over larger expanses.

The exposure of the particles to lake water contact is somewhat different than when the previously discussed sedimentary processes are in effect. These sediments are carried out in a container and there is only a short period of contact with the lake waters while they settle to the bottom. It is during this time that conditions are favorable for the desorption or solution of the pollutants.

Dredging and disposal are carried out during the relatively warmer months when water temperatures and biological conditions favor agal blooms. Although the natural discharge of sediments from streams takes place mainly during times of high runoff, which usually occurs during the colder months of the year, some outward flow of sediments and natural transport out into the lake takes place throughout the year. The slow drift or natural transport of sediments allows for maximum time under aerobic conditions, particularly in the breaker zone.

One view is that the release of phosphatic nutrients to lake waters is probably minimized under aerobic conditions. In the case of artificial carriage of sediments by scow or dredge, because of the bulk of the material, conditions may remain anaerobic and thus greater amounts of this nutrient may tend to be released.

Another view is that phosphatic and nitrogenous nutrients sorbed onto silt and clay particles are released mainly at the mud-water interface. So long as the sediments are kept in a mass, the desorption process is minimized; whereas, separate particles maximize the mud-water interface. Moreover, if they are churned up in water, the particles may give up the sorbed nutrients more easily. Thus, in the case of dredgings disposal, there can be two opposing lines of reasoning: (1) release of nutrients because of anaerobic conditions; and (2) retention of sorbed nutrients because the bulk of sediments minimizes the mud-water interface. Similarly, in the case of natural transport, the opposing lines of reasoning may be: (1) retention of nutrients because of aerobic conditions; and (2) release of sorbed nutrients because of thorough mixing.

One of the principal assignments to the Board of Consultants was to evaluate the effect on water quality and biota of disposal of dredgings in open water areas of the Lakes. The Board states that the ultimate fate of the dredgings deposited into the Great Lakes and their effect on water quality remains unknown despite much sampling and analytical work in 1967 and 1968. The Board concludes that they cannot yet state unequivocally just what the long-term impact will be for the present method of disposal of dredgings into the Great Lakes, but they acknowledge that in-lake disposal of heavily polluted dredgings must be considered presumptively undesirable because of long-term effects on the ecology of the Great Lakes, as evidenced, among other things, by the results of bio-assay tests. While it had been hoped that the sampling and analysis work would yield more definite answers, the reporting officer concurs with and adopts the Board's statement.

Although the Board's conclusions relate specifically to heavily polluted dredgings, they apply also to polluted sediments reaching the Lakes by natural transport. Such polluted sediments are also presumptively undesirable for the Lakes. However, the exact ratio of the sum total of harmful effects of polluted sediments transported to the Lakes as harbor dredgings to that of polluted sediments naturally reaching the Lakes from harbors must remain an open question for as long as a reliable mass balance can not be struct between the two. Included in this mass balance, moreover, must be not only the weight of the respective sediments, but also their opportunity to damage the lake.

As will be discussed in Sections 10.6 and 10.8.2, answers to the above question greatly influence the allocation of costs of alternate disposal systems. Moreover, if the plans of FWPCA to keep pollutants out of streams entering the harbors and navigational channels of the Great Lakes should not succeed, the above question bears directly on whether or not serious consideration should be given to ceasing the maintenance dredging of harbors in evaluation of the cost-benefit relationship of alternate disposal systems for polluted dredgings.

At this point, it should be noted that the exclusion of polluted sediments from entering the Lakes in one way or another would, by all accounts, make for a greater improvement in the environment of the Lakes than the cessation of maintenance of harbors.

Having adopted the view that in-lake disposal of heavily polluted sediments is undesirable, the remainder of the discussion will deal with how something may be done to solve this problem.

10.6 Dredging and Disposal: A Dual Purpose Project

The Board has suggested that sedimentation by itself is a form of pollution when it interferes with natural or human functions, e.g., navigation. As stated in Section 9.5.2, to the degree that dredged sediments are composed of material induced or produced by human activities, the Corps is currently performing a waste disposal function for the social institutions generating such sediments. The reporting officer concurs with the Board that sedimentation is a form of pollution. Accordingly, the costs of removal of culturally produced sediments are waste management costs that should be charged to project purposes other than navigation. Further, transportation savings should not be required to balance costs chargeable to non-navigation purposes in determining economic justification for navigation projects.

That culturally produced sediments should not impede or interfere with beneficial navigable use of waterways is confirmed by Sections 10 and 13 of the River and Harbor Act of 3 March 1899, (33 U.S.C. 403, and 407) which make it unlawful to discharge or cause to be discharged refuse matter into navigable streams. Materials flowing into streams in a liquid state from streets and sewers were exempted. Recently, there has been successful enforcement of the Act in litigation against three major steel companies regarding the deposition of flue dust (steel mill wastes) in the Calumet River, Illinois. In this case, <u>United States v Republic Steel Corp., et al.,</u> 362 U.S. 482 (1960), the Supreme Court of the United States affirmed the applicability of the Act of 1899 to suspended solids contained in industrial wastes. Since that time the Corps of Engineers has entered into agreements with other industries on the Great Lakes in which the industries pay for the cost of removing their deposits until such time as satisfactory improvements are completed. Payments are also being made by institutions at Indiana Harobr, Monroe, and Toledo Harbors and the Rouge

River area. In addition, negotiations for payment agreements are currently under way at Grand Haven, Ludington, Buffalo, Cleveland, and Lorain Harbors and the Detroit River area.

To realize the possibility of accomplishing maximum pollution abatement with respect to dredgings, it will be necessary either to (1) extract the pollutants from the sediments prior to disposal in the lake, or (2) prevent the polluted sediments from reaching the lake. Either way, sediments would have to be intercepted before they reach the open lake and removed from the catchment area for subsequent treatment or disposal in a permanent retention area.

Consider first a tributary stream where there is no harbor improvement. To cause deposition of sediments, it would be necessary to excavate a settling basin of suitable size and depth in the lower portion of the stream. This would be similar to the Emscher District of the Ruhr Valley, Republic of West Germany, where the entire stream is cleaned before discharge into the Rhine by passage through a large sedimentation basin. The accumulated sediments would have to be removed periodically and transported either to a treatment plant or a disposal site. Costs would include the initial costs for the catchment basin, the periodic excavation costs, and transportation and subsequent costs depending on the ultimate disposition of the sediments. Since no navigation project would be involved, the purpose would be entirely pollution abatement.

For a tributary stream where a harbor development is maintained, the harbor itself acts as a settling basin, and periodic excavation is already being performed incident to harbor maintenance. Transportation and subsequent handling at a treatment plant or disposal site would be additional operations. The dredging activities are dual purpose, serving both navigation and waste management purposes, and costs should be shared in accordance with some acceptable cost-sharing system in use for water resource projects. The cost-sharing system would have to take into account the relative volume of naturally versus culturally produced sediment.

Should alternate disposal be required for future maintenance dredgings, the Corps would be performing a waste management function to an even greater degree than at present. The additional costs for transportation and handling at a treatment plant or disposal site would again be dual purpose serving both navigation and pollution abatement to the extent that artificial movement of sediments is more harmful than naturally moved sediments. Costs, then, should be divided between the two purposes taking into account not only the relative volumes of naturally and culturally produced sediments, but also, with respect to naturally produced sediments, the relative pollutional effects of natural and artificial transport of the sediments to in-lake disposal sites.

Ideally, dredging and disposal costs, regardless of the method of disposal, should be allocated to the social institutions producing the wastes. Practically, though, such an allocation on a large scale basis would encounter many difficulties in the form of administrative problems and unanswered questions such as: (1) what is the ratio of naturally to culturally produced sediments; (2) what are the relative effects of natural and artificial transport of polluted sediments to the Lakes; and (3) on what basis is the allocation to be made. The last question arises because the usual allocation of costs is in proportion to the benefits of each of the purposes of a proposed project. However, at the present time, the benefits of pollution abatement through alternate disposal of polluted dredgings, though they may be real, are largely intangible.

There is no workable method at present of allocating the costs of dredging and disposal to the individual purposes of navigation and pollution abatement. In view of the forgoing discussion, a suggested somewhat arbitrary allocation would be for all conventional dredging costs to be charged to the navigation project and the additional costs involved in the alternate disposal methods be charged to pollution abatement.

10.7 Methods of Pollution Abatement

At this point, it would be well to examine the several means of preventing pollutants from entering the Lakes. The method which would appear to be most beneficial is the elimination of pollutants at the source. This could eliminate not only the solid pollutants which contaminate the sediments, but also the soluble pollutants which contaminate the tributary waters. Elimination of pollutants at their source would involve land management and stream bank protection to minimize erosion in the drainage basin, and adequate treatment of industrial wastewaters and municipal sewage. Measures are underway by various agencies to accomplish these objectives. The FWPCA, in its report on Lake Erie in August 1968, estimated costs of about 1.8 billion dollars for immediate municipal and industrial waste treatment construction and control of agricultural runoff. A similar report for Lake Ontario estimated a cost of $430 million. Programs of this magnitude will require a number of years for funding and implementation. The investment of these sums and completion of such programs should prevent large quantities of pollutants from reaching harbors, thus probably permitting open lake disposal of dredgings at that time without fear of harmful effects.

Decision makers will face essentially two choices: (1) Make these investments to clean up the influents to the Lakes as the surest long-term and most economical way to solve pollution problems including the disposal of dredgings - that is, permit open lake disposal to continue, recognizing that the sediments reaching the Lakes may have some undetectable decreasing harmful effects for a period of a few years; or (2) Make these investments and also, in an effort to expedite lake improvement, invest added sums and resources in a ten-year program of alternate spoil disposal along the lines discussed in Section 10.8.

A period of ten years for the alternate disposal systems considered in this report was chosen based on the schedules now in effect to provide new and improved treatment facilities for municipalities and industries in the various states. These schedules are set by the states and by FWPCA.

The latest scheduled facilities run to 1977. Thus, within ten years, all scheduled improvements should be completed. However, failure to meet scheduled dates has been noted. For municipalities, the schedules are dependent on the Federal construction grant program which has so far not provided funds at the rate required to attain scheduled improvements.

The programmed facilities do not cover all sources of pollution. But as time goes on, facilities will be programmed for other sources presently known and for new sources that will be created or discovered.

Accordingly, the ten-year period may be inadequate. However, it is useful in obtaining some appreciation of the magnitude of the problem, costs and resources required. It will also provide a period of observation during which extension, curtailment or other modification of the program can be considered. The ten-year period appears to be a reasonable time for purposes of this report.

The subsequent discussion and conclusions are designed to assist decision makers in choosing one of the two courses of action set out earlier in this section. The magnitude of dredgings compared to the overall input of pollutants into the Lakes is covered in the next section, and alternate methods of disposing of dredgings in the following section.

10.7.1 Role of Dredging in Pollution Problem

An approximation of the relative importance of dredging to the overall solids input to the Lakes, in general, and Lake Erie, in particular, can be obtained from Table 9. It is indicated that 133 million pounds of suspended solids and 200 million pounds of dissolved solids per day (24 and 37 million tons per year, respectively) enter Lake Erie exclusive of dredgings. The footnote to Table 9 indicates about five million tons per year of total solids (suspended plus dissolved) are associated with dredgings. The ratio between suspended and dissolved solids in a mud sample is variable but the dissolved fraction is trivial with respect to the suspended solids. Accordingly, it appears that about 17 percent of the suspended solids and an insignificant fraction of the soluble solids reaching Lake Erie are associated with dredgings. The combined total solids involved in dredging operations constitute eight percent of the total solids reaching Lake Erie. Thus, a complete program for alternate disposal of Lake Erie dredgings would prevent about eight percent of the solids from reaching the lake. Indications are that the percentage would be considerably lower for the other lakes.

The portion of the solids which contributes to the pollution of the Lakes is difficult to evaluate. As pointed out in Section 3.1.1, the concentration of dissolved solids has been used at times as one of the indicators of the degree of eutrophication of a lake. Of the total solids reaching Lake Erie, 60 percent are in solution in waters flowing into the lake from Lake Huron and streams tributary to Lake Erie. As indicated in the preceding paragraph, only insignificant volumes of dissolved solids, which are contained in interstitial water in the sediments and supernatant waters in the bins of hopper dredges, are associated with dredging operations.

Of the total pollutants that reach the Lakes, the fraction that is involved in dredging operations is also difficult to determine. Sufficient data are not available for a precise determination. Such data as are available are presented in Section 3.2 of the present report. The most comprehensive data on any tributary stream are for the Cuyahoga River at Cleveland, Ohio, and are given in Table 11. These data indicate that about half of the volatile (organic) matter reaching the lake from that basin is contained in the sediments. Phosphorus, currently the center of attention as an important nutrient, is contained for the most part in these sediments. For the few harbors on Lake Michigan for which there are comparable data in Tables 4 and 5 (Green Bay, Milwaukee, Manitowic, and Muskegon Harbors), phosphorus is contained predominantly in the soluble solids rather than the sediments. There are no comparative data for harbors on the other Lakes.

Extrapolation of these meager data to all of the Great Lakes can not be supported because (1) the ratio of pollutants from individual drainage basins that reach the Lakes in dredged sediments applies only to the small volume of solids involved in harbor projects, (2) no dredging is involved in the large volume of solids and included pollutants that reach the Lakes from other sources, and (3) pollutants in sediments are thought not to degrade the lake environment to the same extend as equivalent amounts of pollutants in solution in the waters entering the lake.

The most that can be said is that some small fraction of the pollutants from individual drainage basins reach the Lakes in the sediments dredged from the harbor at the mouth of the tributary and deposited in the open waters of the lake. In some instances such as for Cleveland Harbor, the fraction is as high as one half due to inadequacies of municipal sewage treatment facilities. The remainder is carried out either in solution or suspension in river flow or in other direct discharges to the lake.

Pollutants that remain fixed in sediments do not affect water quality. The importance and magnitude of the interchange of nutrients from sediments to water and of dissolved oxygen from overlying waters to sediments has been established previously; however, the mechanism of the transfer is not completely clear. The concensus is that, at a given time, phosphorus in harbor sediments is not likely to degrade the lake environment to the extent of an equivalent amount of the same element in solution in river water. Opinions vary considerably on the relative effects. The Board of Consultants stated that there was insufficient knowledge on the subject for the Board to offer a firm opinion, but it felt that phosphorus in the sediments would have considerably less effect on water quality than the same amount of phosphorus in solution. Similar comments can be made with respect to other pollutants. The degree to which volatile matter is tied up in the sediments and not available for degrading water quality is not known.

Lacking information on the volume of pollutants involved in the much larger volume of solids input to the Lakes from sources other than dredgings, and the relative effects of pollutants in sediments as compared to equivalent amount of soluble pollutants, only a rough estimate can be made of the relative role of dredgings in the pollution of the Great Lakes. The most that can be said at present is that a complete program of alternate disposal of dredgings could expect to reduce (1) overall solids reaching the Lakes by about eight percent, and (2) pollutants by probably the same general percentage as for solids. The changes in water quality resulting from an alternate disposal program would be difficult to isolate from other changes taking place in the total Great Lakes environment.

10.7.2 Shore-based Treatment of Dredgings

Consideration was given to delivering the dredgings to a shore-based treatment plant where the material would be processed to eliminate the pollutants by one of several possible processes. The processed solids would then be transported to a disposal area in the open lake or a fill area if more economical. The various treatment processes considered are described in Section 7.4.3. Estimated costs for the most economical treatment methods are shown in figure 27. These costs are only for the treatment and do not include dredging and delivery costs nor ultimate disposal costs. These additional costs would vary considerably from project to project. For illustrative purposes, the overall costs for a large project, Cleveland Harbor, Ohio, and a moderately sized project, Ashtabula Harbor, Ohio, are used in the following discussion.

Dredging at Cleveland Harbor averages 500,000 cubic yards annually by hopper dredge and 720,000 cubic yards annually by clamshell dredge. Costs for the normal practice of disposing of dredgings in the open lake average $0.78 per cubic yard. Estimated costs for the dredging and delivery to a treatment plant located in the outer harbor frontage are $1.56 per cubic yard. Treatment costs by the multi-hearth process for Cleveland Harbor material, which averages 10 percent volatile solids, and assuming a favorable solids concentration of 45 percent, would be $3.20 per cubic yard. Disposal of the treated material into an open lake area would add another $0.35 per cubic yard for a total cost of $5.11 per cubic yard.

At Ashtabula Harbor, dredging averages 220,000 cubic yards annually by hopper dredge and the cost for open lake disposal averages $0.35 per cubic yard. Estimated costs for dredging and delivery to a treatment plant close to the harbor are $0.58 per cubic yard. Ashtabula dredgings average about five percent volatile solids. Multi-hearth treatment, assuming 10 percent volatile solids for purposes of this discussion and a 45 percent solids concentration, would be $7.60 per cubic yard. Disposal of the treated material into open lake area would add $0.90 per cubic yard for a total cost of $9.08 per cubic yard.

From these examples, it can be generalized that treating dredgings before disposal in open lake areas would add about $4.00 a cubic yard to dredging costs for projects with large volumes of annual dredging, such as Cleveland, Ohio, and $8.00 a cubic yard for moderately sized harbors such as Ashtabula, Ohio, and even more for the many smaller projects.

While the treatment methods investigated would produce presumptively clean materials, their costs are high. Accordingly, they probably would not be adopted over other less costly, but equally effective, alternate disposal methods unless there were some overriding circumstances at a particular harbor project.

10.7.3 Disposal of Dredgings in Diked Areas

The other basic method for diverting from the lakes pollutants contained in sediments is the disposal of the dredgings on land or into diked water areas where the solids would be retained permanently as landfills with no exposure to lake waters. Surveys to locate sites for such disposal are described in Section 7.5.3. Table 41 lists the projects and the estimated dredging costs for the least costly site at each. The additional costs for such disposal, although substantial at most projects, are significantly less than the additional costs for treatment of dredgings discussed in Section 10.7.2.

The additional costs for disposal in diked areas as listed in Table 41 do not include costs for treatment of either the effluent or solids. The Board of Consultants suggests that consideration should be given to stabilization of solids in fill areas by aeration to improve the quality of the fill for beneficial use of the areas. Based on data contained in Appendix C6, aeration costs would exceed one dollar a cubic yard. If a 10-foot depth of fill were assumed, stabilization costs would amount to at least $15,000 per acre. Few of the sites are in areas where land conceivably could be that valuable. However, for such sites, if authorized for dredgings disposal as a result of the present report, consideration should be given to inclusion of stabilization facilities.

Treatment of effluent from landfill or diked water areas might have to be considered. Experimental treatment of supernatant waters at the Cleveland, Ohio, and Buffalo, New York, pilot disposal areas is described briefly in Section 7.4.4. It was found that coagulation was effective in clearing the supernate. Experiments with coagulation of spoil area effluents at Toledo Harbor, Ohio are described in Section 7.4.6. Here also it improved the effluent. Whether coagulation will be required at any of the considered disposal areas cannot be ascertained until the facility is placed in use, but, if found necessary, it would add a few cents per cubic yard to the costs.

No generalization can be made as to whether disposal on land or in diked water areas is more economical. Dikes in water areas are very costly, but the new land areas created in a harbor complex could serve other purposes to a degree which could justify greater costs. Such situations usually are recognized by the local community and necessary dikes are constructed by and under the initiative of the community. An example of this is the land areas in Maumee Bay planned by the Toledo Port Authority. Accordingly, alternate disposal in the diked area to be provided by the Port Authority will involve only the cost of transporting and pumping the dredgings into the inclosure. Another example is the new land areas proposed in Cleveland Harbor to enable the enlargement of the Burke Lakefront Airport. Here, the City of Cleveland, in the absence of a project to use the site for disposal of dredgings, would construct the needed dikes and fill. It could be considered that the dikes would be justified by airborne-commerce benefits, and costs for alternate disposal would consist only of the cost of transporting and transferring dredgings to the inclosure. In both examples, there would still be some unevaluated effects. Depositing the dredgings into the areas would provide some of the fill, but the fill would not be of the quality needed for the local project. Use of dredgings for fill might engender costs for other measures to permit the type of occupancy planned for the new land areas, which would exceed the value of the dredgings as a space filling medium.

The land sites investigated for alternate disposal are mostly unused and undeveloped areas as close as possible to the harbor projects. Because of poor strength characteristics of unstabilized maintenance dredgings and possible, though unlikely, odor nuisances, most of the property owners and local governments controlling the areas, have indicated objection to the use of land areas for spoil disposal.

Some property owners have indicated they would accept the dredgings for fees ranging up to $0.50 a cubic yard. A few owners have requested fill. Other sites would have to be condemned to obtain use of the lands, which could revert to former owners after filling. Nevertheless, the costs for many of the sites investigated include land acquisition at appraised present values with no salvage value when filled. In addition, State Governments have indicated strong objections to the use of wetlands which have conservation values. However, no evaluation was made of possible extinction of conservation values or damage to surrounding properties from odor and other nuisances. Experience at existing diked disposal areas has been that odor nuisances are evident only in the close proximity of the disposal area during actual disposal operations.

The Board has suggested that disposal of dredgings in shore-line waters for the formation of marshes and other shallow-water refuge for fish and wildlife should be investigated. The Board suggests, also, that such disposal could be inclosed by low dikes and filled with enough spoil to adjust the depth of water to the needs of marsh or emergent acquatic plants. Shore-line water areas are subject to attack to some extent by storm generated waves on the Lakes. In order to prevent the dispersion of the polluted sediments over the lake and minimize sediment-lake water contact, it may be necessary to construct expensive protection facilities to prevent major overtopping by waves.

Such development for wildlife would require areas larger than would otherwise be needed. The loss of fill volume resulting from keeping the surface at or near water level would have to be made up by increasing the fill area with a consequent lengthening of dikes required. Dikes in along-shore water areas exposed to lake storms are usually the most costly type to construct. Any increases in cost of the disposal area would have to be weighed against the conservation values created. Development for conservation should be included, wherever it is warranted, in the alternate disposal plan.

Consideration was not given to possible conservation development in connection with the harbor surveys for diked disposal areas made for the present report. If a project for disposal of dredgings in diked disposal areas is adopted by the Congress, such consideration should be made at that time.

The costs indicated in Table 41 are for the use of what appears to be the most economical sites at each harbor. Increased costs range up to five dollars per cubic yard with the higher costs generally incurred at projects of smaller volumes. The overall estimated additional annual costs for the 35 projects listed is $13 million including about eight million dollars for interest and amortization on the $67 million capital cost for constructing and providing the needed facilities. This is an increase from current annual costs of $5 million. These increased costs are significantly less than those for treatment methods discussed in Section 10.7.2.

If a project for alternate disposal is to be adopted, the diked disposal method appears to be most feasible for the reasons given in the foregoing discussion. Therefore, the 10-year diked area plans listed in Appendices K, L, and M, should be used as a basis for planning such a project. Not all harbors have been classified as to their pollution nor have all those that are classified as polluted in whole or in part been surveyed and plans developed for diked disposal areas. The extent to which the program should apply to all harbors is discussed in Section 10.8.1.

10.7.4 Other Control Methods

Various other suggestions for disposal of dredged materials have been made and came to mind during the progress of studies for the present report. Some are discussed briefly in the sections that follow. These are (1) using abandoned strip mines for disposal sites, (2) aeration of harbors and sediments before dredging, and (3) depositing current dredgings in excavated holes in the lakes. Other suggestions were obviously impractical or prohibitively costly and not considered further. Amongst these were: removing organic matter over the entire bottom of Lake Erie by dredging; diking the western end of Lake Erie and using the diked area for agriculture; and diverting sewage into streams flowing away from the Great Lakes.

10.7.4.1 Disposal in Abandoned Strip Mines

All types of land areas have been considered, including abandoned strip mines and other low-use lands, in the individual surveys to locate and evaluate land disposal sites. Filling of abandoned strip mines with dredgings could convert low-use land to some beneficial use, but the cost of transportation of dredgings to such areas is a controlling factor. Methods of transportation considered in the present report are too costly to consider sites at great distances from the dredging area. The economics for more distant areas will be reviewed upon completion of studies of high pressure pumping referred to in Section 7.5.3.1.

10.7.4.2 Aeration of Harbors and Sediments

It has been suggested that aeration of harbor waters might stabilize sediments as they are being deposited in the harbor areas. The stabilized sediments could then be deposited in open lake disposal areas without degrading the lake. Treatment studies by Nebolsine, Toth and McPhee Associates (Appendix C6) indicate that it would be necessary to keep the sediments in suspension for about 15 days of close contact with bacteria and oxygen to oxidize about 40 percent of the organic material. Havens and Emerson[1] considered aeration in the navigation channel in Cuyahoga River at Cleveland Harbor to improve harbor waters. To avoid the heavy oxygen demand of the sediments, they ruled out any method that would mix harbor sediments with the waters and, accordingly, planned off-channel aeration facilities for the waters only. Computation of the oxygen required was based on a reduced oxygen demand which considered planned improvements in sewage disposal facilities and excluded nitrogenous oxygen demand. Havens and Emerson found that the annual costs would be about $210,000. Considerably greater volumes of oxygen and many more aerators probably would be required to stabilize the sediments. Aeration alone may not be feasible in heavily polluted areas such as the Cuyahoga River, but it may be a possible solution in less heavily polluted areas particularly where alternate disposal in diked areas would be very costly. Aeration of harbor areas should be investigated further to determine under what conditions it might be competitive with diked disposal areas.

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[1] Havens and Emerson, Study of Cuyahoga River Water Quality, 1968, pp. 76-88.

10.7.4.3 Disposal of Dredgings in an Excavated Area of the Lake

The Board of Consultants has suggested that a study of the response of sediments to various environmental conditions in diked disposal areas might lead to location of lake bottom areas where conditions would not be too different from those possessed by diked inclosures. It is envisioned that a deep cut could be made in the lake bottom into which dredgings would be deposited and buried in a manner comparable to the filling of a diked disposal area.

Such an operation would be a compromise between open lake disposal as now practiced and diked disposal areas. It would differ from current disposal methods in that (1) the dredgings would be in a deep cut and not dispersed as easily, (2) the dredgings would be covered periodically by succeeding layers of spoil, thereby minimizing the interfacial contact between sediments and water, and (3) the harbor dredgings would be covered by cleaner material dredged from nearby lake bottom. However, anaerobic conditions and release of nutrients to the lake waters could occur and affect lake waters until covered with cleaner material. In a diked disposal area, with dikes of impermeable or nearly impermeable materials, the exposure of sediments to lake water would be practically nil. Sediments would degrade only water used for conveyance of the sediments to the disposal area.

Disposal in a deep cut would be partially effective and not comparable with a diked disposal area, and is considered only because it might be less costly. The amount of excavation for the deep cut would be at least equal to the amount of dredging and cover material expected to be deposited there. Experience with the excavation and maintenance of channels cut into lake bottoms has been that the littoral drift of adjacent bottom materials tend to fill the cut. It could be expected that the initial excavation would have to be larger than the volume of material to be deposited therein by some amount depending on the depth of water at the site. If the disposal site were located in an area where the depth of water was about 35 feet or more, only a limited amount of littoral drift of the adjacent lake-bottom materials would take place, it any.

To be effective, the excavated disposal areas would need to be as small in areal extent and as deep as site conditions permit. The hopper dredge would be the most economical and practical means for making the excavation because it is not restricted by lake weather conditions that delay other types of dredges. The hopper dredge, however, can excavate only relatively soft material. Thus, the characteristics of the lake bottom as well as the depth of water will have to be considered in using this type of alternate disposal.

Disposal in an excavated site in the lake probably would not be as effective as diked disposal. But in view of the possible economy, investigations should be made to locate possible sites for this types of disposal.

10.8 Programs for Pollution Abatement

10.8.1 Alternate Disposal Program Scope

The Board of Consultants suggested that selective dredging may be helpful in overcoming problems of exposing polluted sediments to the lake waters. This could be done by dredging the most polluted material first in a harbor, disposing of it in the lake, then covering it with lightly polluted or non-polluted materials dredged from another part of the harbor. Or it might be feasible to place the heavily polluted material from a harbor in a diked area and continue to dispose of the non-polluted or lightly polluted sediments in the lake. From years of observation during dredging at the various harbors, it has been learned that (1) certain areas, usually the enlarged section of a stream, contain the worst sediments, (2) the outer harbor areascontain considerably cleaner sediments, and (3) the material in the channels leading out from the breakwaters is usually clean sand.

FWPCA has confirmed a variation in pollutants within harbors (see listing in Table 19), However, further refinement will be possible with more sampling and analysis.

If a program for alternate disposal of polluted dredgings is adopted, it will be necessary to refine the present subjective means of determining the degree of pollution of harbor sediments. Some objective evaluation, perhaps similar to the preliminary criteria developed by FWPCA and reported in Table 18, and the data developed by the University of Wisconsin and presented in Figure 37, would be needed in order to differentiate and establish varying degrees of pollution of harbor sediments. Following the establishment of objective criteria, the sediments of a particular harbor project could be classified into the various pollution categories. Then, a plan could be adopted for alternate disposal of, for example, the sediments falling into the two most polluted categories and the continuance of open lake disposal for sediments in the lower pollution classifications.

Classification of sediments of different harbor projects and for different areas within individual harbor projects, into several ranges of pollution would not only permit definition of which harbor projects or portions of projects fall within the scope of a pollution abatement project, but would permit limited resources to be applied first to alternate disposal for those sediments falling into the most polluted classification. As additional resources become available, the sediments in lower pollution classifications can be scheduled for alternate disposal.

An adequate system of classification, coupled with sampling and analysis would provide a means of determining when control of pollutants at the source has resulted in a sufficient change in character of harbor sediments to no longer require alternate disposal.

It would be helpful to decision makers if cost estimates could be prepared for alternate disposal of sediments of different degrees of pollution. It is difficult to do so at the present time because only two classifications of sediments are currently definable, i.e., "polluted" and "unpolluted".

However, three magnitudes of a ten year plan of diked disposal are presented below. They are based on rough approximations of sediment classification, quantities to be dredged, and geographic factors. Decision makers will thus be enabled to determine what portions of the program they may be able to adopt with limited funds.

As indicated in Section 10.7.3, not all projects have been classified as to the degree of pollution of the sediments, nor have surveys for alternate disposal sites been made at all projects where sediments have been classified as polluted. The largest omission is Duluth-Superior Harbor where a survey is underway. Other omissions are generally of small magnitude.

Program Scope 1 includes projects or portions of projects where sediments are most polluted and of substantial volume (Table 42).

Program Scope 2 includes all those in Scope 1 and in addition other projects or portions of projects where sediments are moderately to highly polluted and of significant volume (Table 43).

Program Scope 3 includes all of the projects or portions of projects where sediments are classed as polluted. This program is one for which estimates are presented in Table 41, and is repeated here for convenience as Table 44.

All of the above program scopes are based upon the continuance of open lake disposal of unpolluted dredgings. As pointed out by the Board of Consultants in Sections 9.7.1 and 9.8.6, economic restraints on the disposal of dredgings will continue to point back to the Lakes as the recipient of dredgings until more is known about the long-range possibilities of managing the Great Lakes water resource in all its manifold aspects. Until more is known about beneficial uses of unpolluted dredgings, the reporting officer concludes that their open lake disposal can be safely continued.

Summarizing the data in Tables 42 through 44, Program Scope 1 (ten harbors) would take care of 3,027,000 cubic yards which represents 35 percent of all polluted dredgings at an increase in annual costs of $2,616,000. Since these dredgings are from the most highly polluted harbors, Program Scope 1 comprises well over 35 percent of the total pollutants contained in all sediments dredged from

Great Lakes harbors. Program Scope 2 (20 harbors) would take care of an additional 2,860,000 cubic yards (33 percent) at an additional cost of $5,677,000. Program Scope 3 (35 harbors) adds 2,686,000 cubic yards (32 percent) of the least polluted dredgings at an added cost of $4,578,000 annually.

Table 42

Diked Disposal Program Scope 1

	Average annual quantity and cost									
	Polluted maintenance dredging quantity	Cost of dredging with open lake disposal		Cost of dredging with diked disposal		Increase in cost of dredging due to diked disposal				Capital cost for diked disposal
Project		Total	Unit	Total	Unit	Fixed[a]	Operation & maintenance	Total	Unit	
	(C.Y.)	($)	($/C.Y.)	($)	($/C.Y.)	($)	($)	($)	($/C.Y.)	($)
Toledo Harbor, Ohio (except lakeward of mile 5)	1,120,000[b]	353,000	0.32	392,000	0.35	0	39,000	39,000	0.03	[c]
Cleveland Harbor, Ohio (Cuyahoga and Old Rivers only)	720,000	828,000	1.15	1,468,000	2.04	721,000	-81,000	640,000	0.89	6,010,000[d]
Rouge River, Michigan	300,000[b]	372,000	1.24	522,000	1.74	150,000	0	150,000	0.50	1,852,000
Calumet River, Ill. & Ind.	200,000	500,000	2.50	785,000	3.93	[e]	285,000	285,000	1.43	[e]
Monroe Harbor, Michigan (Inner channel)	176,000	77,000	0.44	170,000	0.96	60,000	33,000	93,000	0.52	550,000
Indiana Harbor, Indiana	151,000	332,000	2.20	422,000	2.80	56,000	34,000	90,000[f]	0.60	537,000
Green Bay Harbor, Wisc.	137,000	137,000	1.00	555,000	4.05	0	418,000	418,000	3.05	[c]
Buffalo Harbor, New York (River only)	125,000	194,000	1.55	688,000	5.50	85,000	409,000	494,000	3.95	720,000
Milwaukee Harbor, Wisc. (Rivers only)	50,000	53,000	1.07	309,000	6.19	[e]	256,000	256,000	5.12	[e]
Chicago River, Illinois	48,000	82,000	1.70	233,000	4.85	[e]	151,000	151,000	3.15	[e]
TOTAL	3,027,000	2,928,000		5,544,000		1,072,000	1,544,000	2,616,000		9,669,000

[a] Interest and amortization of capital costs

[b] Present disposal is in diked areas

[c] Diked area provided in connection with other projects

[d] Includes $2,500,000 under pilot program

[e] Minor costs included in operations and maintenance

[f] All additional costs are in first two years and have been averaged over 10-year period.

Table 43

Diked Disposal Program Scope 2

	Average annual quantity and cost									
	Polluted maintenance dredging quantity	Cost of dredging with open lake disposal		Cost of dredging with diked disposal		Increase in cost of dredging due to diked disposal				Capital cost for diked disposal
Project	(C.Y.)	Total ($)	Unit ($/C.Y.)	Total ($)	Unit ($/C.Y.)	Fixed[a] ($)	Operation & maintenance ($)	Total ($)	Unit ($/C.Y.)	($)
Toledo Harbor, Ohio (Except lakeward of mile 5)	1,120,000b	353,000	0.32	392,000	0.35	0	39,000	39,000	0.03	c
Detroit River, Mich.	800,000	272,000	0.34	2,846,000	3.56	2,284,000d	290,000	2,574,000	3.22	14,971,000
Cleveland Harbor, Ohio (Cuyahoga and Old Rivers only)	720,000	828,000	1.15	1,468,000	2.04	721,000	-81,000	640,000	0.89	6,010,000e
Saginaw River, Mich.	600,000	162,000	0.27	284,000f	0.47	132,000	-10,000	122,000	0.20	1,210,000
Rochester Harbor, N.Y.	360,000	162,000	0.45	709,000	1.97	277,000	270,000	547,000	1.52	2,440,000
Rouge River, Mich.	300,000b	372,000	1.24	522,000	1.74	150,000	0	150,000	0.50	1,852,000
Erie Harbor, Penn.	300,000	114,000	0.38	581,000	1.94	340,000	127,000	467,000	1.56	2,870,000
Fairport Harbor, Ohio (Grand River only)	230,000	97,000	0.42	380,000	1.65	187,000	96,000	283,000	1.23	2,120,000
Buffalo Harbor, N.Y. (Buffalo River & RRC & Tonawanda Harbor)	225,000	349,000	1.55	1,287,000	5.72	603,000	335,000	938,000	4.17	5,080,000
Calumet River, Ill. & Ind.	200,000	500,000	2.50	785,000	3.93	g	285,000	285,000	1.43	g
Monroe Harbor, Mich. (Inner channel)	176,000	77,000	0.44	170,000	0.96	60,000	33,000	93,000	0.52	550,000
Lorain Harbor, Ohio (Black River only)	175,000	74,000	0.42	356,000	2.03	209,000	73,000	282,000	1.61	1,757,000
Indiana Harbor, Ind.	151,000	332,000	2.20	422,000	2.80	56,000	34,000	90,000h	0.60	537,000
Green Bay Harbor, Wisc.	137,000	137,000	1.00	555,000	4.05	0	418,000	418,000	3.05	c
Sandusky Harbor, Ohio (Dock Channel only)	100,000	30,000	0.30	328,000	3.28	256,000	42,000	298,000	2.98	2,153,000
Harbor Beach Harbor, Mich.	95,000i	106,000	1.12	412,000	4.34	272,000	34,000	306,000	3.22	1,460,000
Grand Haven Harbor, Mich.	50,000	31,000	0.62	66,000	1.32	16,000	19,000	35,000	0.70	135,000
Milwaukee Harbor, Wisc. (Rivers only)	50,000	53,000	1.07	309,000	6.19	g	256,000	256,000	5.12	g
Ashtabula Harbor, Ohio (River only)	50,000	18,000	0.35	337,000	6.73	184,000	135,000	319,000	6.38	1,546,000
Chicago River, Ill.	48,000	82,000	1.70	233,000	4.85	g	151,000	151,000	3.15	g
TOTAL	5,887,000	4,149,000		12,442,000		5,747,000	2,546,000	8,293,000		44,691,000

a Interest and amortization of capital costs.

b Present method is disposal in dike areas.

c Diked disposal area provided in connection with other projects.

d No alternate area can be made available for calendar year 1969, 1970 or 1971. Average annual figures are based on a 7 year period. About 19% of annual cost would be borne by permit dredging.

e Includes $2,500,000 under pilot program.

f Estimates assume lands would be made available at no cost.

g Minor cost included in operations and maintenance.

h All additional costs are in first two years and have been averaged over 10 year period. No additional costs in last 8 years.

i Based upon project restoration in 1973 and continued maintenance through 1978.

Table 44

Diked Disposal Program Scope 3

Project	Polluted maintenance dredging quantity	Average annual quantity and cost								Capital cost for diked disposal
		Cost of dredging with open lake disposal		Cost of dredging with diked disposal		Increase in cost of dredging due to diked disposal				
		Total	Unit	Total	Unit	Fixed[a]	Operation & maintenance	Total	Unit	
	(C.Y.)	($)	($/C.Y.)	($)	($/C.Y.)	($)	($)	($)	($/C.Y.)	($)
Cleveland Harbor, Ohio	1,220,000	953,000	0.78	2,309,000	1.89	1,347,000	9,000	1,356,000	1.11	11,530,000
Toledo Harbor, Ohio	1,120,000	353,000[b]	0.32	392,000	0.35	0	39,000	39,000	0.03	c
Detroit River, Mich.	800,000	272,000	0.34	2,846,000	3.56	2,284,000[d]	290,000	2,574,000	3.22	14,971,000
Buffalo Harbor & B.R.C., N.Y.	625,000	413,000	0.66	1,821,000	2.91	934,000	474,000	1,408,000	2.25	7,870,000
Saginaw Harbor, Mich.	600,000	162,000	0.27	284,000[e]	0.47	132,000	-10,000	122,000	0.20	1,210,000
Sandusky Harbor, Ohio	600,000	180,000	0.30	1,021,000	1.70	799,000	42,000	841,000	1.40	6,729,000
Fairport Harbor, Ohio	400,000	148,000	0.37	600,000	1.50	240,000	212,000	452,000	1.13	2,723,000
Rochester Harbor, N.Y.	360,000	162,000	0.45	709,000	1.97	277,000	270,000	547,000	1.52	2,440,000
Erie Harbor, Penn.	300,000	114,000	0.38	581,000	1.94	340,000	127,000	467,000	1.56	2,870,000
Lorain Harbor, Ohio	300,000	126,000	0.42	459,000	1.53	224,000	109,000	333,000	1.11	1,965,000
Rouge River, Mich.	300,000	372,000b	1.24	522,000	1.74	150,000	0	150,000	0.50	1,852,000
Ashtabula Harbor, Ohio	220,000	77,000	0.35	518,000	2.36	250,000	191,000	441,000	2.00	2,220,000
Calumet R. & H., Ill & Ind.	200,000	500,000	2.50	785,000	3.93	f	285,000	285,000	1.43	f
Huron Harbor, Ohio	200,000	44,000	0.22	572,000	2.86	362,000	166,000	528,000	2.64	3,134,000
Monroe Harbor, Mich.	176,000	77,000	0.44	170,000	0.96	60,000	33,000	93,000	0.52	550,000
Indiana Harbor, Ind.	151,000	332,000	2.20	422,000	2.80	56,000	34,000	90,000[g]	0.60	537,000
Green Bay Harbor, Wisc.	137,000	137,000	1.00	555,000	4.05	0	418,000	418,000	3.05	c
Chicago River & Harbor, Ill.	108,000	184,000	1.70	608,000	5.62	f	424,000	424,000	3.92	f
Conneaut Harbor, Ohio	100,000	40,000	0.40	323,000	3.23	239,000	44,000	283,000	2.83	2,075,000
Harbor Beach Harbor, Mich.	95,000[h]	106,000	1.12	412,000	4.34	272,000	34,000	306,000	3.22	1,460,000
Oswego Harbor, N.Y.	80,000	26,000	0.33	272,000	3.40	197,000	49,000	246,000	3.07	1,730,000
Milwaukee Harbor, Wisc.	70,000	75,000	1.07	423,000	6.05	f	348,000	348,000	4.97	f
Two Rivers, Wisc.	51,000	51,000	1.00	176,000	3.45	f	125,000	125,000	2.45	f
Grand Haven Harbor, Mich.	50,000	31,000	0.62	66,000	1.32	16,000	19,000	35,000	0.70	135,000
Michigan City, Ind.	48,000	48,000	1.00	212,000	4.42	6,000	158,000	164,000	3.42	53,000
Manitowoc Harbor, Wisc.	43,000[i]	43,000	1.00	199,000	4.60	15,000	141,000	156,000	3.60	108,000
Holland Harbor, Mich.	40,000[j]	39,000	0.98	65,000	1.63	19,000	7,000	26,000	0.65	132,000
Waukegan Harbor, Ill.	32,000	26,000	0.80	142,000	4.38	f	116,000	116,000	3.58	f
St. Joseph Harbor, Mich.	32,000	22,000	0.68	64,000	2.00	17,000	25,000	42,000	1.31	160,000
Racine Harbor, Wisc.	30,000	30,000	1.00	171,000	5.70	f	141,000	141,000	4.70	f
Kenosha Harbor, Wisc.	29,000	25,000	0.86	132,000	4.55	f	107,000	107,000	3.69	f
Sheboygan Harbor, Wisc.	23,000	23,000	1.00	113,000	4.90	2,000	88,000	90,000	3.90	20,000
South Haven Harbor, Mich.	16,000	16,000	1.00	57,000	3.68	15,000	26,000	41,000	2.68	133,000
Frankfort Harbor, Mich.	10,000[k]	7,000	0.66	61,000	6.12	46,000	8,000	54,000	5.40	320,000
Menominee Harbor, Mich.	7,000	7,000	1.00	30,000	4.05	4,000	19,000	23,000	3.05	27,000
TOTAL	8,573,000	5,221,000		18,092,000		8,303,000	4,568,000	12,871,000		66,954,000

a Interest and amortization of capital costs.

b Present method is disposal in dike areas.

c Diked disposal area provided in connection with other projects.

d No alternate area can be made available for calendar year 1969, 1970 or 1971. Average annual figures are based on a 7 year period. About 19% of annual cost would be borne by permit dredging.

e Estimates assume lands would be made available at no cost.

f Minor cost included in operations and maintenance.

g All additional costs are in first two years and have been averaged over 10 year period. No additional costs in last 8 years.

h Based upon project restoration in 1973 and continued maintenance through 1978.

i Both harbor and river assumed polluted. Average annual quantities are based on an 8 year maintenance dredging period.

j Average for a period of 8 years. Polluted dredgings are currently being placed in a dike disposal area which has sufficient volume available for 1969 and 1970 dredgings.

k Average for a period of 8 years.

10.8.2 Allocation of Costs

As indicated in Tables 42, 43 and 44 of Section 10.8.1, the provision and use of diked disposal areas for containment of polluted dredgings would increase materially the cost of maintenance dredging over the cost of using open-lake disposal. For new project situations, such as constructing a new harbor or deepening an existing harbor, where the materials to be dredged are polluted, there also would be an increase in costs.

Existing national policy with respect to both navigation projects and pollution-abatement measures requires cost-sharing between Federal and non-Federal interests. This policy is discussed briefly in the following paragraphs and, for the possibility that a program of diked disposal may be decided upon, views on cost allocation are presented.

For the construction and maintenance of navigation projects, economic justification is required; that is, the benefits must exceed the costs before a project will be presented to Congress for possible authorization. It is noted that Federal navigation projects pertain to the general navigation channels and do not include harbor areas between such channels and individual dock facilities. Provision and maintenance of navigation depths from the Federal channel to the docks are responsibilities of the dock owner or operator, who may make such provision and do such maintenance following a permit procedure.

With respect to the Federal project, there are also local cooperation requirements to be met before construction is undertaken. Such requirements are covered in the authorizing document and, typically, they include:

(1) provide without cost to the United States all necessary land, easements, and rights-of-way for the construction and maintenance of the project when and as required; (2) hold and save the United States free from damages that may result from the construction and maintenance of the project; and (3) accomplish, without expense to the United States, alterations as required in sewer, water supply, drainage and other utility facilities (including commercial cable and pipeline crossings).

Congressional documents authorizing projects subsequent to 1962 require local interests to furnish lands for spoil disposal areas and for some projects, to dike the areas for containment of spoil. In some cases, the disposal areas may be for spoil dredged during construction only; in others, for spoil from both construction and maintenance. For projects authorized prior to 1962, including many of the harbors on the Great Lakes, the authorizing documents do not require such an item of local cooperation.

Charging a navigation project with the additional costs of diked disposal over that for open-lake disposal is illogical since there would be no navigation benefits, and navigation does not contribute in any appreciable way to pollution of the materials dredged. Invoking in the interest of pollution abatement the requriement that local interests provide disposal facilities, found in only a limited number of the Congressional documents authorizing navigation improvements, would result in gross inequities among the Great Lakes harbors. A more logical procedure would be to charge the additional costs of diked disposal to pollution abatement and to determine Federal and non-Federal participation in the costs on a basis appropriate to that purpose.

National policy for justification of pollution abatement and water quality control projects and the allocation of costs between Federal and non-Federal agencies is not well defined. The Federal Water Pollution Control Act as amended (33 USC 466 et seq.) provides for grants to any municipality or other public body which has authority to construct, maintain and operate waste treatment works. Under this legislation, a grant for the construction of waste treatment works, including intercepting and outfall sewers, may be 40 percent of the estimated reasonable cost if the state also contributes at least 30 percent, and 50 percent if the state contributes 25 percent and the project conforms with enforceable water quality standards. In metropolitan areas, the grant may be increased by 10 percent if the project conforms with a comprehensive metropolitan plan. Thus, under conditions whereby a proposed waste treatment project conforms with both enforceable water quality standards and a metropolitan comprehensive plan and the state contributes 25 percent, the Federal Government contribution will be 55 percent. Under this legislative program there is no requirement for a showing of benefits commensurate with project costs. There is only a requirement that the State Water Pollution Agency certify a need for the project and a need for financial assistance of the municipality or other public body sponsoring the project.

In 1961, the Federal Water Pollution Control Act was amended to direct agencies preparing plans for Federal reservoir projects to: (1) consider the inclusion therein of capacity for the regulation of streamflow for the purpose of "water quality control", and; (2) request Congress for authority to provide such capacity if found needed and justified. In determining the need for, and value of, water quality control storage, the proposing agency is directed to seek the advice of the Secretary of the Department of the agency responsible for administering the Federal Water Pollution Control Act; currently that is the Secretary of the Interior. The amendment also provides for allocation of costs to the water quality control purpose and requires that beneficiaries be identified. The amendment states that if benefits are found to be widespread or national in scope that the agency shall recommend that the Federal government assume the costs allocable thereto.

Since enactment of this legislation, reporting officers by and large have been relying on the Federal Water Pollution Control Administration to determine the need for, and value of, storage for water quality control in connection with the development of their reports. Because the legislation does not provide a rigid formula for dividing cost-sharing responsibility between Federal and non-Federal interests, and becaue the FWPCA has in all instances found benefits for water quality control to be widespread and recommended Federal assumption of the entire cost, non-Federal participation in the cost has been recommended for very few of the reservoir projects submitted thus far.

The Bureau of the Budget has questioned the propriety of Federal assumption of such costs and has pointed out that releases of stored water during periods of low flow serve several purposes, and that under existing laws those benefited should be contributing in accordance with the cost-sharing policies applicable to those purposes.

Various attempts have been made to form a policy which would require (1) the identification of the end water uses for which the water quality control was needed, (2) the allocation of water quality control costs to the end water uses, and (3) allocation of costs for each end water use to Federal and non-Federal interests in accordance with existing cost-sharing policies for each purpose. To date no uniform policy has been established.

In the present case, efforts to evaluate benefits to water uses resulting from elimination of some fraction of the pollutants entering the lakes are described in Section 8. The water uses that could benefit are domestic and industrial water supply, commercial fishing, and recreational activities including sport fishing, boating, and swimming. Other water related benefits would be enhancement of water front land values. As indicated in Section 8, benefits cannot be evaluated and must be considered intangible. Accordingly, no allocation to benefitting water uses can be made at this time. Furthermore, even if allocation to water uses were possible, the benefits would be so widespread that any attempt to allocate costs to recipients would be impracticable.

Another approach has been considered; one that allocated pollution abatement or water quality control costs to those who produce the wastes polluting the watercourses. Such allocation of costs is generally accomplished by requiring the adequate treatment of wastewaters before they are discharged to receiving streams. This is essentially the method being followed by the Federal and State Water Pollution Control Agencies. However, many polluters cannot be identified, or, where known, presently are not able to control the introduction of pollutants into the waterways. Agricultural sources are examples. Indeed, one of the reasons for the present study of alternate disposal practices is the time required to implement control at the source. The control measures being considered in the present study extend only 10 years to mitigate damage to the Lakes pending the implementation of pollution control at the source.

There are three factors that appear cogently relevant to cost allocation with respect to a program for containment within diked areas of polluted materials dredged from Great Lakes harbors. These three factors are:

(1) Any such program would be a pollution-abatement measure rather than a navigation improvement (see discussion in Section 10.6). While magnitude for a diked-disposal program would be established by the navigation need for dredging of polluted sediments, the program should be recognized as a pollution-abatement measure and paid for as such. The costs of the program would be the additional costs over those for open-lake disposal, both for the construction of alternate disposal facilities and for the utilization of the facilities after they are provided.

(2) The source of pollutants found in the bottom sediments that must be dredged is from man's activities both in the immediate harbor area and in the upstream tributary area. For almost all harbors, pollutants are brought into the harbor via a river from areas upstream that, generally speaking, are within the same state in which the harbor is situated.

(3) The nature of benefits from containment of polluted dredgings within diked areas is such that, although mostly intangible and actually very small in those aspects that can be quantified, the benefits properly may be characterized as long-term and widespread. They are long-term because the adverse effects on lake ecology that would be eliminated by containment of the dredgings are quite probably accummulative. They are widespread because all of the Great Lakes are involved and the intangible benefits would accure to several interests.

In view of the foregoing, the reporting officer considers that: (1) additional costs for a diked disposal program should in no way enter into the economic evaluation of a navigation project; (2) there should be both Federal and non-Federal participation in the costs; and (3) the allocation of such participation should be consistent with the precedent established by the Federal Water Pollution Control Act with respect to waste treatment works. The reporting officer considers further that, in the case of diked disposal areas, the allocation should extend to the additional disposal costs associated with the utilization of the diked disposal areas, as well as to the costs of constructing them.

10.8.3 Procedures for Carrying out Disposal Program

Should it be decided to undertake an alternate disposal program, the procedures to carry it into operation could be visualized as follows:

(a) The Congress would pass legislation to require that after some stated period following adoption, all maintenance dredgings from specified rivers and harbors projects or portions of projects in the Great Lakes be disposed of ashore, or in diked in-lake disposal areas, or disposed of in some other manner that would provide equivalent retention of pollutants. The projects or portions of projects to be specified would be selected. from the programs set forth in Tables 42, 43, and 44 of Section 10.8.1. Local authorities would be responsible for selecting and procuring the alternate disposal site and making it available to the Corps of Engineers for the purpose of disposal of polluted dredgings. The legislation would provide a policy for Federal and non-Federal participation in the diked disposal program. Further, legislation would provide for cessation of maintenance dredging of the polluted sediments of any project if suitable disposal areas were not provided by non-Federal interests; and that in-lake disposal could be resumed at any project when the appropriate State Water Pollution Control Agency with the concurrence of the FWPCA determines that such disposal could be resumed safely.

(b) For the harbor area concerned, the outline of the alternate disposal plans from Appendix K, L, or M would be used as a basis for further planning. The appropriate local authorities would develop the plan in more detail and could call upon the FWPCA and Corps of Engineers for information to assist in this planning. If the plan involved structures in navigable waters, the local authorities would apply for a Department of the

Army permit for the structure and would coordinate with other Federal agencies such as the Department of Health, Education and Welfare and the Fish and Wildlife Service of the Department of the Interior.

(c) At harbors where diked disposal has been the practice for economic reasons, these areas would continue to be constructed and managed as they now are by the Corps of Engineers.

If a dike disposal program for a ten-year period of some magnitude is decided upon, it will take approximately two years to construct dikes. In addition, time will be needed to consider such a program, provide funding and establish procedures. During this time, it might be desirable to construct diked areas for dredgings at the worst problem harbors to hold two to four years of dredgings, using Federal funds still available from the pilot program and any other funds subsequently appropriated for this purpose.

Section 11

COORDINATION WITH OTHER AGENCIES

11.1 Coordination of the study.

There was coordination with the appropriate Federal agencies through the course of the study. By letter dated 5 January 1967, the Chicago Regional Office of the Federal Water Pollution Control Administration provided comments on the Corps' draft outline for the program of experimental studies. As noted in Section 6, much of the water and bottom sediment sampling, the analyses of samples, and evaluation of sampling results was accomplished by the FWPCA. The FWPCA had representation at most of the periodic meetings with the Board of Consultants, where progress on the studies was reviewed and the direction of the studies was guided. At many of the meetings, the FWPCA representation included personnel from that agency's Washington staff, as well as from its Chicago Regional Office and local area offices. At several of the meetings, the FWPCA office at Cincinnati, Ohio was represented also. Other Federal agencies, including the Fish and Wildlife Service, and the Public Health Servide had representatives at a number of the meetings with the Board of Consultsnts. The cooperation by the FWPCA and the participation in the discussions by all concerned was most helpful.

11.2 Coordination of the report.

Upon completion of the present report, efforts to obtain views of others on the matters contained in the report included:

(a) Distribution of the complete 12 volumes of the present report excluding the present section, and including a tentative draft of Section 12 CONCLUSIONS, to the representatives of the Governors of the eight States bordering the Great Lakes who have been designated to coordinate with the Corps on water resources projects. Following the distribution of the report, each of the Governors or his representatives, except for the States of Illinois and Minnesota, was given a personal briefing by the reporting officer or one of the other District Engineers in the North Central Division of the Corps of Engineers. Comments were invited from each.

(b) Distribution of the complete report to the Bureau of Commercial Fisheries and the Bureau of Sport Fisheries, of the Department of Interior, the Division of Solid Waste Disposal of the Public Health Service, Department of Health, Education, and Welfare, and the Great Lakes Basin Commission. Comments were invited from each.

(c) Holding of twelve public meetings during April and May 1969 at Buffalo and Rochester, New York; Cleveland (two meetings) and Toledo, Ohio; Detroit, Grand Haven and Bay City, Michigan; Milwaukee and Green Bay, Wisconsin; Chicago, Illinois; and Duluth, Minnesota. In addition to a general briefing these meetings provided a forum for anyone wishing to make statements concerning their views on the subject problems. All participants were additionally requested to fill out written questionnaires.

A summary of the views and comments expressed through these various mediums is contained in the Sections that follow.

11.3 Comments from the States.

Comments relative to the detailed draft report have been received from representatives of most of the eight State Governments bordering the Great Lakes. Some of the more significant opinions and views expressed in these comments are as follows:

(a) The States are of the opinion that alternative methods of polluted dredge spoil disposal are necessary.

(b) In general, all appear to take exception to the draft report's tentative conclusion that extra costs should be chargeable to pollution abatement with cost sharing between the different levels of government. They feel it is impossible to break down responsibilities for pollution and point out that all benefits are widespread and even interstate in nature. Consequently, they feel additional costs resulting from alternate dredging disposal should be chargeable directly against the individual navigation projects and financed solely with Federal funds. The states of Ohio and Pennsylvania appear to be more flexible on this point and indicated a willingness to cooperate in financing in the same manner they do for flood control and streamflow augmentation projects by furnishing necessary lands and rights-of-way.

(c) The States endorse continuation and even expansion of the study of dredging and water quality problems.

(d) Comments from New York State differ from the other concerned States in several respects. New York State agrees to the expedient program of diking to contain two years dredgings at the worst problem areas using Federal funds. However, they do not favor any ten year program of alternate disposal of dredgings or any long range use of diking. They favor instead a more permanent solution of utilizing funds for treatment of the pollution and reduction of sediment at the source. They indicate the amount of funds necessary for a diking program would be a significant drain on the States Pure Water Program. New York State urges that necessary dredging of harbors and channels be continued in the best interests of the States economy.

11.4 Comments from representatives of Federal Agencies and Government.

Comments received to date from Federal Agencies and Government include statements and letters from congressmen, a letter addressed to the Honorable Charles A. Vanik, Representative in Congress from Ohio, from the U. S. Department of the Interior, several statements for the public meetings from various offices of the FWPCA and comments from the Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife. The comments from the U. S. Department of the Interior and the FWPCA indicate they are based upon only a preliminary review of the detailed draft report. Some of these comments are as follows:

(a) The FWPCA indicates they are in general agreement with the findings in the detailed draft report. They concur that in-lake disposal of heavily polluted sediments is undesirable. The FWPCA emphasizes there is a broad disparity in the amount of pollution in the dredgings of the various Great Lake harbors and although there is no question on requirements for the heavily polluted harbors to have alternate disposal methods, decisions will have to be made as to this necessity for those harbors considered to be lightly polluted.

(b) The U. S. Department of the Interior on the basis of their preliminary review indicate they are not wholly in agreement with some of the tenative conclusions of the Corps in the report. They make the following comments:

(1) They feel that although studies did not conclusively demonstrate a massive deleterious effect on water quality from open water dredging, it did show that polluted sediments were toxic to small forms

of animal life. They believe that this fact should be recognized in the conclusions of the report.

(2) The Interior Department indicates the cost of a program to prevent pollution cannot and probably should not be justified on a cost-benefits basis. They point out the real benefits involved are incalculable and any attempt to assign dollar values to them will, at best, provide questionable results.

(3) The U. S. Department of the Interior emphasized they have taken and are maintaining the position of opposing the continued dumping of polluted materials in the open waters of the Great Lakes. To this end they feel the report has shown alternative dredging disposal in diked or on-land sites to be a realistic and highly effective approach.

(c) The Bureau of Sport Fisheries, believe that a ten year program to deposit polluted dredgings in diked areas with authority and funding to undertake a two-year expedient program of diking to be most compatible with programs underway to preserve, protect and enhance fish and wildlife. They indicate full accord with the Board of Consultant's view that further research into the dredging and spoil effects on the quality and use of the aquatic environment should continue for an indefinite period by competent, well equipped, and adequately staffed harbor survey units.

(d) Statements and letters from Congressman representing States bordering the Great Lakes included a telegram statement read at the Buffalo public meeting from the Honorable Richard D. McCarthy, Representative in Congress from New York; a letter and statement read at the Milwaukee public meeting from the Honorable Glen R. Davis and the Honorable Henry S. Reuss respectively, both Representatives in Congress from Wisconsin; and statements read at the Chicago public meeting from the Honorable Robert McClory and the Honorable Abner J. Mikva both Representatives in Congress from Illinois. All congressmen expressed interest in the subject problems.

Congressman McCarthy, Reuss, McClory and Mikva advocated the discontinuance of polluted dredgings disposal in the open lakes. Congressman McCarthy indicated he would do all he could to insure that Congress acts promptly to provide funds for alternate disposal costs. Congressman Reuss thought all additional costs should be borne by the Federal Government. Congressman McClory indicated Federal, State and Local benefits should be weighed carefully in determining a method for sharing costs of the alternate disposal programs.

11.5 Comments from others.

Other comments received include those from local government, industry, navigation interests, private organizations, and individual citizens. Generally, comments from these diverse groups and individuals indicate almost unanimous agreement for the need to maintain and even improve the overall water quality in the Great Lakes. However, comments on the means necessary to accomplish this, the seriousness of the present situation and the overall effect of dredging disposal, reflected a wide range of views. Following is a generalization of the comments received:

(a) Representation at the public meetings included generally representatives from government, industry, navigation interests, conservation oriented organizations and individuals directly involved in the alternate site utilization. As might be expected, there was almost no representation from what could be called the general public.

(b) The comments received from local government (town, county and city, etc.) reflected a fairly distributed and as wide a range of views as found in any other classification. Some local government organizations considered the contribution of dredging disposal on lake pollution in general to be insignificant and wanted open lake disposal continued as before. Others wanted all open lake disposal discontinued immediately with all further disposal in alternate sites. Others were not exactly sure what should be done. They wanted further testing of the individual harbors to conclusively determine if dredgings from their particular harbors are polluted. Still others expressed no opinion on dredging disposal practices other than to take exception to certain proposed alternate sites for their individual harbors.

(c) Industry and navigation interests generally indicated they considered the results of the study to be inconclusive and felt the funds for the alternate disposal program could be used better to combat pollution at its sources.

(d) Private organizations (Conservation groups, League of Women Voters, Garden Clubs, etc.) and individuals again presented a variety of views. For the most part, however, they favored a program for alternate disposal of dredgings with a program of the largest scope.

(e) One other view of note concerned the use of low-lying or marsh type lake perimeter lands for dredging alternate disposal sites. Comments received from all sources except individual private owners, expressed a unanimity of opposition to the use of these sites.

(f) Each participant, at the public meetings, was given a questionnaire and requested to fill it out. The response to this request, however, was rather disappointing with only 156 questionnaires returned from the approximately 490 people in attendance at all the public meetings. Two different questionnaires were used at different meetings. One questionnaire simply asked for answers to whether some program for alternate disposal of dredgings was required, how it should be financed, and which of the three scopes described in the meeting notice it should be. A later revision to this question was more comprehensive and asked if the individual participant felt a program of alternate disposal of dredgings would be beneficial to the water quality of the Great Lakes and opinions on program scopes for various combinations of financing costs. The revised questionnaire also asked if investments were made for adequate treatment for municipal and industrial wastes and agricultural runoff, would you favor making additional investments for some 10-year program of alternate disposal of dredgings? Results from the questionnaires were as follows:

(1) Some program of alternate disposal was favored by a 5 to 1 margin. These same participants favored the largest scope program with financing to be shared between Federal and State governments.

(2) The participants by a 7 to 1 margin indicated they felt a program of alternate disposal would be beneficial to Great Lakes water quality. They favored the largest scope program if financing was borne solely by the Federal Government or shared by the Federal, State and local governments. If financing was to be borne entirely by State and local governments, the choice was no program at all by a narrow margin over the smallest scope program second choice. Obviously the participants were concerned with funding an alternate disposal program and were willing to compromise their position depending upon necessary local interest financial responsibility.

(3) Results from the questionnaire in answer to the question described previously, about the necessity of a 10-year alternate disposal program if pollution was effectively treated at the source, still favored a program but by only a narrow margin.

Section 12

CONCLUSIONS

The reporting officer concludes:

(a) Because of the size of the Great Lakes and their inherent and wind induced water movements, the ultimate fate of polluted sediments deposited in the Great Lakes and their effect on water quality remain unknown despite much sampling and analytical work during the progress of the study.

(b) Heavily polluted sediments from tributary streams when transported to the Lakes either naturally or by dredging equipment must be considered presumptively undesirable because of their possible long-term effects on the ecology of the Great Lakes, as evidenced by bio-assays of the effects on bottom organisms and plankton.

(c) Cessation of dredging operations at polluted harbors would have but little effect on the volume of polluted sediments which are deposited and dispersed over vast areas of lake bottom. Natural stream gradients would be reestablished and polluted sediments would be transported to the lakes by streamflow and dispersed by natural lake forces.

(d) To obtain the maximum abatement of such deterioration of lake ecology as may be caused by the deposition of polluted sediments in the lakes, through stream flow processes as well as the dredging disposal process, it would be necessary to intercept the sediments and extract the pollutants or withhold the sediments from the lakes by depositing them in confined areas.

(e) The polluted sediments carried by tributary streams which have harbors at their mouths largely settle out in the harbor areas, and the materials which settle out are being removed by maintenance dredging operations. Materials carried in solution by tributary streams do not settle out in the harbor areas, although some may be precipitated and deposited by reaction with other pollutants introduced in the harbor areas.

(f) Withholding all dredgings from the Lakes could expect to reduce (1) total solids reaching the Lakes by about eignt percent, and (2) potential pollutants by the same general percentage as for solids.

(g) While the benefits to the Lakes that would be derived by withholding polluted sediments associated with dredgings are real, they are not measurable. Except for limited areas and temporary situations the resulting improvement in overall water quality would probably be undetectable under present conditions.

(h) Studies to date indicate that disposal in diked areas would be the least costly effective method of withholding from the Lakes pollutants associated with dredgings.

(i) A program for diked disposal of polluted dredgings for ten years is feasible and may be desirable in the interest of pollution abatement. The estimated costs for such a program -- of three different scopes -- are stated in Tables 42, 43 and 44 of Section 10.8.1. The total estimated costs, capital costs plus additional annual charges for the ten-year period are: $25,109,000 for Scope 1, including 10 harbor projects; $70,151,000 for Scope 2, including 20 projects; $112,750,000 for Scope 3, including 35 projects.

(j) At the present time justification for a program of diked disposal of polluted dredgings can be based only upon public objectives regarding the quality of the Great Lakes and the resulting evaluation of presently intangible benefits.

(k) The increased costs of an alternate disposal program should not be charged to navigation projects. Costs for dredging and deposit of polluted sediments in diked disposal areas, in excess of the comparable costs for dredging and disposal in usual open-lake areas, should be charged to pollution abatement; and the cost allocation between Federal and non-Federal interests should be consistent with the precedent established by the Federal Water Pollution Control Act.

(l) Since it would require some time for review of this report and subsequent authorization and funding of one of the programs presented for consideration, as well as additional time to construct diked areas for the program approved, it may be advisable to continue the limited program of alternate disposal at the worst polluted harbors as carried out under the pilot program.

(m) Present knowledge indicates that open lake disposal of non-polluted dredgings can be safely continued. Also, at some of the smaller harbors, because of the high costs, the small amount of dredgings and limited or uncertain benefits that would be derived from alternate disposal, it is reasonable to continue open-lake disposal, pending further studies, even though sediments are somewhat polluted.

(n) Continuation of the testing and studies is desirable to improve the technical basis for any future modification of the diked disposal programs considered in this report.

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