DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-76-2

TREATABILITY OF DREDGED MATERIAL (LABORATORY STUDY)

by

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U. S. Army Engineer Waterways Experiment Station
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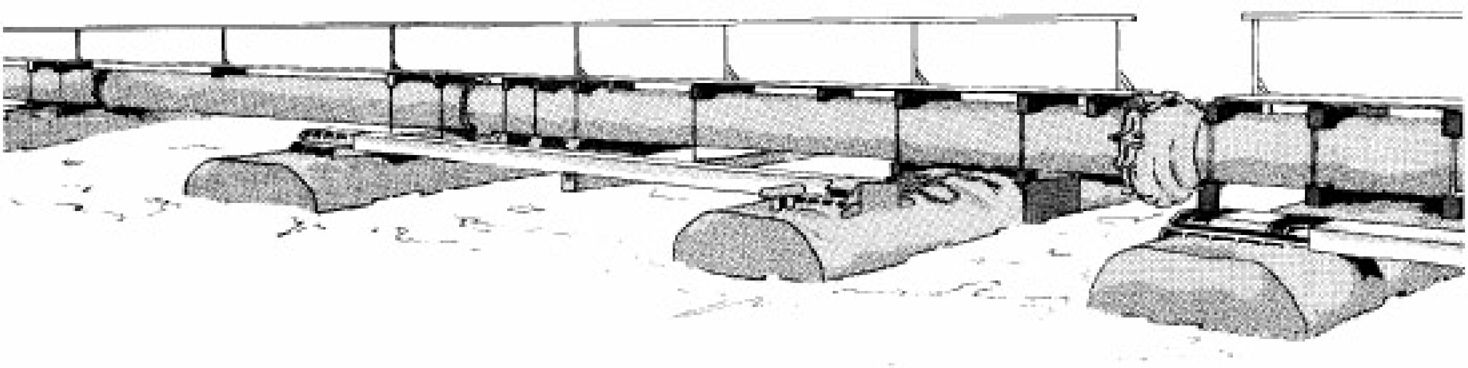
February 1976

Final Report



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Under DMRP Work Unit No. 6B02

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IN REPLY REFER TO: WESYV 17 February 1976

SUBJECT: Transmittal of Technical Report D-76-2

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of a laboratory study on the treatability of dredged material. The study is one of six research efforts initiated to date in Task 6B (Treatment of Contaminated Dredged Material) of the Corps of Engineers' Dredged Material Research Program (DMRP). This task, included as part of the Disposal Operations Project of the DMRP, is concerned with evaluation of physical, chemical, and/or biological methods for the removal of contaminants from dredged material.

2. In recent years there has been continued concern over the adverse environmental impact of dredging and disposal operations on water quality and aquatic organisms. Rapid industrial and population growth in areas adjacent to navigable waterways has continued to contribute to the contamination of the water bodies and the sediments that eventually must be dredged. It becomes apparent during the planning phases of the DMRP that it may be necessary to treat contaminated dredged material before it could be returned to open water or the effluent discharged back to waterways from containment areas. Therefore Task 6B was developed to meet this potential need.

3. This investigation was designed to evaluate the adequacy of certain parameters commonly used to describe the pollution potential of dredged material, to assess the effectiveness of various methods for treatment of contaminated dredged material, and to recommend applicable treatment schemes. The investigation focused on the treatability of dredged material as it is being disposed in open water and of dredged material that has been deposited in confined (diked) areas.

4. An evaluation of 18 physical and chemical parameters commonly used as indices of the pollution potential of dredged material showed that bulk analysis methods do not provide an adequate assessment of the environmental effects of dredged material disposal.

5. Results of the study indicate that three alternative systems have demonstrated potential for the treatment of dredged material. The systems are listed and their potential described briefly in the following paragraphs:

a. In-line aeration provides a means of satisfying the immediate oxygen demand and thus reducing or eliminating the adverse effects of depletion of dissolved oxygen in the receiving water body.

b. Treatment by confinement of dredged material in diked areas takes advantage of natural sedimentation processes to separate solid and liquid fractions.

c. A system of vacuum filtration, though experimental, offers the advantages of a more rapid means of fraction separation and a smaller containment area requirement than the confined area needed when only natural sedimentation treatments are involved.

6. Because the results are based on limited laboratory analyses of samples from only three disposal areas, further laboratory and field studies are recommended in order to refine techniques and aspects of the three alternative treatment systems.

G. H. HILT
Colonel, Corps of Engineers
Director

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A laboratory study was made of the amenability of contaminated dredged material to various treatment procedures; the test results support the observation that many conventional wastewater treatment techniques are inapplicable and/or impractical prior to open-water disposal.

Results of the study indicate that the following three alternative systems have demonstrated potential for the treatment of dredged material. In-line aeration provides a means of satisfying the immediate oxygen demand (Continued)

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20. ABSTRACT (Continued).

and thus reducing or eliminating the adverse effect of depletion of dissolved oxygen in the receiving water body. Treatment by confinement of dredged material in diked areas takes advantage of natural sedimentation processes to separate solid and liquid fractions. A system of vacuum filtration, though experimental, offers the advantages of a more rapid means of fraction separation and a smaller containment area than the confined area used for natural sedimentation treatment.

An evaluation of 18 physical and chemical parameters commonly used as indices of the pollution potential of dredged material shows that bulk analysis methods do not provide an adequate assessment of the environmental effects of dredged material disposal.

Because the results are based on limited laboratory analyses of samples from only three disposal areas, further laboratory and field studies are recommended in order to refine techniques and aspects of the three treatment systems suggested.

EXECUTIVE SUMMARY

In recent years there has been increased concern over the adverse environmental impact of dredging and disposal operations on water quality and aquatic organisms. Rapid industrial and population growth in areas adjacent to navigable waterways has continued to contribute to the pollution of the water bodies and sediments. In a 1970 report to the President, the Council on Environmental Quality recommended that ocean dumping of contaminated dredged material be phased out as soon as alternative schemes were developed and that dredged material disposal in estuaries and coastal areas be regulated. The report further recommended that research be undertaken to determine the effects of open-water disposal.

Objectives

The primary purpose of this study was to assess the effectiveness of various methods for the treatment of contaminated dredged material. The study also sought to investigate the adequacy of certain parameters commonly used to describe the pollution potential of dredged material and to recommend applicable treatment schemes.

Methods

The investigation focused on the treatability of dredged material as it is being disposed in open water and of material that has been deposited in confined (diked) areas. The third type of disposal, deposition in unconfined areas, accounts for less than 2 percent of all material dredged during maintenance operations.

To conduct the study, dredged sediment material and liquid samples were collected at three selected areas: (1) three sites within Mobile Bay near Mobile, Alabama; (2) one site in Maumee Bay at Toledo, Ohio; and (3) one site in Mare Island Strait near Vallejo, California.

Standard analytical tests were performed to determine the chemical and physical characteristics of the dredged materials. These tests included analysis for solids, sulfides, total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total phosphorous (P-Total), phosphate phosphorus (PO_4-Total), mercury (Hg), lead (Pb), zinc (Zn), cadmium (Cd), manganese (Mn), iron (Fe), cation exchange capacity, and grain-size analyses. From the analyses conducted in this study, an assessment was made of the adequacy of each of these parameters as indices of environmental quality.

Laboratory studies were performed to establish the basic effectiveness of various biological, chemical, physical, and aeration processes considered applicable for treatment of contaminated dredged material. The parameters used to determine the organic nature and biological treatability of dredged material were the biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and immediate oxygen demand (IOD). The effect of the dredged material on a mixed liquor suspended solids (MLSS) concentration was also evaluated. A chemical coagulation analysis was performed to evaluate the amenability of dredged material to chemical treatment. To assess the feasibility of physical treatment, the specific resistance to filtration, the sedimentation or settling characteristics, and the dissolved air flotation were studied.

Aeration studies were also performed in the laboratory in order to determine the nature of the IOD, the total amount of oxygen required by the dredged material, and the effects of aeration on dredged material.

Treatment Effectiveness

Tests on the samples of dredged material collected for this study agree with the results reported by others in indicating that the bulk analysis methods of evaluating the characteristics of dredged material do not provide an adequate assessment of environmental effects of dredged material disposal.

With regard to the treatment of dredged material, it has been observed that many conventional wastewater treatment techniques frequently are inapplicable and/or impractical prior to open-water disposal: dredged material generally presents a high solids content, a high magnitude and variability of flow, and a complex makeup of physical and chemical properties and organic matter.

For the three areas represented in this study, the analyses demonstrated that biological treatment techniques would be ineffective, but that the chemical coagulation treatment procedure could be employed to reduce turbidity. In studies of physical treatability, it was shown that vacuum filtration can, at least in the laboratory, effectively dewater dredged material. Sedimentation is a useful technique, but the time required for settling out varies and increases as the organic content increases. Direct application of the dissolved air flotation method to dredged material slurries proved to be ineffective in the removal of suspended matter from the samples.

Rapid oxygen depletion is one of the most documented and noticeable effects of dredged material disposal. During laboratory aeration studies it was observed that the depletion of DO can be appreciably reduced by aerating the slurry. This means that an excess of oxygen, when added to the carrier water, would temporarily meet the oxygen demand and would reduce the IOD to a tolerable level during the passage of dredged material through the water column. In the disposal site it may not be necessary to supply a quantity of oxygen sufficient to satisfy the entire demand because of the dilution and dispersion occurring in the receiving water.

Recommended Treatment Schemes

Three systems demonstrate potential for the treatment of dredged material:

(1) In-line aeration, which can greatly reduce or eliminate the depletion of DO in the receiving water body.

(2) Confinement in diked areas, which takes advantage of natural sedimentation to separate solid and liquid factions. The liquid faction can then be subjected to other procedures in order to remove specific pollutants, fines, and organic matter.

(3) Large-scale vacuum filtration, a dewatering process which separates liquid and solid factions more rapidly than natural sedimentation. The containment area required for this scheme would be smaller than that needed for settling treatment in confined dike areas. The dewatered dredged material can then be handled for sand and gravel reclamation or used as fill material. The liquid faction can be further treated for pollutant removal.

PREFACE

This report presents the results of an investigation of the laboratory treatability of contaminated dredged material. The investigation was conducted as part of the Corps of Engineers Dredged Material Research Program (DMRP). The DMRP is sponsored by the Office, Chief of Engineers (DAEN-CWO-M), and was formally authorized by letter dated 27 December 1971.

This study was conducted by the Environmental Engineering Division (EED) of the Environmental Effects Laboratory (EEL) during the period July 1973 to June 1974 by Messrs. T. K. Moore and B. W. Newbry. The study was conducted under the direct supervision of Mr. A. J. Green, Chief, EED, and under the general supervision of Dr. John Harrison, Chief, EEL; Dr. John Keeley and Dr. Roger T. Saucier, Special Assistants, EEL; and Dr. Robert M. Engler and Mr. Charles C. Calhoun, Jr., Project Managers, EEL.

The Directors of WES during the study and preparation of this report were BG E. D. Peixotto, CE, and COL G. H. Hilt, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	0.0254	metres
feet	0.3048	metres
yards	0.9144	metres
miles (U. S. statute)	1.609344	kilometres
acres	4046.856	square metres
cubic yards	0.7645549	cubic metres
gallons (U. S. liquid)	3.785412	cubic decimetres
pounds (force) per square inch	6894.757	pascals
gallons per minute	3.785412	cubic decimetres per minute
feet per second	0.3048	metres per second
cubic feet per second	0.02831685	cubic metres per second
cubic feet per minute	0.02831685	cubic metres per minute

NOTATION

$Al_3(SO_4)_2 \cdot 14H_2O$	- Alum
BOD	- Biochemical oxygen demand (five-day)
CaO	- Lime
Cd	- Cadmium
C_o	- Initial slurry concentration
COD	- Chemical oxygen demand
C_u	- Underflow slurry concentration
DO	- Dissolved oxygen
DO_F	- Final dissolved oxygen content (at saturation)
DO_I	- Initial dissolved oxygen content
e	- Transcendental constant used as the base of natural logarithms; equal to 2.7182818
Eh	- Standard oxidation-reduction potential
Fe	- Iron
Fe^{++}	- Ferrous iron
$FeCl_3$	- Ferric chloride
Hg	- Mercury
$HgSO_4$	- Mercuric sulfate
H_o	- Initial height of interface
H_u	- Underflow height
IOD	- Immediate oxygen demand
JTU	- Jackson turbidity units
meq	- milliequivalents
MLSS	- Mixed liquor suspended solids
Mn	- Manganese
Mn^{++}	- Divalent manganese
NH_4-N	- Ammonia nitrogen
NO_3-N	- Nitrate nitrogen

O_2	- Oxygen
O_D	- Oxygen dissolved
O_{sr}	- Oxygen supply rate
O_T	- Oxygen transferred
O_u	- Oxygen used
P-Total	- Total phosphorus
Pb	- Lead
PO_4-Total	- Phosphate phosphorus
ppb	- Parts per billion
ppm	- Parts per million
psi	- Pounds per square inch
psig	- Pounds per square inch, gage
Q	- Flow rate
$S^=$	- Sulfides
TKN	- Total Kjeldahl nitrogen
TOC	- Total organic carbon
TS	- Total solids
TVS	- Total volatile solids
t_u	- Time to reach underflow concentration
V	- Total volume of sediment and water
V_F	- Final oxygen volume of reservoir
V_I	- Initial oxygen volume added to reservoir
V_R	- Total oxygen reservoir volume
W_s	- Weight of sediment
Zn	- Zinc
^oC	- Degrees centigrade
δ	- Density
μ	- Microns

PART I: INTRODUCTION

Background

1. The Corps of Engineers (CE) is responsible for the development and maintenance of navigable waterways throughout the United States. The fulfillment of this task results in the production of large volumes of dredged material with an average of 80,000,000 cu yd* per year over the last 3 years associated with new projects alone. Dredging required to maintain authorized project dimensions now totals an additional 300,000,000 cu yd per year.

2. Dredged material can be divided into three principal types: coarse-grained, fine-grained, and organic. The coarse- and fine-grained material can be further described on the basis of grain size. In addition, dredged material often contains various amounts of rock, wood, pieces of metal, broken glass, and other debris. According to a report to the President on "Ocean Dumping - A National Policy," dredged material accounts for 80 percent by weight of all ocean dumping and 34 percent of this amount is estimated to be polluted.[1] The material dredged from new work projects is generally less detrimental to the environment and has better engineering properties than the material dredged from maintenance projects. Material obtained during maintenance dredging is usually fine-grained material, such as silt and clay, soil from surface erosion, or sludges from municipal and various industrial sources that have resulted from the rapid industrialization and population of areas adjacent to navigable waterways.

3. As a result of concern over the possibility of adverse effects on water quality and aquatic organisms resulting from dredging and the discharge of dredged material into open water, the CE began investigating the feasibility of alternative disposal methods for material

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 11.

dredged from selected harbors on the Great Lakes as early as 1966. After pilot studies,[2] it was concluded that assessing the impact of open-water disposal of polluted dredged material was more difficult than anticipated and that a continuing study would be desirable.

4. Many examples of the Nation's increasing concern over the environmental impact of dredging and dredged material disposal and man's activities can be cited. Two important examples are mentioned in the U. S. Army Engineer Waterways Experiment Station (WES) Technical Report H-72-8.[3] One is the National Environmental Policy Act of 1969, which requires a detailed statement of the environmental impact of dredging for proposed new and maintenance projects (along with all other proposed activities affecting the environment). The second example is a report on ocean dumping, which recommends, among other things, that ocean dumping of polluted dredged material be phased out as soon as alternatives can be employed and that dumping of unpolluted dredged material be regulated to prevent damage to estuarine and coastal areas.[1] Further, the report states that serious information deficiencies exist and recommends broad-based research in a number of major areas to provide a better understanding of the effects of ocean waste disposal.

5. Section 123(i) of the River and Harbor Act of 1970 (Public Law 91-611) authorized the Chief of Engineers to carry out a comprehensive program of research, study, and experimentation related to dredging and disposal of dredged material. This authorization resulted in the development of the Dredged Material Research Program (DMRP), which consists of four phases. Phases I and II, which are now complete, included a review of literature and available data and the development of the research program; Phase III involves research accomplishment; and Phase IV involves prototype tests. This report is a portion of the Phase III effort of the DMRP.

Problem Definition

6. Prior to this study, virtually no research had been documented on the treatment of dredged material. Design information and

dredged material characterization and treatability data necessary to modify existing treatment processes and equipment or to develop new techniques were not available. Since the types of contaminants found in dredged material are for the most part the same as those found in domestic and industrial wastes, it seemed reasonable to assume that similar treatment processes might also be applicable. However, major differences between treatment of dredged material and conventional waste treatment systems are attributed to the highly variable volume and characteristics of the dredged material.

7. The physical, chemical, and biological characteristics of bottom deposits to be dredged are major factors in determining viable treatment alternatives. Also, dredging operations produce large quantities of materials in terms of hydraulic loadings. Discharge rates may range from approximately 2,000 gpm (8-in. pipe) to 38,000 gpm (36-in. pipe) when flowing at 12 fps. These rates compare with those of domestic wastewaters for municipalities up to 250,000 in population size, and are much greater than the relatively small flow rates from various industrial processes. The character of the material being pumped at these rates is highly variable due to the operating procedures practiced during dredging and to the varying nature of the material being dredged. Figures 1 and 2 depict distinctively different materials being pumped from the same discharge pipe within minutes of each other. Figure 3 shows rubble and scrap metals of various types resulting from dredging operation in waters used as a ship repair facility.

Purpose

8. The objective of this study was to determine the amenability of various contaminated dredged materials to treatment by physical, chemical, or biological methods. This study was also designed to provide a more meaningful characterization of dredged material, to ascertain the adequacy of certain parameters used to describe the pollution potential of dredged material, to establish the basic

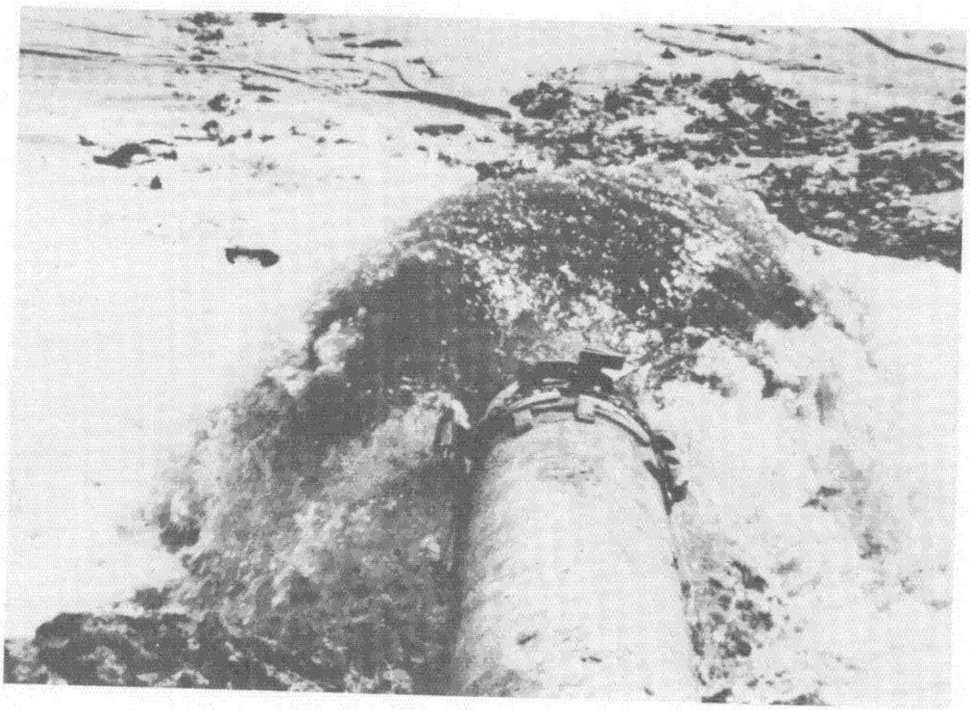

Figure 1. Hydraulic pipeline dredge discharge during line flush-out period (low solids content)

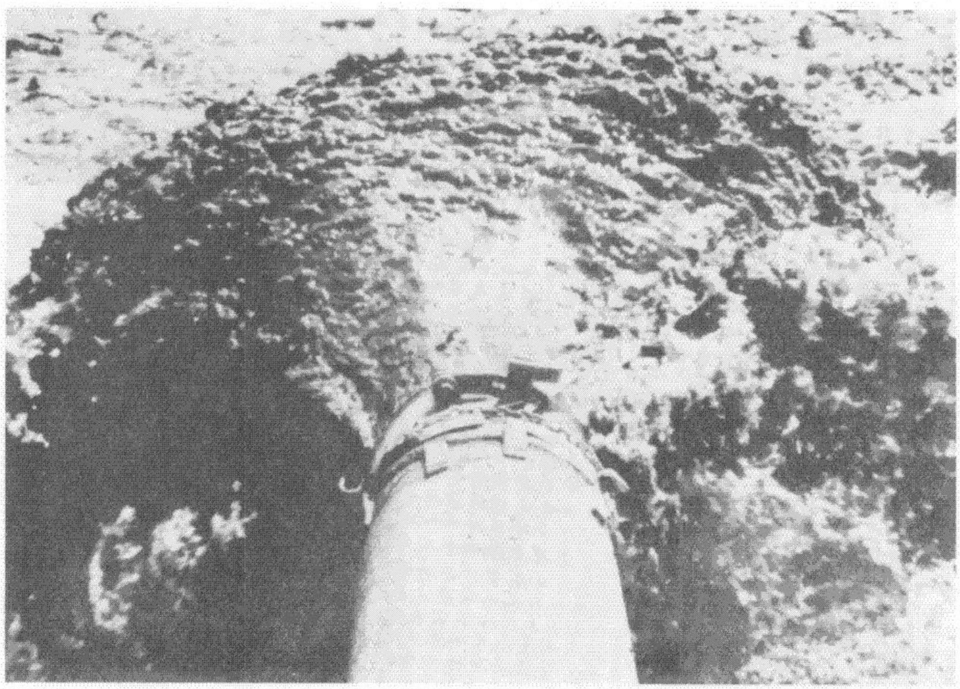

Figure 2. Hydraulic pipeline dredge discharge during cutting period (high solids content)

Figure 3. Material dredged from ship repair facility

effectiveness of various treatment processes considered applicable for treatment of polluted dredged material, and to recommend possible treatment schemes.

Approach

9. The vast majority of maintenance or new project dredging is accomplished by hydraulic pipeline dredges (Figure 4). In the past the material dredged during these operations was deposited at selected disposal sites in close proximity to the dredging operations for the purpose of minimizing disposal costs, but also in locations that would have a minimum direct effect on important activities in the area, such as beaches, water intakes, commercial fishing areas, etc. The three common methods of disposal used are open-water disposal, confined (diked) disposal, and unconfined upland disposal. Open-water disposal accounts for some two-thirds of the material dredged during maintenance operations.* Therefore, the first year's effort was directed primarily toward treatability of dredged material either as it is being disposed of in open water or after it has been deposited in diked areas.

10. Sediment or dredge discharge samples were obtained from selected dredging sites by WES personnel and were transported to the WES. The samples were prepared for testing either in-house or by a commercial laboratory. Standard analytical tests were performed to determine the physical and chemical characteristics of the dredged material. Bench-scale studies were performed to determine the effects of biological treatment, chemical and physical treatment, and aeration

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* According to Reference 3, the total quantity of material dredged annually in maintenance operations by all CE Districts is estimated to be 298.4 million cu yd; the methods of disposal of the dredged material is distributed as follows:

	10^6 cu yd	Percent
Diked disposal area	67.1	22.5
Unconfined upland disposal	4.9	1.7
Open-water disposal	182.1	61.0
Undifferentiated	44.3	14.8

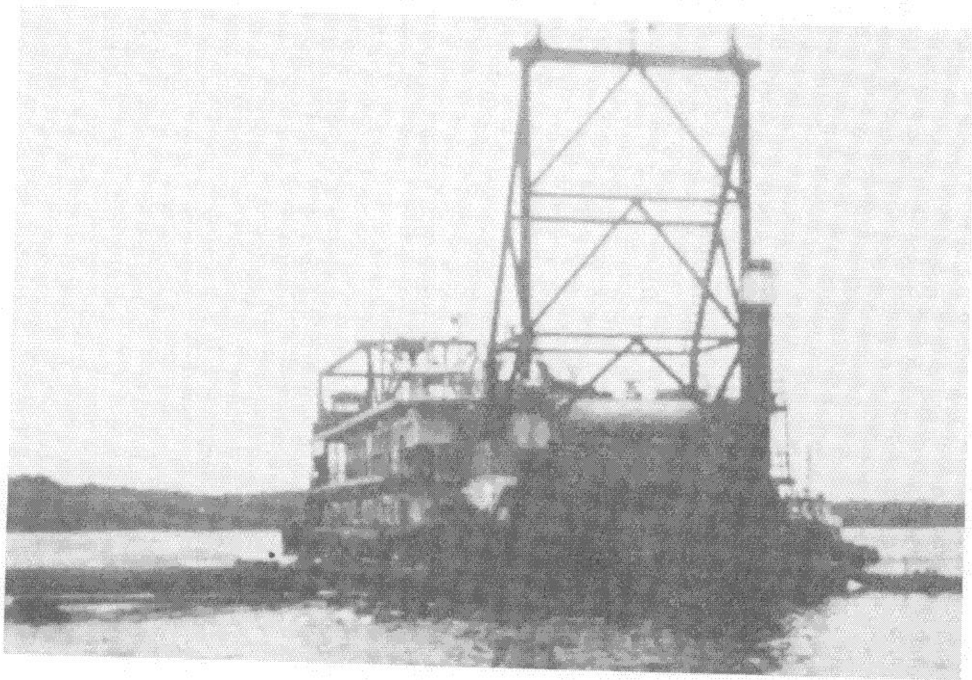


Figure 4. Hydraulic pipeline dredge

and to characterize physical and chemical properties of dredged material. Various alternatives for treatment of dredged material were also developed.

PART II: SAMPLING AND TESTING PROGRAM

Sampling Areas

11. Sediment samples were obtained from three areas: Mobile Bay, Alabama; Maumee Bay at Toledo, Ohio; and Mare Island Strait near Vallejo, California. Site location maps indicating sample points for the areas are shown in Plates 1-3. The study areas and specific sites are described in the following paragraphs.

Mobile Bay

12. Mobile Bay was chosen as a principal study area due to its proximity to WES, availability of baseline data, and the fact that a variety of dredged material or sediment types and contaminants could be found there.

13. Mobile Bay is a large shallow body of water at the mouth of an extensive river system that drains approximately 44,000 square miles. The bay is 27 miles long by 11 miles wide with 248,900 acres of water surface; the average depth is about 9.7 ft. A 400-ft-wide by 40-ft-deep navigation channel traverses the length of the bay. Specific sites for sampling within the bay area are described in the following paragraphs.

14. Fowl River site. The Fowl River discharges into Mobile Bay on the east side approximately 17 miles south of the city of Mobile. Samples were taken from the 10-in.-diameter discharge line of a hydraulic pipeline dredge operating at a point approximately 400 ft upstream from the river mouth. This dredge was assigned to a new work project, an 8-ft-deep by 100-ft-wide navigation channel.

15. Arlington Channel site. Arlington Channel is 27 ft deep by 150 ft wide and joins the main ship channel approximately 3 miles south of the city of Mobile. Sediment samples were obtained from the channel bottom at Beacon Number 5 using a Petersen dredge.

16. Chickasaw Creek site. Chickasaw Creek enters the Mobile River just northeast of the city of Mobile. The navigation channel

authorized for maintenance extends from the Mobile River approximately three miles up Chickasaw Creek. The creek receives a heavy loading of industrial wastes contributed by various commercial enterprises along its banks. Sediment samples were obtained from the channel bottom approximately 200 ft upstream from its point of entry into the Mobile River.

Maumee Bay and Mare Island Strait

17. Two other areas were selected for comparison. One site was located in Maumee Bay at Toledo, Ohio, and was representative of a freshwater environment near a heavily industrialized area. Maumee Bay samples were obtained within an area in which the channel was being dredged with a hopper dredge operating in the channel at approximately the 5.5-mile point northeast of the city of Toledo.

18. The other sampling area was in Mare Island Strait near Vallejo, California. The sediment samples, typical of a saline environment, were taken from the channel bottom at the north end of the strait approximately 175 yards northeast of Pier 23.

Sampling Equipment and Techniques

19. A Petersen dredge was used to obtain sediment samples for the investigation. This sampler was operated from an 18-ft aluminum boat that had been modified by the installation of a boom and an electric wench.

20. There are no published standard methods for obtaining samples of dredged material from dredging vessels and/or their discharge lines. Two sampling methods were given in the report of a study of dredging and water-quality problems in the Great Lakes.[2] The Great Lakes study indicated that the method described for obtaining samples of material from hopper dredges did not produce representative material and that there was no viable method of obtaining samples from the discharge of the hydraulic pipeline dredge due to difficulties of access and to stratification of flow. Due to the variable characteristics of sediments, sediment suspensions, and dredged material,

it is doubtful whether any of the sampling methods used in the Great Lakes study would yield a representative sample.

21. During this study the sediment samples obtained with the Petersen dredge were later mixed in the laboratory with ambient water collected via metal bucket in proportions that simulated a range of operational conditions, i.e. a range of solids-to-liquid ratios or concentrations for a dredged material slurry. The solids content of a typical dredged slurry as defined by practicing dredge operators may vary from 5 to 20 percent by volume, i.e. a mixture of one part in situ sediment and 4 to 20 parts carrier water makes up a slurry. The actual total solids content depends upon both the amount of overlying water pumped with each volume of sediment and on the moisture content of the sediment itself. Water and sediment samples were mixed in the laboratory to approximate these concentrations when actual dredged discharge samples were not used. Where reference is made herein to dredged material with no reference to solids content, a slurry with 20 percent solids by volume was used.

22. Water samples for the bulk of the analyses were collected from the surface of the waterbody and transported to WES in 50-gal Teflon-lined drums. Matching sediment samples were transported in 5-gal Teflon-lined metal buckets. All containers were filled as full as possible and sealed to avoid contamination by air. Portions of the sediment and water samples were collected in half-gallon polyethylene jars and preserved by packing in ice within minutes after collection to minimize biological activity that could significantly alter test results, such as the biochemical oxygen demand (BOD) or total organic carbon (TOC) analysis. The samples that were not used immediately were refrigerated at 4°C at the laboratory. Biological activity during shipment of these samples was not considered to have a significant effect on the results of the analyses for which the samples were used, since transportation time from the Mobile area never exceeded 12 hr.

Laboratory Equipment and Test Procedures

23. Major items of laboratory equipment used in the treatability studies included the following instruments:

- a. An Oceanography International Carbon Analyzer, Hach Turbidimeter, Yellow Springs International Model 57 dissolved oxygen meter, Phipps and Bird stirring apparatus with illuminated base, and a Bechman Zeromatic SS-3 pH meter.
- b. A Princeton Aqua-Science Model EG-300 aerobic treatability unit (Figure 5).
- c. A New Brunswick Scientific Corporation microfilm fermentor (Figure 6).
- d. A total oxygen demand apparatus (Figure 7).
- e. A 6-1/2-ft-high by 5-1/2-in.-diameter settling column equipped with a variable-speed motor and stirring bar (Figure 8).
- f. A dissolved air flotation pressure vessel (Figure 9).

24. The standard laboratory test procedures followed are cited by reference. Variations to standard procedures and nonstandard test procedures are explained in the text.

Dredged material characterization procedures

25. The following tabulation outlines the analyses performed for characterization of the dredged material used in this study and gives the source references for the test procedures.

Analysis	Reference
Analysis Performed at WES	
BOD	4
COD	4
TOC	4
Solids	4
Sulfides	5 (pp 41-44, 551-559)

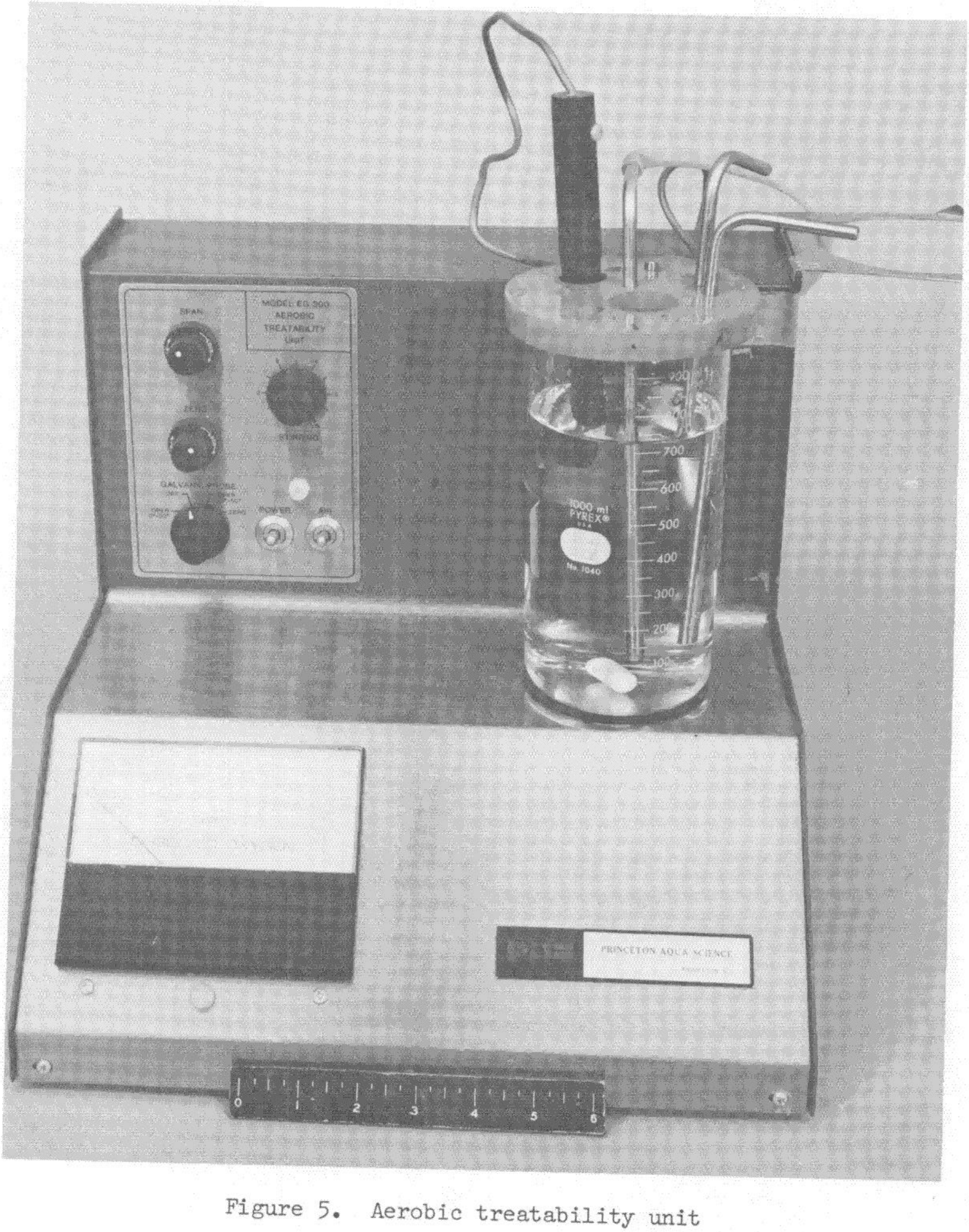


Figure 5. Aerobic treatability unit

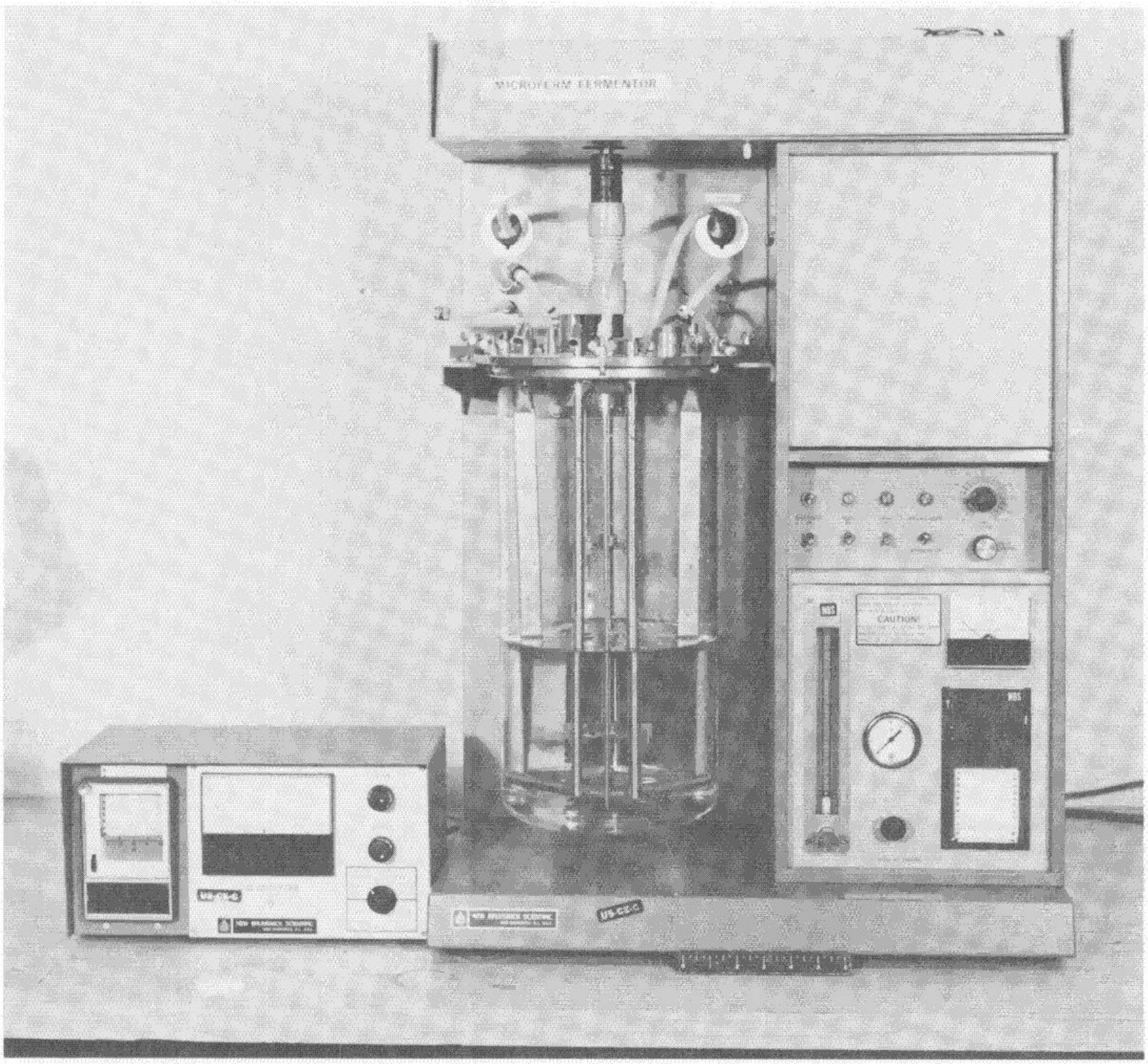


Figure 6. Microfilm fermentor

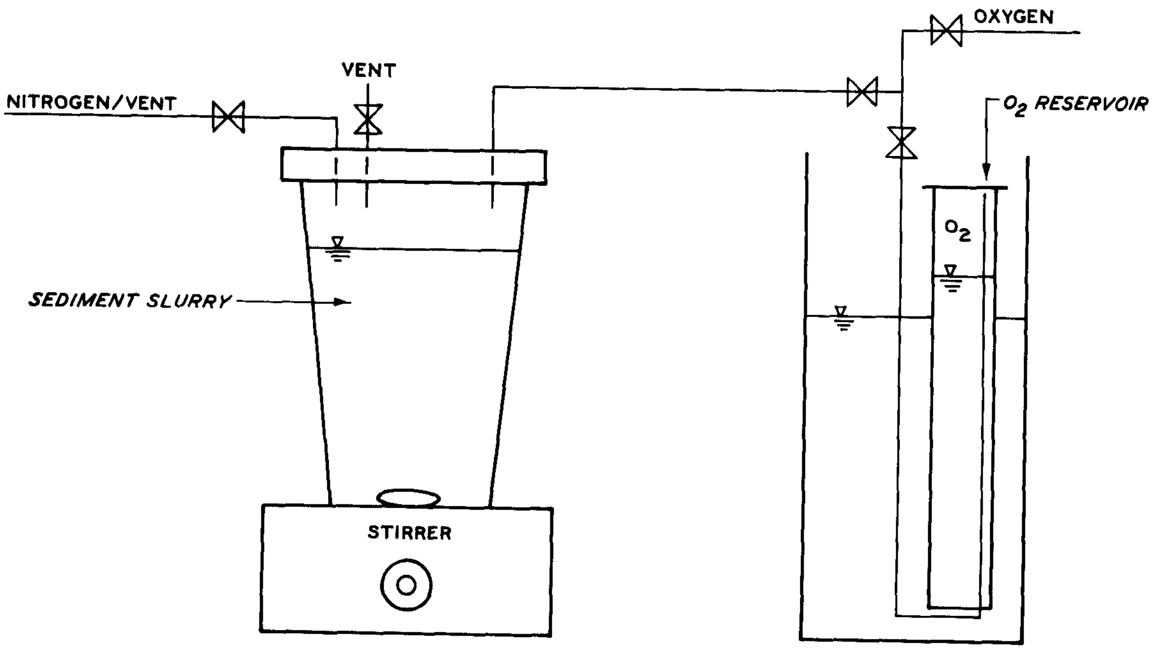


Figure 7. Apparatus for determining total oxygen demand

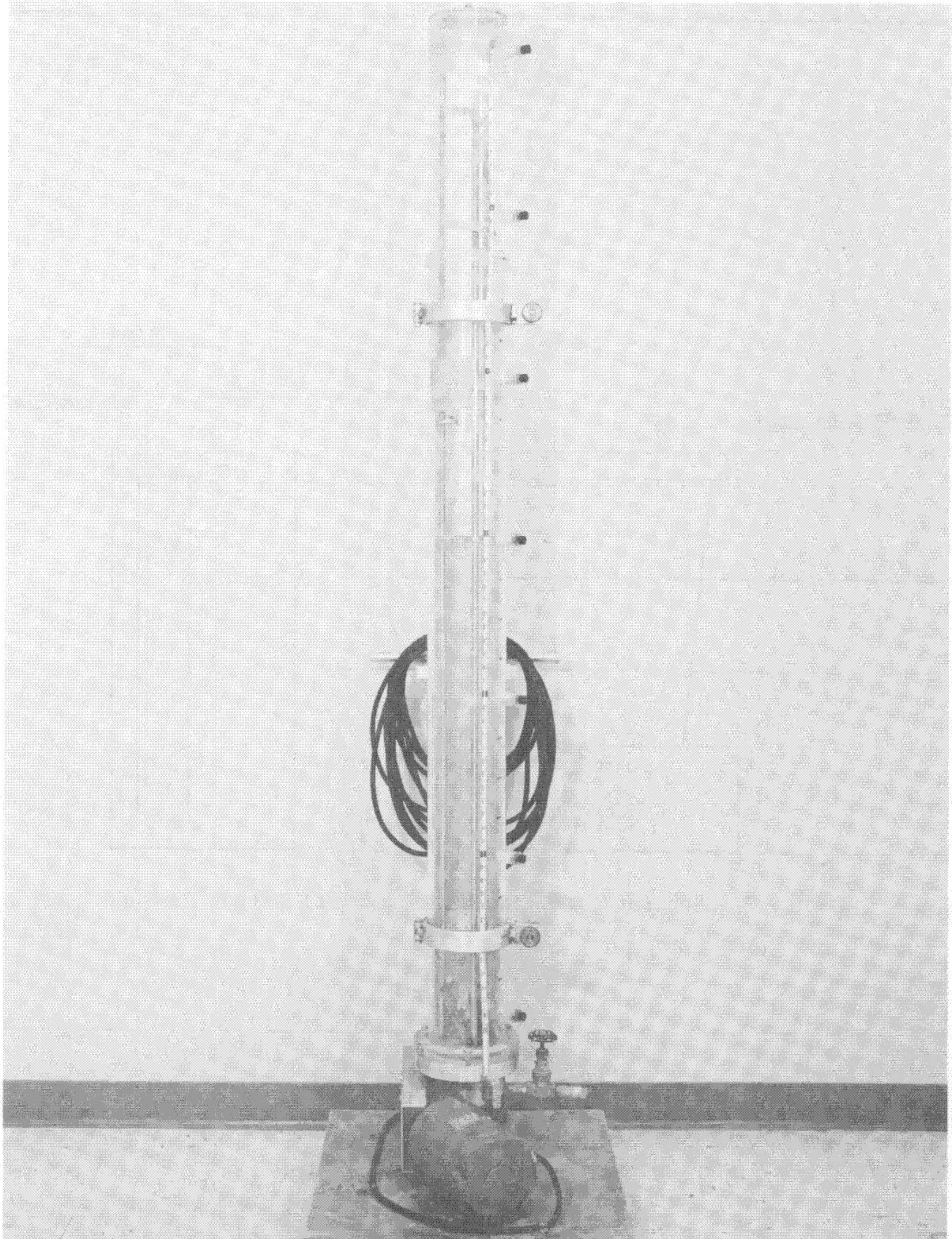


Figure 8. Settling column equipped with variable speed motor

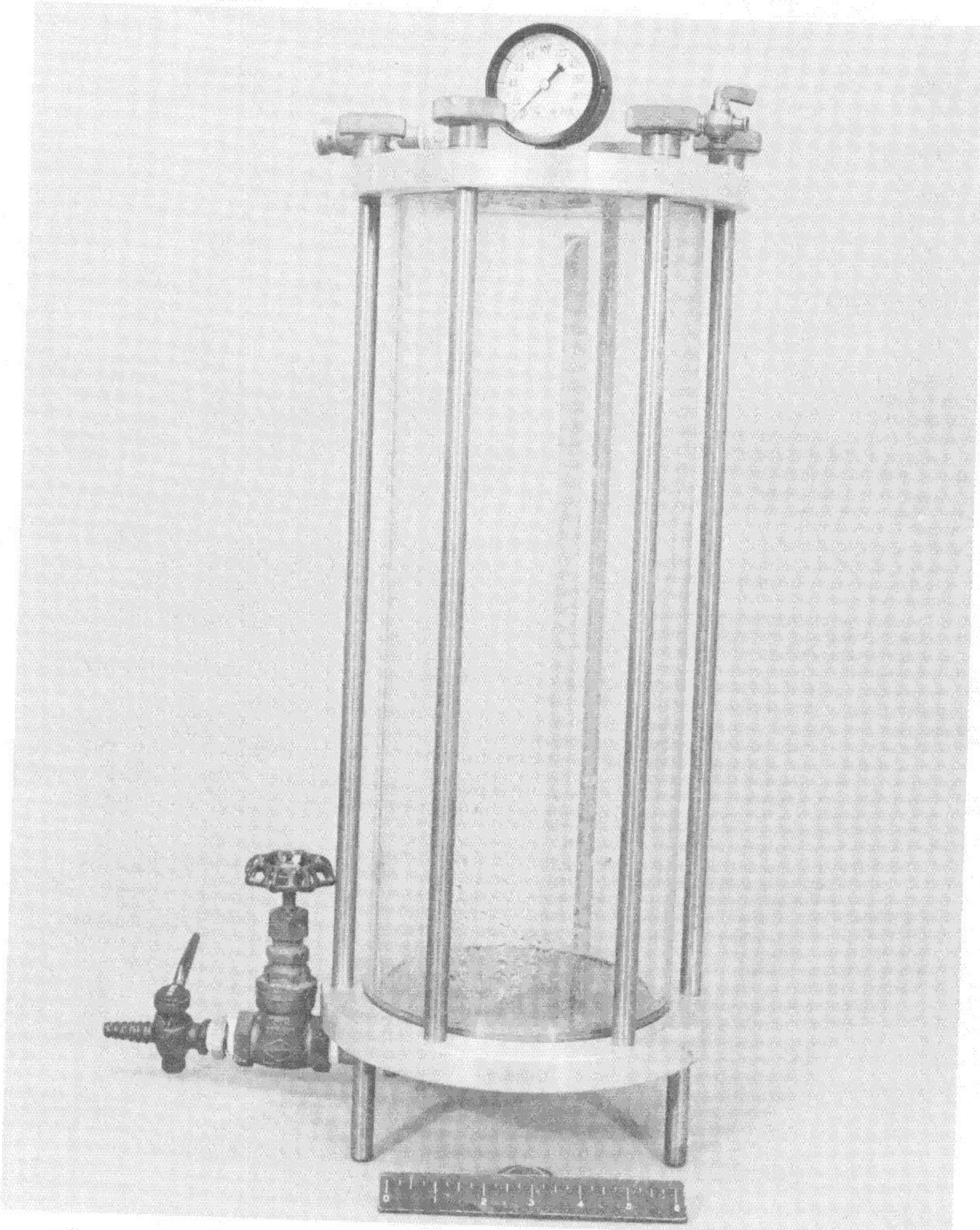


Figure 9. Dissolved air flotation pressure vessel

Analysis	Reference
Analysis Performed by Commercial Laboratory	
TKN	6 (pp 143-147, 81-85) 7 (pp 1149-1177)
NH_4-N	7 (pp 1179-1207)
NO_3-N	6 (pp 71-76) 7 (pp 1179-1207)
P-Total	6 (pp 57-62), 10 (pp 1034-1037)
PO_4-Total	6 (pp 49-55), 10 (pp 1043-1044)
Hg	8
Pb	8
Zn	8
Cd	8
Mn	8
Fe	8
Cation exchange capacity	7 (pp 891-901)
Grain-size distribution by ammonium acetate saturation	7

26. Two types of samples were analyzed: liquid and sediment samples.

a. Liquid samples. Analyses of liquid samples were run on (i) ambient water and (ii) supernatant from a centrifuged slurry consisting of one part sediment and four parts carrier water.

b. Sediment samples. Sediment samples were analyzed by suspending a part of the sediment in a large volume of distilled water and analyzing this in the same manner as a water sample.

Biological treatability procedures

27. The analyses described in the following paragraphs were performed in order to determine whether the dredged material was amenable to biological treatment.

28. Biochemical oxygen demand (BOD). BOD is the quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. BOD, determined by the availability of a material as a biological food and by the amount of oxygen used by microorganisms during

oxidation, is not related to the oxygen requirements in chemical combustion.[9]

29. The standard five-day BOD test described in the thirteenth edition of Standard Methods[5] was used. A Yellow Springs YSI Model 54 dissolved oxygen (DO) meter with a self-stirring BOD bottle probe was used for the DO determination and the azide modification of the Winkler method[5] was used as a control. The seed used in the BOD test was acclimated by aerating a mixture of the dredged material and mixed liquor from a domestic treatment plant aeration chamber for a period of 24 hr.

30. Chemical oxygen demand (COD). COD is the measure of oxygen consuming capacity of inorganic and organic matter present in water or wastewater. COD is expressed as the amount of oxygen consumed from a chemical oxidant in a specific test. Since COD does not differentiate between stable and unstable organic matter, it does not necessarily correlate with BOD.[9]

31. Liquid samples were analyzed for COD according to Reference 5. Sediment samples were dried at room temperature and then ground with a mortar and pestle. The procedure followed was the same as for liquid samples except that results were reported in terms of oxygen equivalent per dry weight of sample.

32. Total organic carbon (TOC). TOC analysis, which is the measurement of the amount of organic material in a sample, was performed using an Oceanography International Corporation system. This system uses a wet oxidation of organic carbon by potassium persulfate. A 5- to 10-ml sample was introduced into a glass ampule containing a measured amount of persulfate. The sample was then acidified to convert inorganic carbon constituents to aqueous CO_2. This was driven off by purging with nitrogen. The ampule was then sealed and autoclaved to oxidize the organic carbon. The CO_2 produced by the oxidation was measured by an infrared analyzer and related to the amount of carbon in the sample by means of a standard curve.

33. Immediate oxygen demand (IOD). IOD is a measurement of the depletion of oxygen that occurs upon the introduction of material into

the water column. The method used for this test was the same as that outlined in Reference 5. IOD analyses were performed on a mixture of four parts ambient water and one part sediment (by volume) or on dredge discharge samples if they were available.

34. The following procedure, a variation of the standard IOD test, was used in the aeration studies. A 25-ml sample of the material being aerated was introduced into 100 ml of tap water under constant agitation at room temperature. An arbitrary time period (2 to 15 min) was selected to observe DO depletion. The purpose of this variation was to provide a relatively quick check of the effect of aeration on the IOD. The time period was based on the rate of DO depletion. A time period of less than 15 min was used if the sample fully depleted the DO or reached a constant value before readings were discontinued.

35. Elucidation of BOD and IOD. The 5-day BOD as prescribed by Reference 5 includes the 15-min IOD of the same material. When analyzing sediments for BOD, the IOD attributed to the partial oxidation of ferrous-iron, manganous-manganese, and sulfides causes an error in the reported BOD unless the BOD is partially corrected by subtracting the IOD. The following analyses were performed using an aerobic treatability unit (Figure 5) in order to establish whether the IOD and/or BOD were predominately chemical or biological in nature.

a. Effects of sediment on ambient water.

(1) Unaltered sediment samples were added to 700 ml of ambient water that had been aerated to saturation. DO content was monitored over a period of 10 min. This procedure was used for total solids (TS) concentrations of 2, 4, and 8 percent by weight.

(2) The analysis was repeated for additional mixtures with TS concentrations of 2 and 4 percent by weight. At the end of each run, the mixture was reaerated to saturation with air at a rate of approximately 10 ℓ/min for 15 min. The air was then shut off and the DO concentrations with time were recorded for 40 min.

(3) Sediment samples were altered by aeration for 30 min with air at a flow rate of 10 ℓ/min. The procedure described in paragraph (1) was then

repeated using the aerated sediment at TS concentrations of 1.05, 2.1, and 4.2 percent by weight. The DO concentration with time was monitored for 15 min.

b. Effect of soluble BOD on mixed liquor suspended solids (MLSS). An 8-liter quantity of MLSS was obtained from the aeration basin of a small domestic sewage packaged treatment plant. The MLSS was aerated for a period of 24 hr. Small amounts of dredged material were added during this period in order to acclimate the MLSS. The MLSS concentration was determined and a 700-ml aliquot was withdrawn to determine the oxygen uptake rate. This was accomplished by observing the DO depletion with time for a period of 20 min. At the end of this period, the MLSS was reaerated to saturation. Aeration was then discontinued and a synthetic feed consisting of a mixture of peptonized mild, bacto-peptone and urea was added to the MLSS such that the resulting BOD concentration in the MLSS was 500 mg/ℓ. DO depletion with time was again recorded for a period of 15 min.

c. Effect of sediment on MLSS. The effect of adding sediment to the MLSS was accomplished by adding 100 ml of sediment mixture to 700 ml of MLSS and recording the DO depletion with time. This test was performed using unaltered and aerated sediments.

Chemical treatability procedures

36. A chemical coagulation analysis was made in order to evaluate the amenability of dredged material to chemical treatment. Chemical coagulation is a method commonly used for flocculation of suspended and colloidal matter from municipal and industrial water supplies. It is also used in wastewater treatment for removal of suspended solids and undesirable pollutants.

37. The procedure followed was as described by Eckenfelder and Ford.[10] The coagulant used was $AL_3(SO_4)_2 \cdot 14H_2O$ (alum). A minimum dose was determined by adding small amounts of coagulant to a 200-ml portion of the sample while stirring at a low rate on a magnetic stirrer. When the first sign of floc or thickening of the slurry was observed, the amount of coagulant added to that point was referred to as the minimum dose. Six 1500-ml beakers were then set up on a multiple stirrer. One liter of sample was placed in each

beaker, and the minimum dose of coagulant was added. The pH was adjusted over a range of 4 to 10. The samples were stirred rapidly for 1 min and slowly at 5 rpm for 20 min. The samples were then allowed to settle for 20 min. Turbidity measurements of the supernatant were made using a Hach Turbidimeter. A curve of pH versus turbidity remaining was plotted to determine the optimum pH. A second series of beakers were arranged, and the pH of each 1-liter sample was adjusted to the predetermined optimum. Coagulant dosages of 50, 75, 100, 150, 175, and 200 percent of the minimum dose were added. The stirring and settling procedures were repeated.

38. To simulate diked area effluent, the Fowl River, Arlington Channel, and Chickasaw Creek sediment suspensions were allowed to settle overnight to obtain enough supernatant to perform the jar test[10] using alum as the flocculant.

Physical treatability procedures

39. The analyses described in the following paragraphs were performed in order to determine the amenability of dredged material to physical treatment.

40. Specific resistance to filtration. The Buchner funnel test[10] was used to determine the specific resistance of the sediments to filtration. Alum, ferric chloride, and lime were used as filtering aids. Initial moisture contents were determined by drying a weighed portion of wet sediment at 103°C to constant weight and recording moisture content as a percent of wet weight. A 25-ml aliquot of sediment was taken and thoroughly mixed with the filtering aids to obtain concentrations of 0.5, 1.0, 2.0, 3.0, 4.0, and 8.0 percent on a weighed 7.0-cm Whatman No. 40 filter in the Buchner funnel. A vacuum of 15 psi was applied and the volume of the filtrate was recorded until the vacuum broke. The solids and the filter were then weighed and dried to a constant weight at 103°C. The moisture content was calculated as a percent of wet weight.

41. In order to approximate materials that would be obtained from a diked disposal area for dewatering, analyses were performed on

sediment taken from a 6-ft settling column in which the sediment was allowed to settle overnight.

42. Sedimentation. The method developed by Talmadge and Fitch[11] was used to examine the settling characteristics of the dredged material. Various concentrations of dredged material were introduced to standard 1-liter graduated cylinders. The mixture was thoroughly agitated and allowed to settle. The interface height was then recorded with time. Similar analyses were performed in a 6-1/2-ft-high settling column (shown in Figure 8) for both quiescent conditions and various rates of agitation.

43. Dissolved air flotation. This process is commonly used for the separation of suspended particles from liquids (for example, separation of greases, oils, fibers, and other low-density solids from wastewater) and for the thickening of activated sludge and flocculated chemical sludges. For this study the dredged material was pressurized with air in the pressure chamber shown in Figure 9 in accordance with the procedure outlined in Reference 10. The procedure was applied directly to dredge discharge samples from Fowl River and Maumee Bay and to 20-percent slurry mixtures for Mare Island Strait, Arlington Channel, and Chickasaw Creek.

Aeration effect studies

44. The two most documented and noticeable effects of dredged material disposal are turbidity and oxygen depletion. The effect of turbidity is being studied under a separate task of the DMRP. The efforts of this study, as a result of early laboratory findings, were therefore concentrated on the oxygen depletion problem.

45. Oxygen depletion caused by open-water discharge of dredged material has also been cited in reports of other investigations relative to dredging and/or water quality.[12-16] A major concern in disposal of dredged material in open water, therefore, is the rapid depletion of DO, which is attributed to an IOD. Aeration studies were performed in order to learn the nature of this oxygen demand, to determine the total amount of oxygen required by the dredged material, and to observe the effect of aeration on dredged material.

46. Characterization of oxygen uptake. The apparatus used was similar in concept to that used in the elucidation of BOD and IOD but was larger in order to allow samples to be withdrawn without significantly altering the volume. A modular microferm bench top fermentor with a 14-liter reaction vessel was used (Figure 6).

47. In order to characterize the oxygen-demanding constituents, a sediment sample was added to deoxygenated ambient water and maintained in suspension by constant stirring. Air was then passed through the suspension at a set flow rate. During the aeration period, percent DO saturation, Eh, pH, and IOD were monitored continuously. At various intervals, 50-ml samples were withdrawn from the sediment suspension for analyses of total sulfides ($S^{=}$), ferrous iron (Fe^{++}), and divalent manganese (Mn^{++}).

48. In preparation for analysis of Fe^{++} and Mn^{++}, samples were added to deoxygenated 1.0 N ammonium acetate in a nitrogen-filled glove bag. They were then shaken for 1 hr, filtered through a 0.45μ filter under nitrogen, and preserved by acidification for the analysis of extractable iron and manganese. Ferric iron and manganic manganese are very poorly soluble whereas the reduced forms are very soluble and mobile; so the predominant forms of iron and manganese extracted will be in the reduced state. A separate aliquot of sediment suspension was withdrawn for the $S^{=}$ analysis.

49. These three elements, Fe^{++}, Mn^{++}, and $S^{=}$, are known to create an oxygen demand because they usually exist in anaerobic sediments in their reduced state in significant quantities as well as being very soluble as compared to the very poorly soluble oxides. They are also chemicals that are oxidized by aqueous DO as shown by the following equations.[17]

Ferrous iron, Fe^{++} $$= 2Fe^{++} + \frac{1}{2}O_2 + 5H_2O \rightleftarrows 2Fe(OH)_3 + 4H^+ \quad (1)$$

Divalent manganese, Mn^{++} $$= Mn(II) + O_2 \rightarrow MnO_2 \quad (2)$$

$$= Mn(II) + MnO_2 \rightarrow Mn(II) \cdot MnO_2 \quad (3)$$

$$= Mn(II) \cdot MnO_2 + O_2 \rightarrow 2MnO_2 \quad (4)$$

Sulfides, $S^=$ $$= S^= + 2e \rightleftarrows S^o \quad (5)$$

50. Determination of net oxygen requirement. In channel sediments there are various reduced substances that will be oxidized by an oxygen source. Among these are ferrous iron (Fe^{++}), sulfides ($S^=$), and divalent manganese (Mn^{++}). Several methods are available for measuring the total oxygen requirement of these substances. The two methods described in the following subparagraphs were used in this study.

a. Oxygen reservoir method. The equipment setup for this method of measurement is shown in Figure 7. A quantity of ambient water was placed in the reaction flask and deoxygenated with nitrogen gas. A quantity of unoxidized sediment was added to this water. The space above the liquid surface was purged with nitrogen gas to ensure that no oxygen that could not be accounted for was transferred to the system. The total volume of the sediment and water (V_R) was then recorded. A volume of oxygen (V_I) was added to the oxygen reservoir. The gas lines and space above the liquid interface were purged of nitrogen with pure oxygen gas. The system was sealed and the oxygen reservoir opened to the reaction flask. Stirring was begun and initial DO concentration (DO_I) in the sediment/water slurry was recorded and monitored until it reached saturation (DO_F). The final volume in the oxygen reservoir (V_F) was recorded. While maintaining agitation, samples were withdrawn for determining the total solids (TS). The following equations were used in calculation of total oxygen consumption.

$$O_T = (V_I - V_F) \times \left(\frac{32{,}000}{22.4}\right) \quad (6)$$

$$O_D = (DO_F - DO_I) \times (V_R) \quad (7)$$

$$O_u = \frac{(O_T - O_D)}{(V_R) \times (TS)} \quad (8)$$

where: TS = total solids, g/ℓ

O_T = oxygen transferred, mg

O_D = oxygen dissolved, mg

O_u = oxygen used, mg/g of total solids

V_I = initial volume of oxygen added to reservoir, ℓ

V_F = final volume of oxygen remaining in reservoir, ℓ

DO_F = final dissolved oxygen, mg/ℓ

DO_I = initial dissolved oxygen, mg/ℓ

V_R = volume of sediment and water, ℓ

b. BOD bottle method. This modification of the BOD test involves use of 300-ml glass-stoppered BOD bottles. A volume of water sufficient to fill all of the bottles was saturated with DO by aeration. The bottles were then filled with the DO-saturated water. The initial weight and dissolved oxygen (DO_I) were measured and recorded. A sample of the unoxidized sediment was obtained for the TS determination. A small quantity of the unoxidized sediment (1 to 2 g) was added to each BOD bottle. The bottles were again weighed to determine the exact weight of sediment (W_s). The bottles were stoppered and agitated either by shaking or stirring for 4 hr, unless the DO depletion had stabilized in a shorter time. The final dissolved oxygen (DO_F) was measured and recorded. Calculation of oxygen used by the sediment was determined as follows:

$$O_u = (DO_I - DO_F) \times \frac{0.3}{W_s} \times \frac{1}{TS} \quad (9)$$

where: TS = Total solids, mg/g sediment, and other units are as listed in subparagraph 50a

A method similar to this, which was derived simultaneously and independently, was suggested by Lee and Plumb.[18]

51. Dissolved oxygen profile. These analyses were run to determine how a volume of suspended sediment passing through a water column affects the DO concentration of that water column. The 6-1/2-ft-high settling column (Figure 8) was filled with tap water to a depth of 5-1/2 ft. Volumes of suspended sediment were then mixed to achieve TS concentrations in the column of 5, 10, 14, and 15 percent by weight (about 3, 6, 8, and 9 percent by volume). The suspensions were then added to the top of the column. DO was monitored at distances of

1, 2, 3, 4, 5, and 6 ft from the water surface using dissolved oxygen meters and probes. Readings were taken at approximately 2-min intervals until the readings stabilized over the 2-min period and then at approximately 10-min intervals for a total time period of approximately 1-1/2 hr. DO contours were plotted to observe the oxygen sag curve through the height of the column with time. Two runs were made with each of the TS concentrations: one using a nonoxygenated sediment suspension and one using a suspension that had been subjected to a pure oxygen environment at 40 psig and constant agitation by hand shaking for a period of 3 min. The vessel used for the pressurization with pure oxygen is shown in Figure 9.

PART III: TEST RESULTS AND DISCUSSION

Dredged Material Characterization

Test results

52. The characterization of dredged material associated with this study was limited to the analyses shown in Table 1. The dredged material varied in physical characteristics with a range of 16 to 42 percent total solids by weight (10 to 35 percent by volume). The volatile fraction of the total solids ranged from 9 to 69 percent. The solids consisted mostly of sand and silt. The concentrations of nitrogen and phosphorus were much higher for the Mobile Bay area samples than in those found in the Mare Island Strait and Maumee Bay areas, while the reverse was true of the metals concentrations.

Discussion

53. A review of the literature by Lee and Plumb[18] on the release of chemical contaminants from dredged material and natural water sediment has shown that bulk chemical composition is not a useful index of potential environmental problems. The review points out the intermittent nature of normal open-water dredged material disposal operations and the high available dilutions and indicates that quality criteria based on chronic continuous exposure of the organism to the contaminant are not applicable. Further, Lee and Plumb recommend that the COD test not be used to develop criteria or characterize pollutional characteristics of sediment. Also, Lee and Plumb stated that total Kjeldahl nitrogen (TKN) should not be used alone as dredged material disposal criteria because it is not the TKN concentration in the sediment that is singularly important, but rather it is the amount of ammonia that may be toxic to the biota and this is not differentiated by the TKN analysis.

Biological Treatability

54. The parameters used to determine the organic nature and

biological treatability of the dredged material were the BOD, COD, TOC, and IOD. The effect of the dredged material on a MLSS concentration was also evaluated. The test results and the evaluation of the parameters are described in the following paragraphs.

Biochemical oxygen demand

55. Results. The results of the BOD analyses were as follows:

Site	Type Sample	BOD mg/ℓ
Fowl River	Dredge discharge supernatant	5
Arlington Channel	Ambient water	4
	4:1 mix supernatant*	5
Chickasaw Creek	Ambient water	10
	4:1 mix supernatant*	62
Mare Island Strait	4:1 mix supernatant*	11

*Four parts ambient water to one part sediment (by volume)

56. Discussion. The BODs for the areas investigated were usually found to be in the range of 4 to 5 mg/ℓ. Samples from all the sampling areas had BODs less than 11 mg/ℓ, with the exception of the Chickasaw Creek area. This trend would be expected since the low BOD areas contained generally 10 percent or less volatile solids, while the Chickasaw Creek area contained 69 percent volatile solids. Chickasaw Creek is a relatively small stream that is subject to several industrial discharges: a power plant, two paper mills, and two chemical plants.

Chemical oxygen demand

57. Results. The results of the COD analyses are as follows:

Site	COD			
	Ambient Water mg/ℓ	Sediment mg/kg	Supernatant of 4:1 Mix mg/ℓ	Supernatant of Dredge Discharge mg/ℓ
Fowl River	116.4	65,728	-	67.9
Mare Island Strait	485	36,844	368	-
Maumee Bay	28.3	30,950	-	63
Arlington Channel	14	41,888	30.8	-
Chickasaw Creek	81	156,383	392	-

58. Discussion. The COD test has been used for many years as a measure of the oxygen equivalent of the organic fraction in a sample that is susceptible to permanganate or dichromate oxidation in an acid solution; therefore, the high values found in the sediments might indicate biodegradable materials. However, correct interpretation of the COD value in complex wastewaters has always been a problem. Interpretation of COD of dredged material is further complicated by the fact that the material may contain a variety of industrial or municipal waste constituents or naturally occurring constituents that may be in a highly reduced state. Furthermore, the material is often dredged from estuarine or saltwater environments that contain high chloride concentrations.

59. In the COD test, chlorides are oxidized by the dichromate to chlorine. Quantitatively, 1 mg of chloride will consume 0.113 ml of 1.25 N dichromate. Theoretical and experimental factors are applied to correct the COD results for the chloride interference; however, for samples with high chloride contents (e.g. oceanic and estuarine samples), the errors in applying a correction factor are particularly pronounced. Erroneous corrections are experienced when high chloride-low COD samples or high chloride-high COD samples are analyzed.

Similarly, other reactions may be taking place when high concentrations of ammonia, organic amine, or other nitrogenous forms are in the presence of chlorides.

60. Dobbs and Williams[19] thought that a series of cyclic changes from chlorine to chloride through the formation of chloramines were responsible for interference. Hence, it was postulated that to overcome the chloride interference, some technique of complexing the chloride was needed to prevent it from reacting with the dichromate. Several attempts made to complex chlorides with mercuric salts resulted in various degrees of success. The most satisfying results were obtained by the addition of mercuric sulfate, Hg_2SO_4. It is questionable, however, whether the results are valid for chloride concentrations greater than 2000 mg/ℓ.

61. Burns and Marshall[20] found that for aliquoted samples containing high chloride concentrations, the COD increased markedly with dilutions, even by as much as a factor of two or more for dilutions of 10 to 1. Consequently, the Burns and Marshall procedure is limited to chloride ranges less than 2000 mg/ℓ, provided the COD is not so high as to require that an aliquot be used.

62. The oxidation of the chlorides, reduced metals, sulfides, and other inorganics contribute significantly to any COD thought to be attributable to organic matter. These factors contribute to the nonspecific nature of the test and are reiterated in a report by Lee and Plumb.[18]

Total organic carbon

63. Results. The results of the TOC analyses are as follows:

Site	Total Organic Carbon			
	Ambient Water mg/ℓ	Sediment mg/kg (dry wt)	Supernatant, mg/ℓ	
			4:1 Mix	Dredge Discharge
Fowl River	14.4	--	--	9.0
Arlington Channel	7.7	20,700	19.8	--
Chickasaw Creek	33.6	90,700	129.7	--
Maumee Bay	81.2	16,500	--	49
Mare Island Strait	4.3	16,000	16.8	--

64. Values for TOC for the liquid fractions were generally below the reported value of 56 mg/ℓ for raw municipal wastewater.[18] Exceptions to this were the Chickasaw Creek supernatant and the Maumee Bay ambient water. TOC values for the sediment samples compare with those found for various industrial wastes, which range from 110 to 58,000 mg/ℓ.[18]

65. Discussion. The interrelationship between the organic parameters of BOD, COD, and TOC have been correlated successfully for domestic wastewaters. In particular, the average COD/TOC ratio for raw municipal wastewater is about 4.16.[10] In the case of industrial wastes, however, there are many factors due to the complexity of the waste that might limit any correlations. The COD/TOC ratio for various industrial wastes ranges from 1.75 to 6.65.[10] Correlation of these parameters for dredged material, just as for industrial wastes, would have to be considered on an individual basis. The COD/TOC ratios for the sediments from the Mare Island Strait, Maumee Bay, Arlington Channel, and Chickasaw Creek were 2.30, 1.87, 2.02, and 1.72, respectively.

Immediate oxygen demand

66. The results of the IOD analysis were as follows:

	IOD	
Site	Sample Type	IOD, mg/ℓ
Fowl River	Dredge discharge	35
Arlington Channel	4:1 mix*	38
Chickasaw Creek	4:1 mix	42
Maumee Bay	Dredge discharge	80
Mare Island Strait	4:1 mix	25

*Four parts ambient water to one part sediment by volume.

The IOD values were obtained from very dilute samples so that there was a measurable DO at the end of the 15-min period. Less dilute samples dilutions depleted the DO prior to the end of the time period.

Elucidation of BOD and IOD

67. Effect of sediment on ambient water. Figure 10 depicts the effect of various concentrations of dredged material upon the DO concentration of the ambient water from the Fowl River site. The DO depletion rate increases rapidly with increasing solids concentrations. Figure 11 indicates that, for the Fowl River site, a substantial portion of the oxygen demand was satisfied during the first 15 min. The oxygen uptake after reaeration was significantly lower, suggesting that the oxygen uptake occurring within the first 15 min was primarily chemical in nature. A further result of the effect of aeration upon the oxygen uptake is shown in Figure 12. Sediment from the Mare Island Straits was used in this case, and it is evident that the oxygen demand was completely satisfied. This indicates that aeration is an effective means of satisfying the IOD.

68. Effect of soluble BOD on MLSS. Figure 13 depicts the results of adding a soluble substrate to a MLSS concentration. The oxygen-uptake rate is increased by approximately 10 times by adjusting the MLSS BOD concentration to 500 mg/ℓ. This indicates that a biological system, like a pure chemical oxidation system, can exhibit a rapid depletion of DO.

69. Effect of dredged material on MLSS. As indicated above when a soluble substrate (see paragraph 35b) is added to a MLSS concentration, the increase in oxygen uptake is immediately apparent. At this point it was not evident whether the rapid uptake by dredged material was chemical or biological. As a further check for biodegradable substrate, a mixture of MLSS concentration and dredged material was aerated for 48 hr in order to acclimate the MLSS to the dredged material environment. A fresh quantity of dredged material was then added to the acclimated mixed liquor and to ambient water. The results, plotted in Figure 14, showed no appreciable distinction between the uptake rates, indicating that the dredged material contained little if any biodegradable substrate.

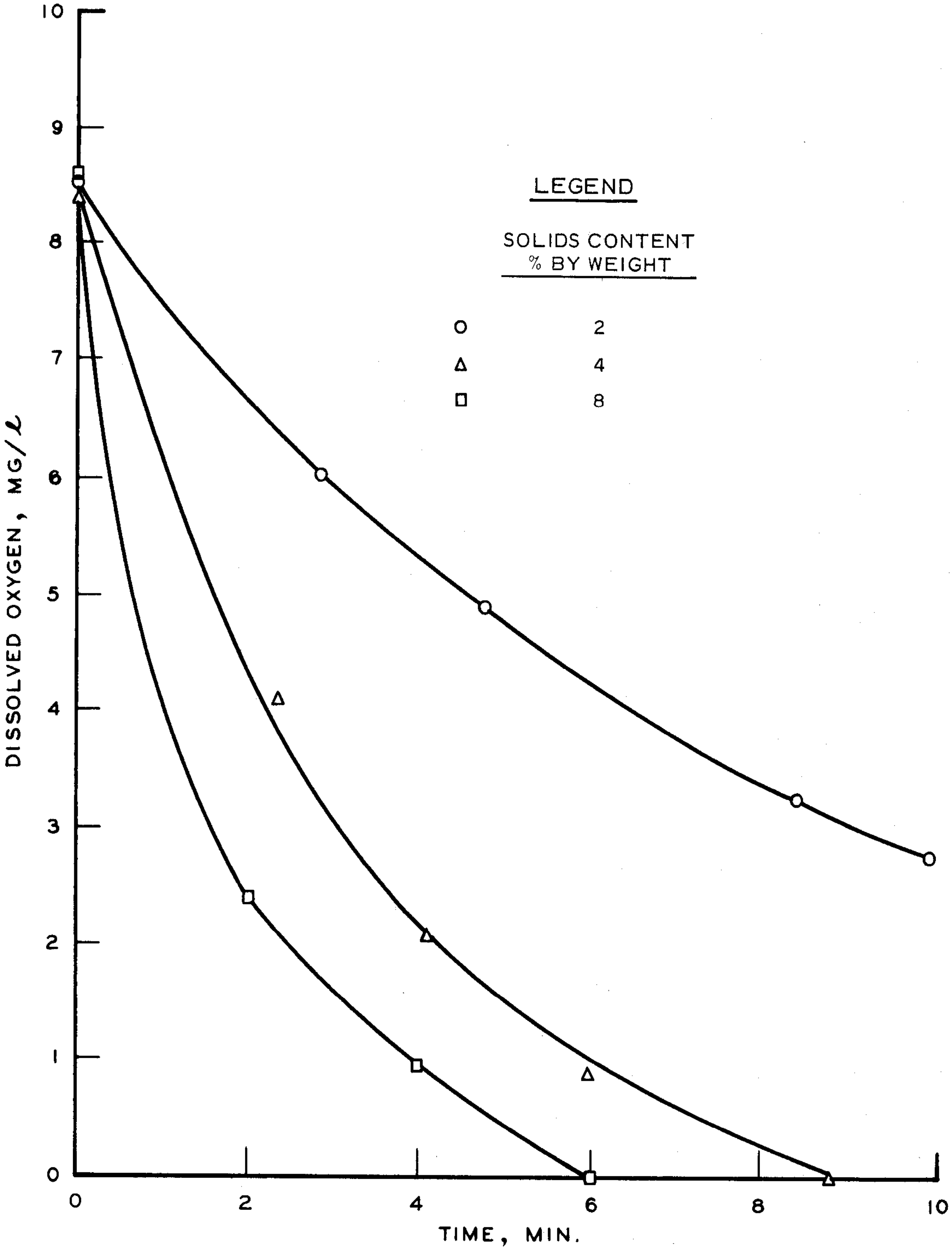


Figure 10. Effect of sediment on DO content of Fowl River ambient water

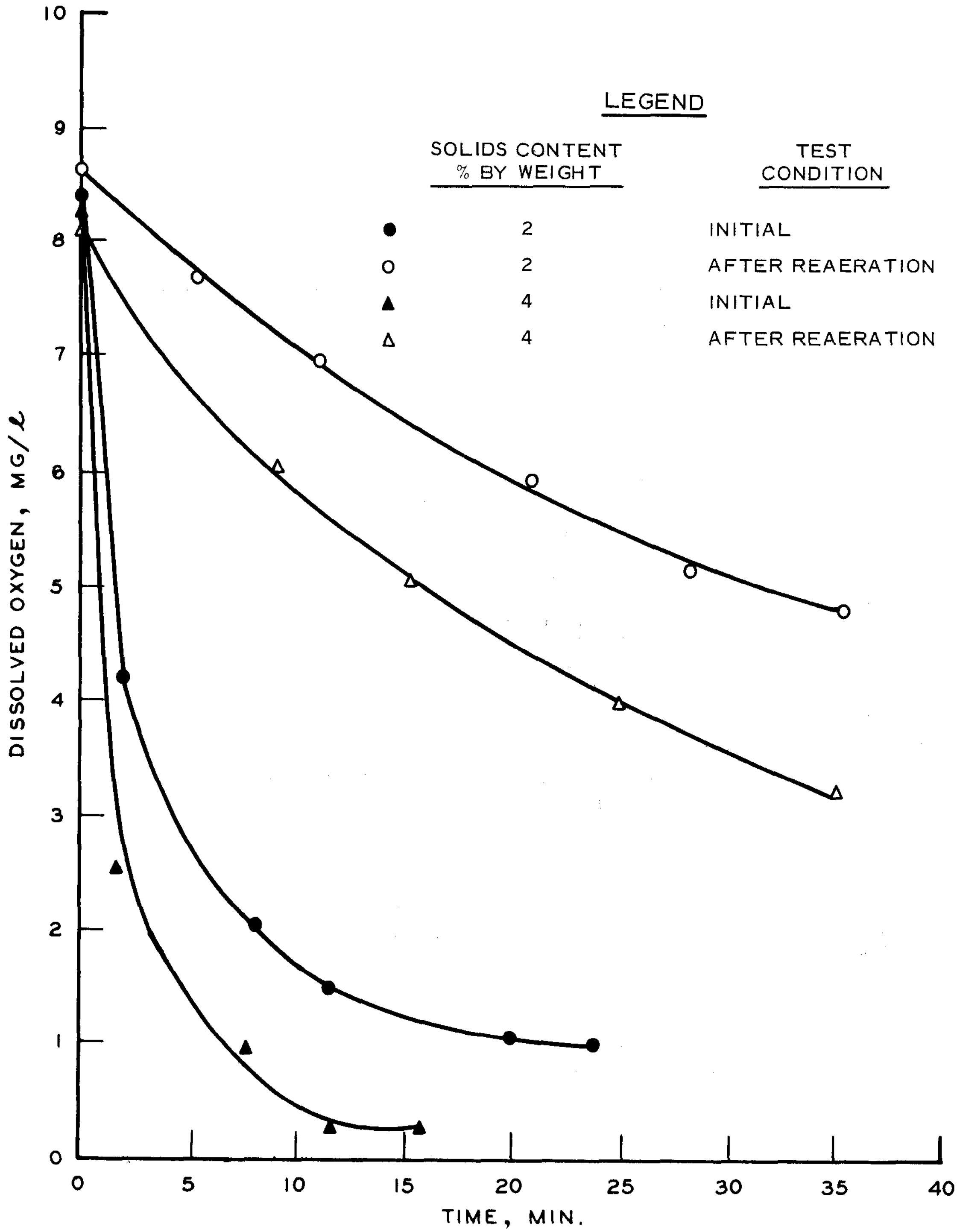


Figure 11. Effect of reaerated sediment on DO content of Fowl River ambient water

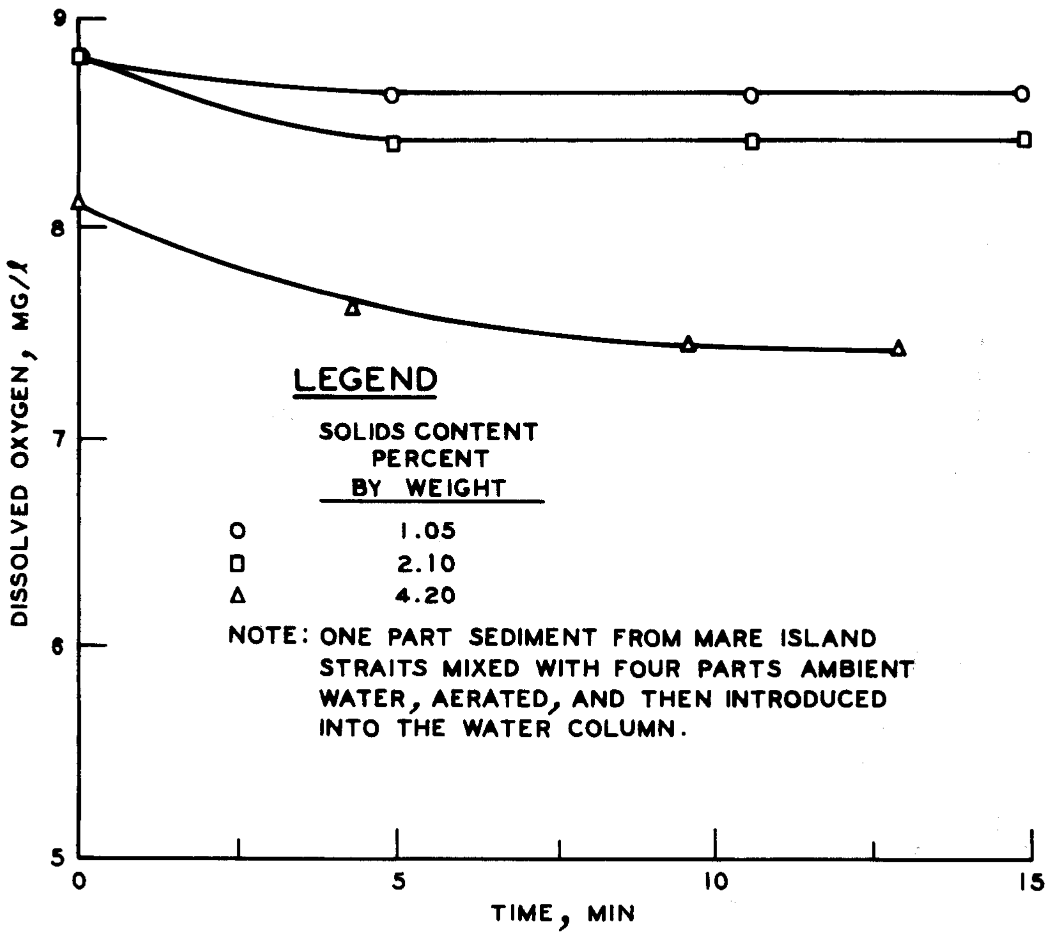


Figure 12. Effect of preaerated sediment on DO content of ambient water from Mare Island Straits site

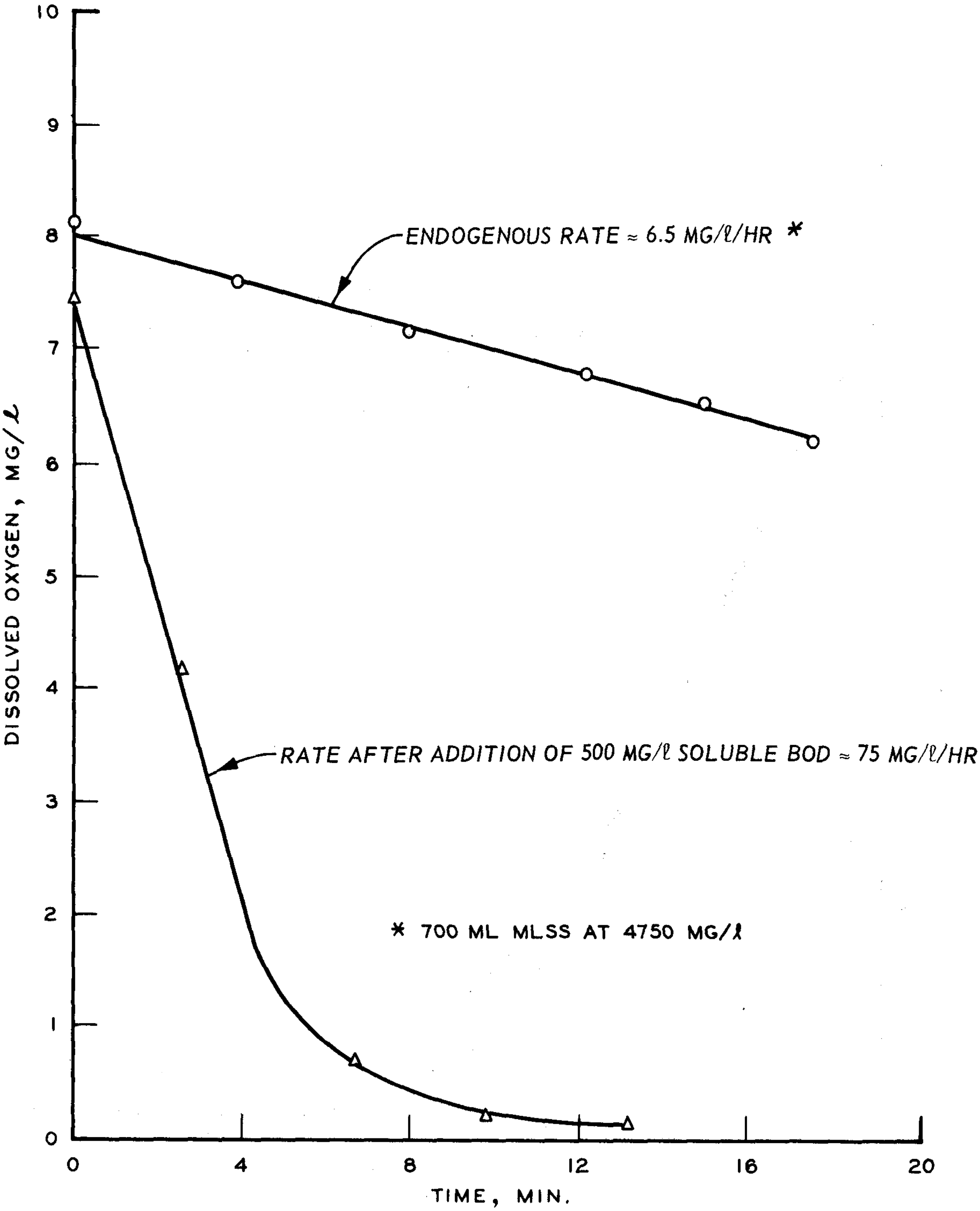


Figure 13. Effect of soluble BOD on DO uptake rate of MLSS

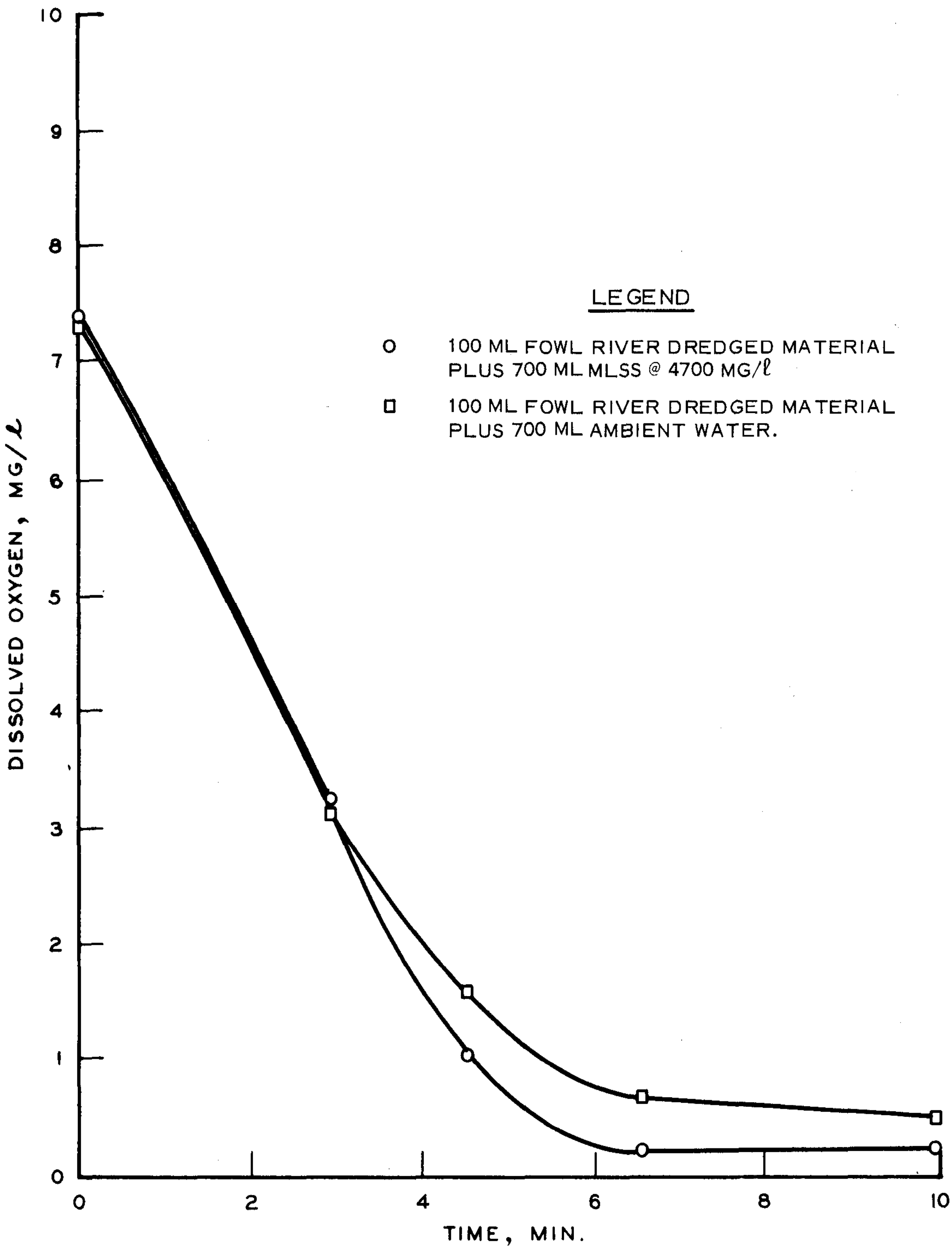


Figure 14. Effect of dredged material on DO uptake rate of MLSS, Fowl River site (2.5% total solids by wt)

70. The MLSS and dredged material mixture was then reaerated three times, as shown in Figure 15. The resulting uptake rate for the first and second reaerations were identical and nearly the same as that of the endogenous rate of the MLSS, indicating that the oxygen demand was satisfied by the aeration. For the third reaeration, soluble substrate was added to the mixture to obtain a concentration of 500 mg/ℓ BOD. The uptake rate increased considerably, further indicating the absence of soluble substrate in the dredged material and confirming that the high initial uptake was primarily chemical in nature.

Evaluation of biological treatment procedures

71. All CE Districts report the presence of organic materials in sediments subject to maintenance dredging; certain areas that are subject to frequent dredging may contain significantly large amounts of degradable organic matter capable of supporting a biological treatment process. In particular, sediments in project areas in the New England Division and the Mobile and Chicago Districts are reported to have significant amounts of organic material. It would appear, therefore, that biological treatment would be a viable method for the treatment of organic dredged material.

72. However, the preceding data indicate that there would be very little if any substrate available for operation of a biological treatment system in the areas evaluated. The organic matter contained in the dredged material tested may have undergone anaerobic degradation in the bottom sediments for long periods before being dredged and as a result is relatively stable, or the organics may be relatively nonbiodegradable substances such as tannins, lignins, etc.

73. Because of these data and the fact that dredging operations generate highly variable volumes of complex materials of fluctuating quantity that would not be compatible with the rather uniform loading and flow rates normally associated with biological processes, further consideration of biological treatment of dredged material does not appear warranted.

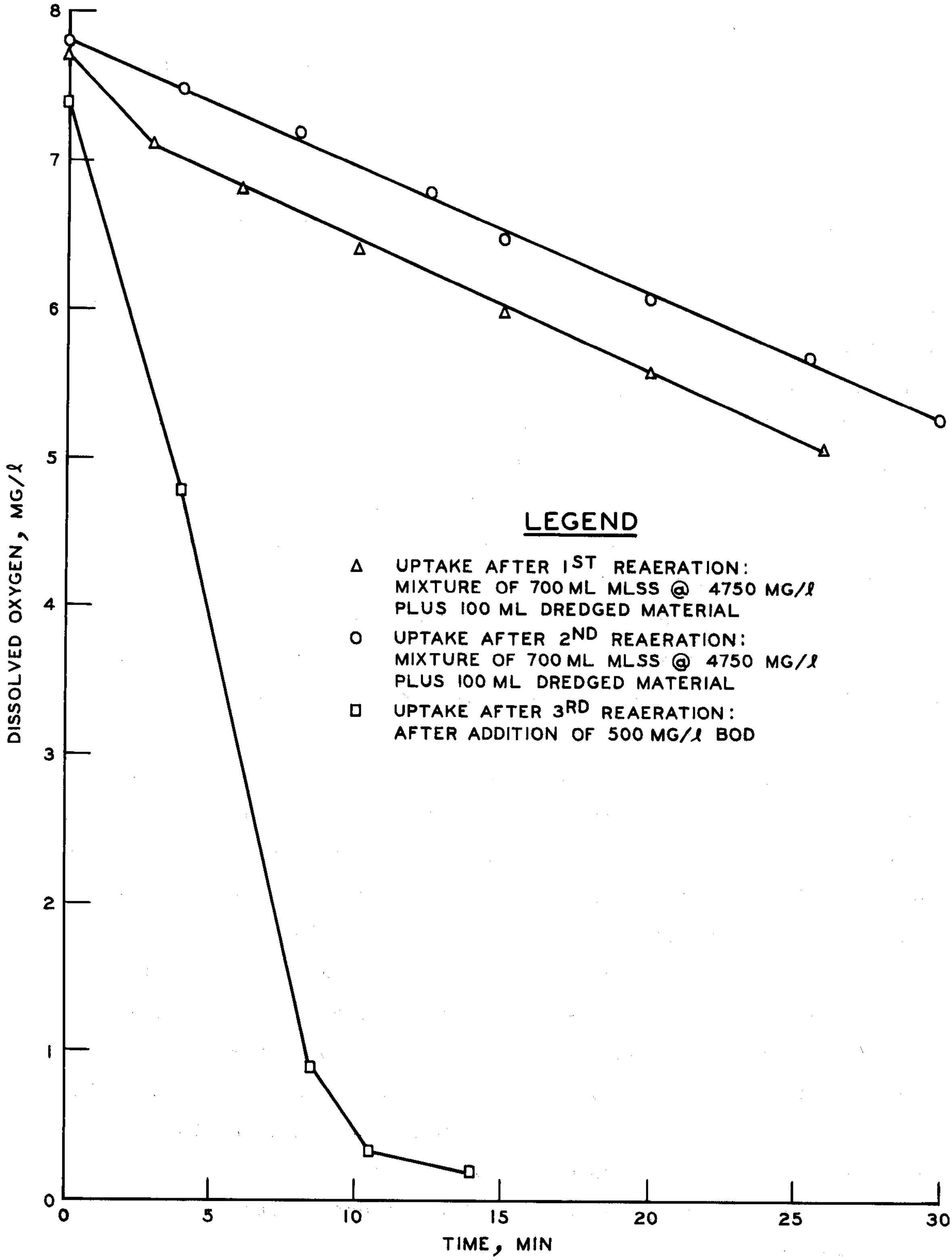


Figure 15. Effect of dredged material on DO uptake of MLSS after reaeration and after addition of BOD

Chemical Treatability

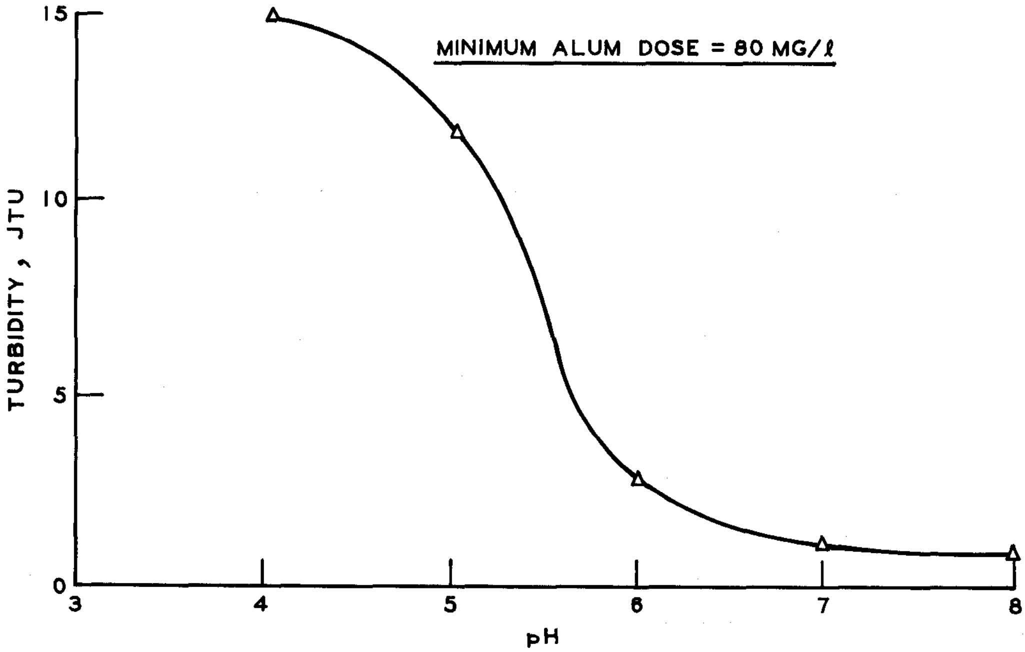
Results

74. The results are shown graphically in Figures 16-18. The initial turbidity of the Fowl River supernatant was 15 JTU (Jackson turbidity units). The coagulation was very effective in removing this turbidity down to less than 1 JTU at a pH of 7.4 and dose of 80 mg/ℓ. The Arlington Channel supernatant turbidity was reduced from 55 to less than 5 JTU at a pH of 6.0 and a dose of 80 mg/ℓ. The Chickasaw Creek supernatant was the most turbid with an initial turbidity of 140 JTU. The turbidity was decreased to 90 JTU at a pH of 9.0 and a dose of 160 mg/ℓ. The alum was not as effective in removing turbidity from the Chickasaw Creek supernatant as it was for the Fowl River and Arlington Channel.

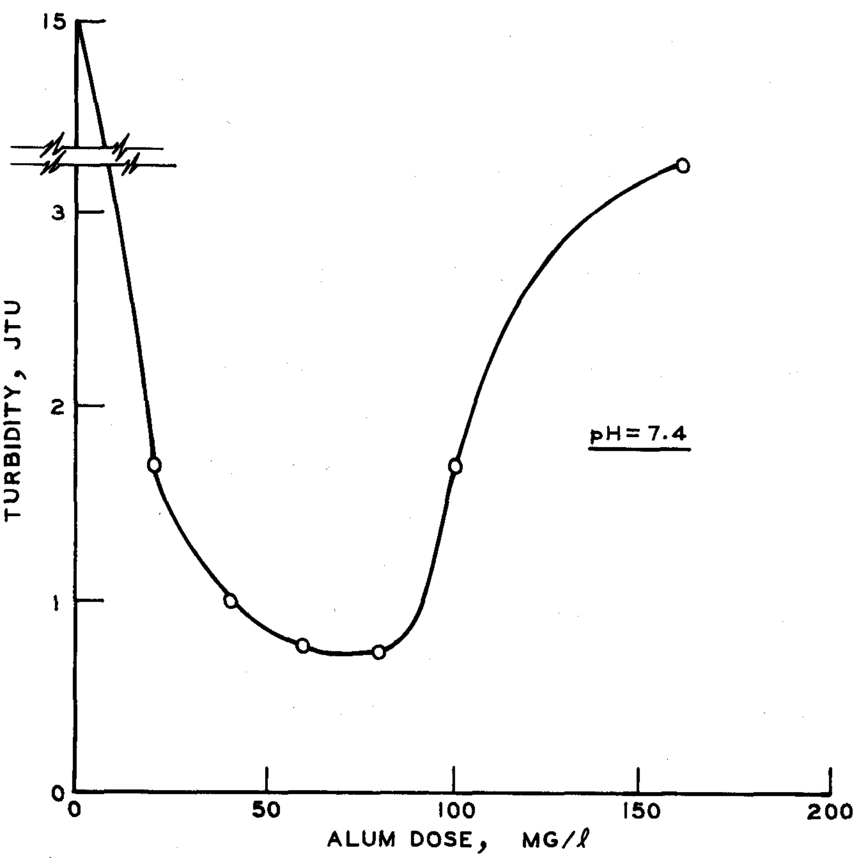
Discussion

75. Other studies have been performed that investigated use of flocculants for treating dredged material. In a study by the Buffalo District,[21] organic polymers were used in several ways in an attempt to reduce the turbidity plume of a hopper dredge. It was concluded that it was not possible to settle out the solids within the hopper bin, but addition of polymers at the overflow significantly reduced the turbidity plume in the bay.

76. The Dow Chemical Company performed another study to evaluate the use of synthetic polymers for the treatment of the effluent from a diked disposal area.[22] Laboratory coagulation tests were performed with return water from two disposal sites: one that contained a high suspended solids concentration and one with a low suspended solids concentration. It was concluded that the best coagulation was accomplished with ferric chloride and a Dow polymer (Purifloc C-31). This combination was then tried in field tests at the disposal site that had the low suspended solids concentration. It was found that 52 percent suspended solids removal and 73 percent turbidity removal were obtained. A reduction in total coliform was also noted, but

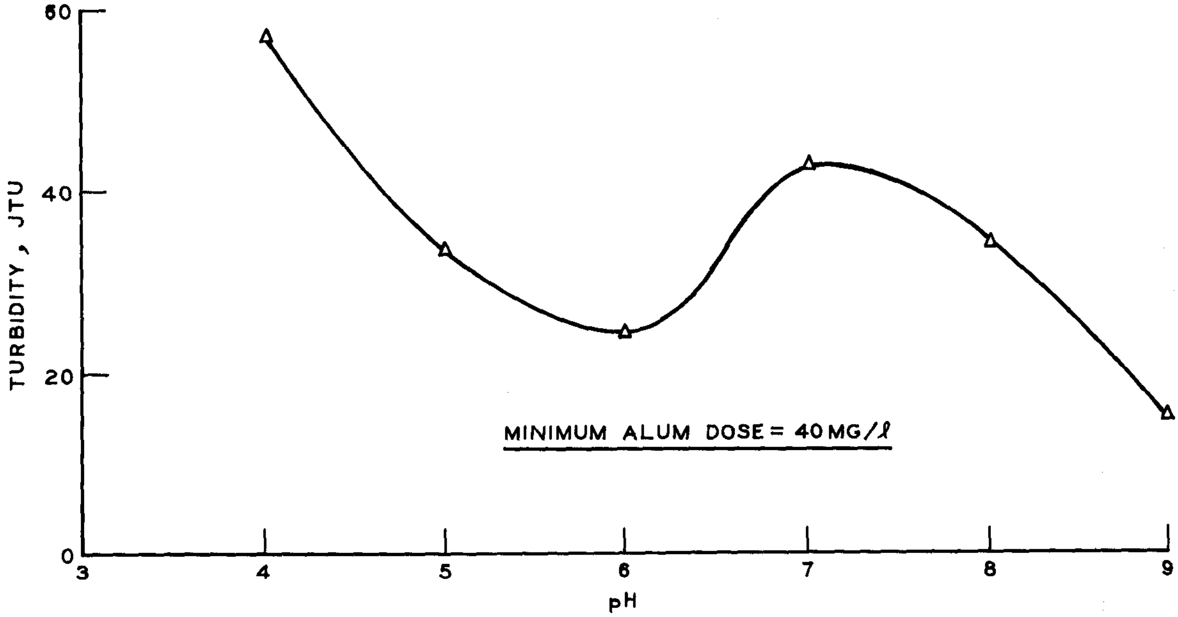


a. OPTIMUM pH DETERMINATION

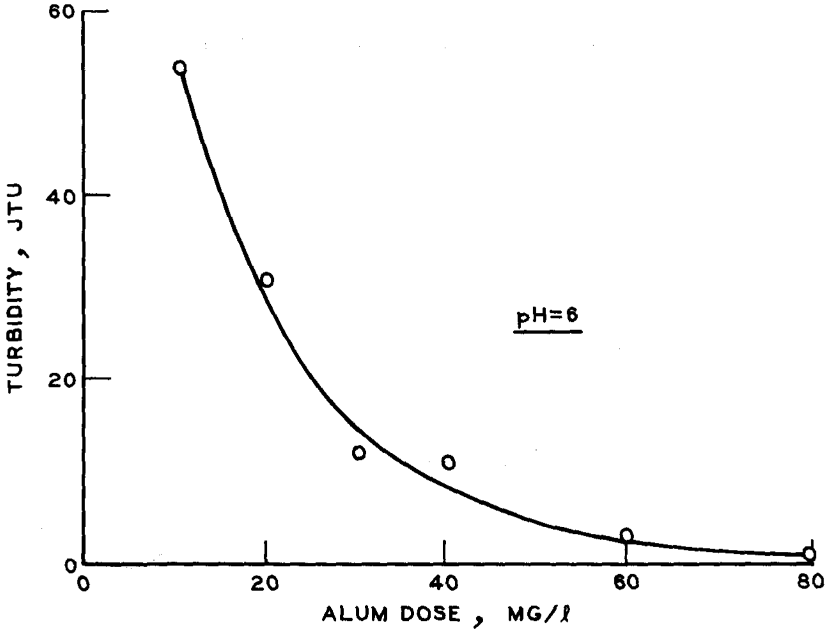


b. OPTIMUM ALUM DOSE DETERMINATION

Figure 16. Chemical treatability of Fowl River supernatant



a. OPTIMUM pH DETERMINATION



b. OPTIMUM ALUM DOSE DETERMINATION

Figure 17. Chemical treatability of Arlington Channel supernatant

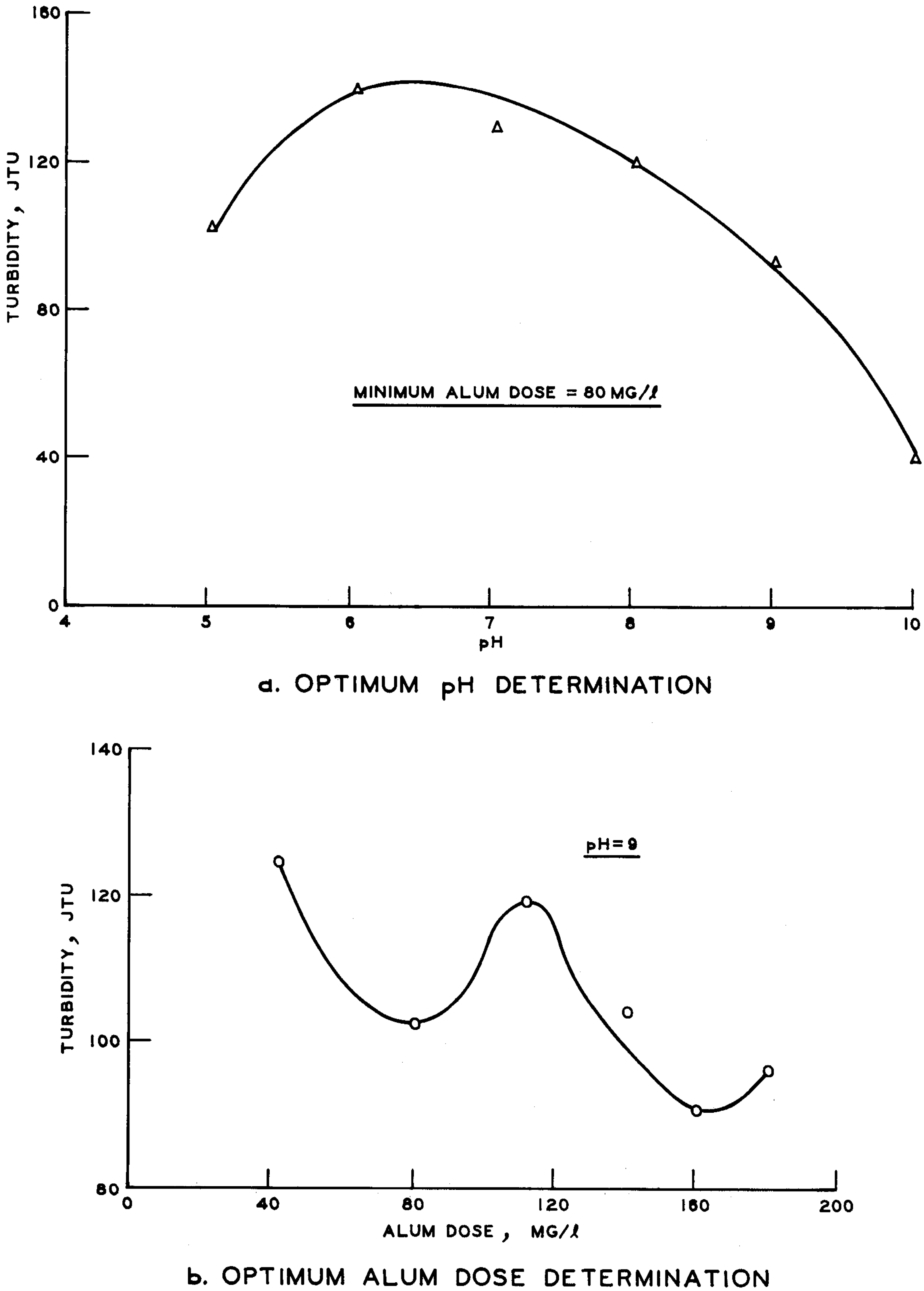


Figure 18. Chemical treatability of Chickasaw Creek supernatant

total phosphorus and COD remained essentially the same, suggesting that these forms were in the dissolved state.

77. The Philadelphia District has reported that a number of laboratory and field tests conducted with chemical precipitants and flocculating agents were unsuccessful because they were not able to increase the density of the dredged material.[23]

Evaluation of the chemical treatment procedure

78. Chemical coagulation may be feasible for treatment of the return flow from diked disposal areas. The dredged materials in these areas are held for long detention times, enhancing solids removal and flow equalization. The diked area return flow might consist of fines, colloidal matter, and dissolved solids.

Physical Treatability

Specific resistance to filtration

79. The Buchner Funnel test for determining the specific resistance was performed on sediment from Arlington Channel and Chickasaw Creek. These two areas represent significantly different sediment properties. When allowed to settle overnight, the sediment concentrated to 25-percent solids for Arlington Channel and 8-percent solids for Chickasaw Creek.

80. Results. Results of the Buchner funnel tests follow:

	Dosage %	Specific Resistance 10^7 sec^2/gm Alum $AL_3(SO_4)_2 \cdot 14H_2O$	Ferric Chloride $FeCl_3$	Lime CaO
Arlington Channel	0	98.7	63.0	120.0
	0.5	92.1	46.5	66.7
	1.0	54.4	28.2	21.1
	2.0	49.8	26.2	111.4
	3.0	37.5	24.3	22.4
	4.0	62.3	33.7	33.1
	8.0	66.7	51.6	32.6

	Dosage %	Specific Resistance 10^7 sec^2/gm Alum $AL_3(SO_4)_2 \cdot 14H_2O$	Ferric Chloride $FeCl_3$	Lime CaO
Chickasaw Creek	0	99.5	148.6	171.0
	0.5	48.7	57.0	54.6
	1.0	47.5	27.5	30.5
	2.0	43.1	51.5	14.2
	3.0	58.6	34.6	12.2
	4.0	69.8	64.9	31.3
	8.0	79.9	49.2	22.4

Note: All values were determined at 15-psig pressure.

81. Discussion. The specific resistance values obtained compare favorably with values reported by Eckenfelder and Ford[10] for domestic sludges and various industrial waste slurries and those reported by JBF Scientific.[24] The values obtained indicate that the sediments are potentially dewaterable by a method such as vacuum filtration. However, there have been no known applications of this process in the dredging industry. Therefore, further laboratory investigations and the development of a pilot system are considered the next logical steps.

82. More specific techniques for dewatering are reported by Hittman Associates, Inc.[25] These deal mainly with the fine-grained fraction of dredged material solids, which are the most difficult to dewater. The techniques include those used or investigated for use on sewage sludges, those used for dewatering unstable soils, and experimental techniques for dewatering of dredged material.

Sedimentation

83. The sediments used for the settling analyses were from the Fowl River and Arlington Channel, which represent fairly clean sediments with low organic content, and from the Chickasaw Creek, which had a high organic content.

84. Results. Figures 19-21 depict the settling curves obtained in standard 1-liter cylinders. The Fowl River concentration of 1-

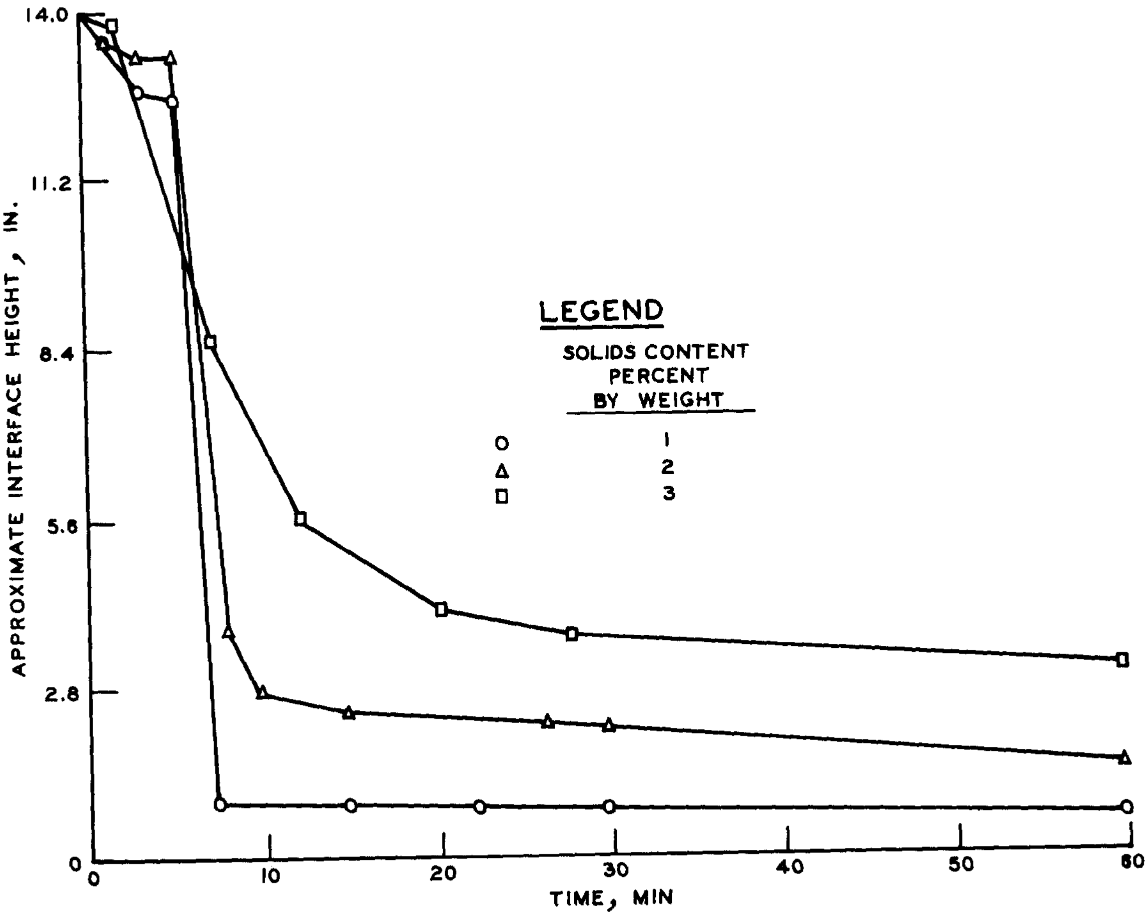


Figure 19. Settling characteristics of sediment from Fowl River site

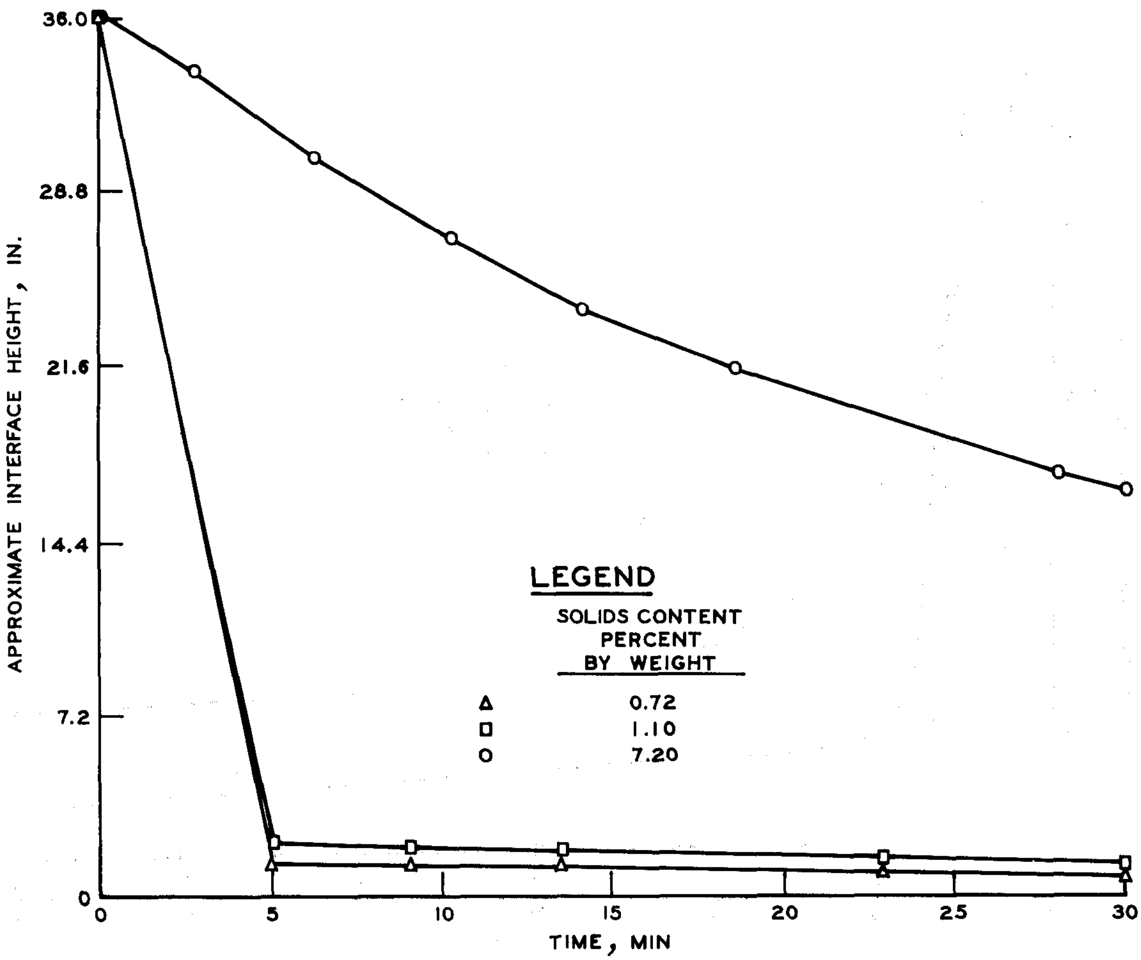


Figure 20. Settling characteristics of sediment from Arlington Channel site

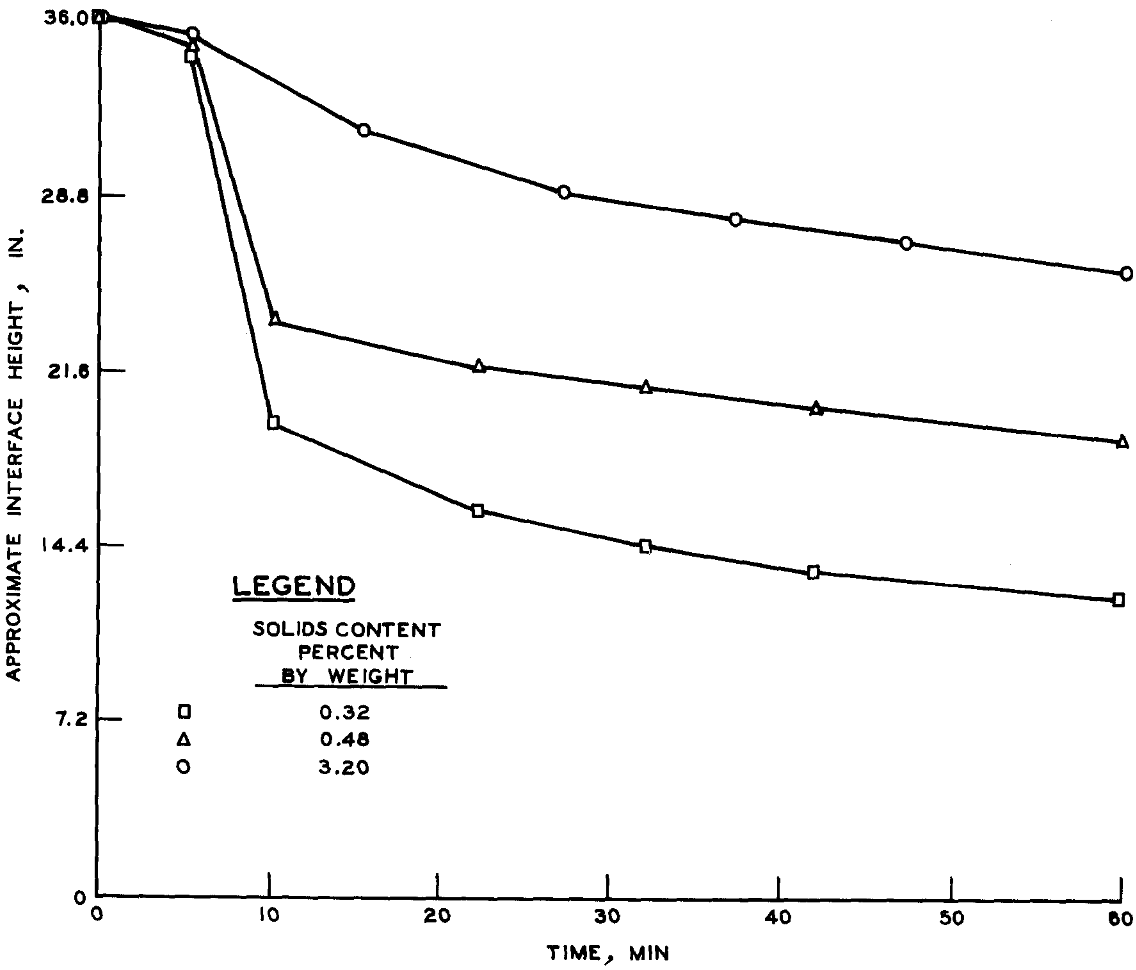


Figure 21. Settling characteristics of sediment from Chickasaw Creek site

and 2-percent solids and the Arlington Channel concentration of 0.72- and 1.1-percent solids exhibited discrete settling characteristics. The coarser materials settled unhindered by neighboring particles and were removed from the suspension quite rapidly. As the concentrations increase to 3 percent for the Fowl River and 7.2 percent for Arlington Channel, the curves become characteristic of zone settling in which the interparticle forces hinder the settling of neighboring particles. All three concentrations (0.32, 0.48, and 3.2 percent by weight) of the Chickasaw Creek sediment exhibited zone settling characteristics.

85. Discussion. The above analyses were made under quiescent conditions. It was hypothesized that under actual field conditions, moderate turbulence could possibly enhance the settling properties of the materials. Figures 22-24 depict the effect of gentle to moderate stirring of the sediment suspensions in the 6-1/2-ft-high settling column. The stirring was not beneficial to the settling properties in any case.

Dissolved air flotation

86. This procedure was performed on all of the sediment samples; no visible interface between the air bubbles and the suspended material was formed in any test. It was not effective in separating any low-density fractions of the dredged material solids. This method is not normally used on materials that contain large percentages of high density solids. The gravity forces on the larger more dense particles and conglomerates are greater than the buoyant forces offered by the dissolved air bubbles that may interface with these particles.

Aeration Effects

Characterization of oxygen uptake

87. Results. The sampling schedule and data are presented in Table 2, and the results are shown graphically in Figures 25-28. Oxygen was added to the system, resulting in an increase in DO concentration, pH, and Eh with time and a decrease in Fe^{++}, Mn^{++}, and $S^{=}$ concentrations. The pH of the suspensions increased slightly with

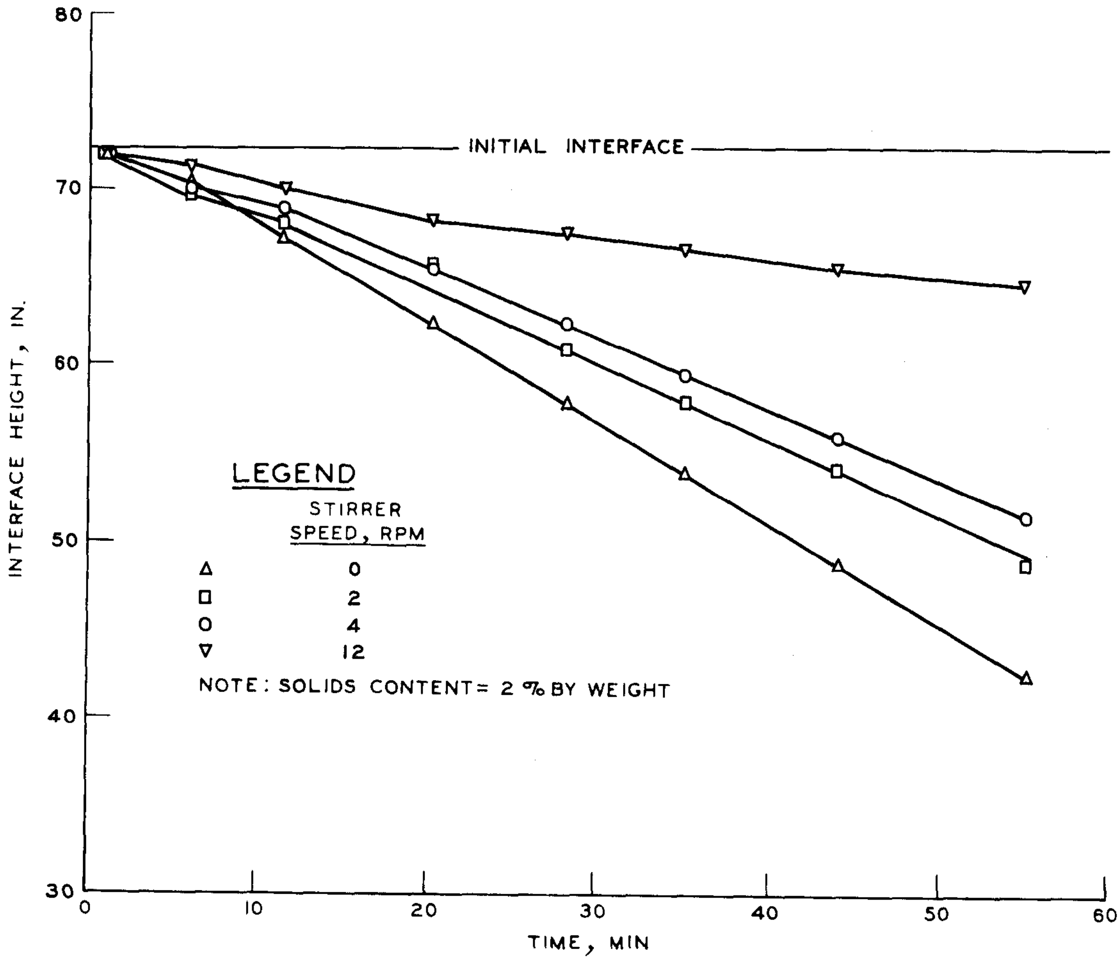


Figure 22. Effect of turbulence on settleability - Fowl River

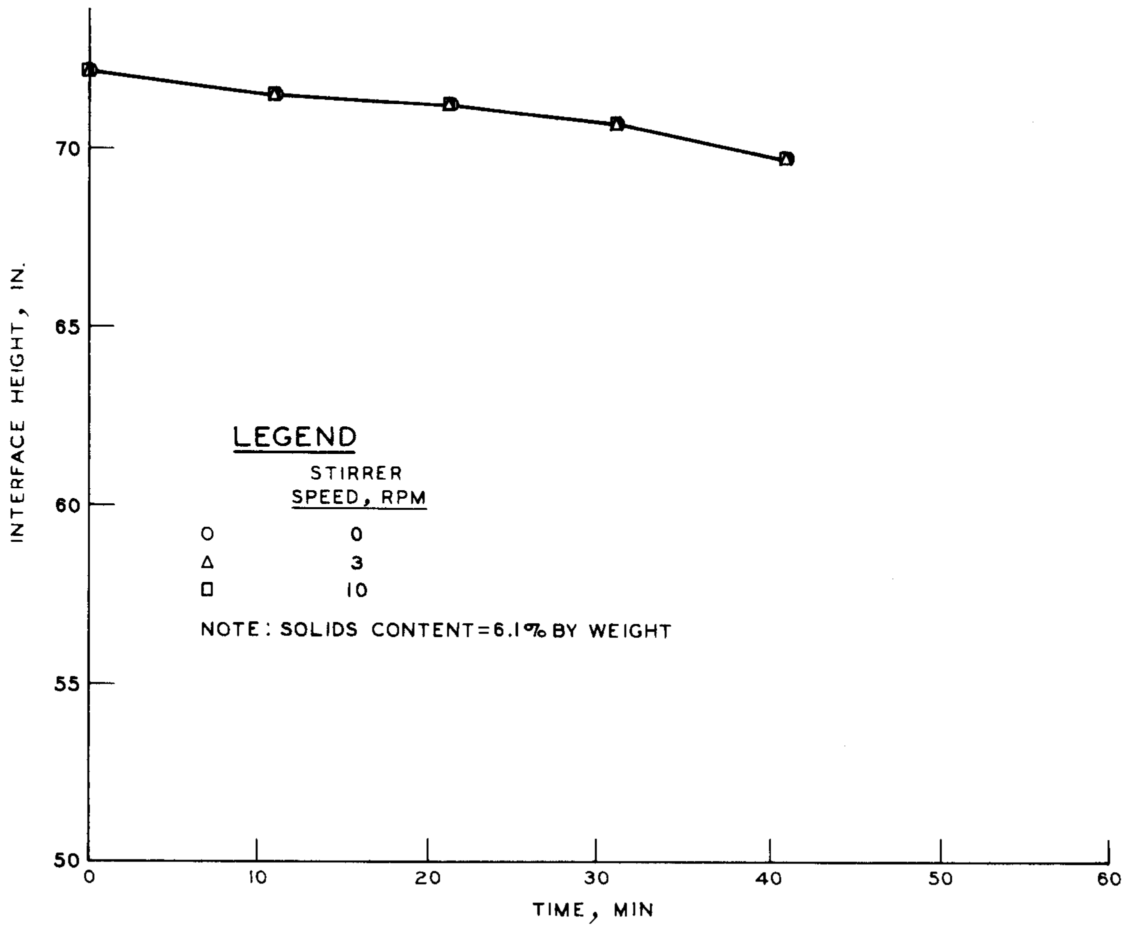


Figure 23. Effect of turbulence on settleability - Arlington Channel

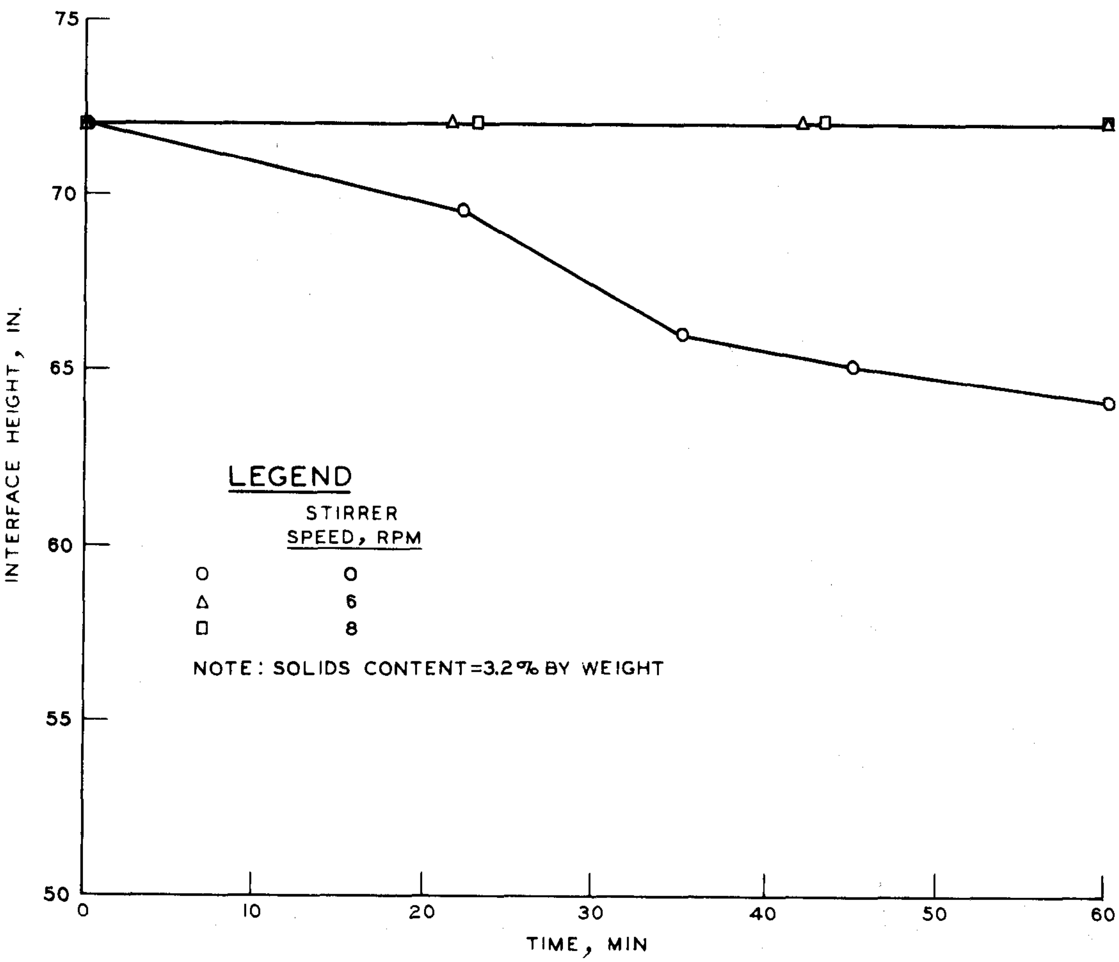


Figure 24. Effect of turbulence on settleability - Chickasaw Creek

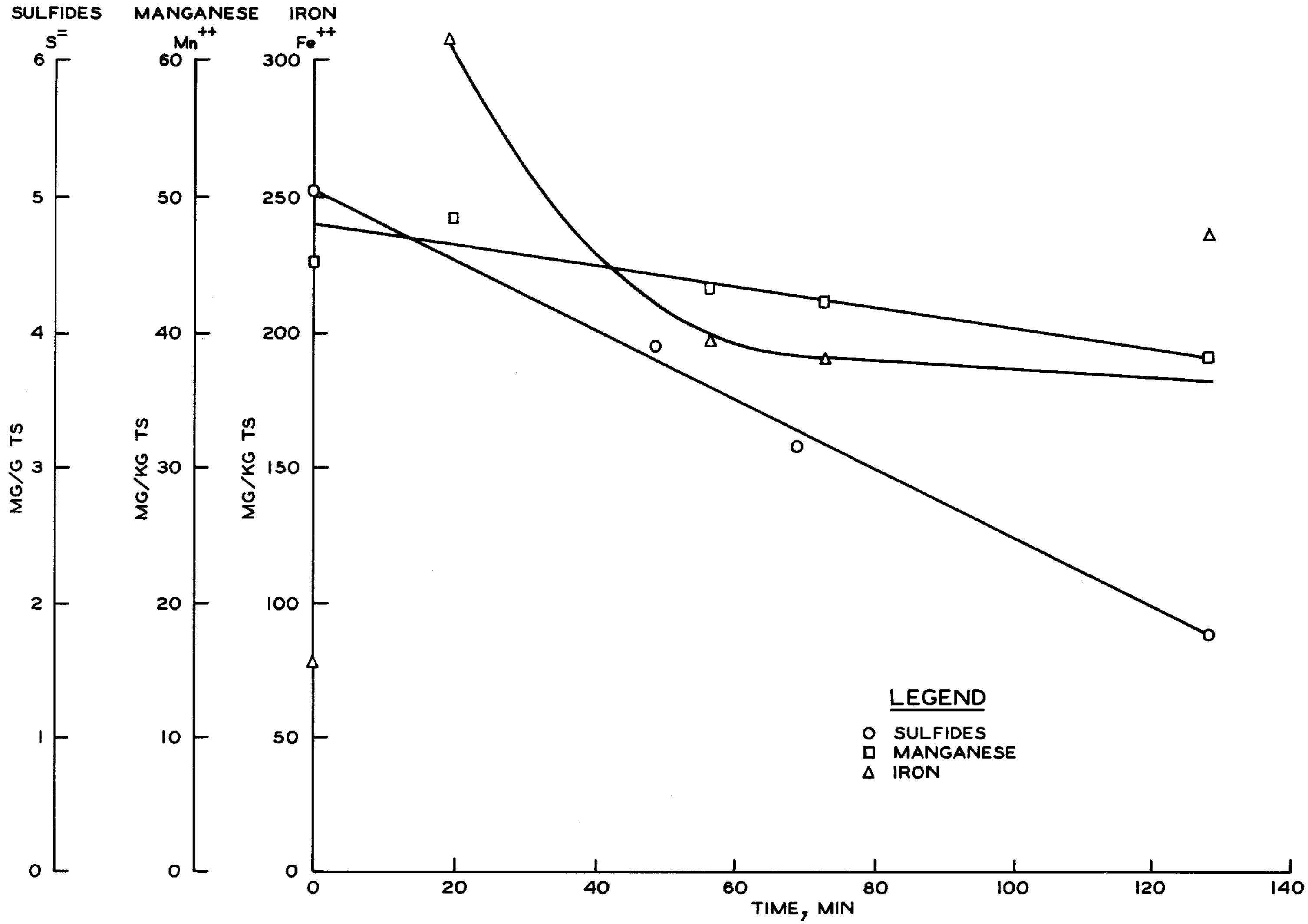


Figure 25. Time-related changes in sulfides, manganese, and iron concentrations - Chickasaw Creek sediment plus ambient water

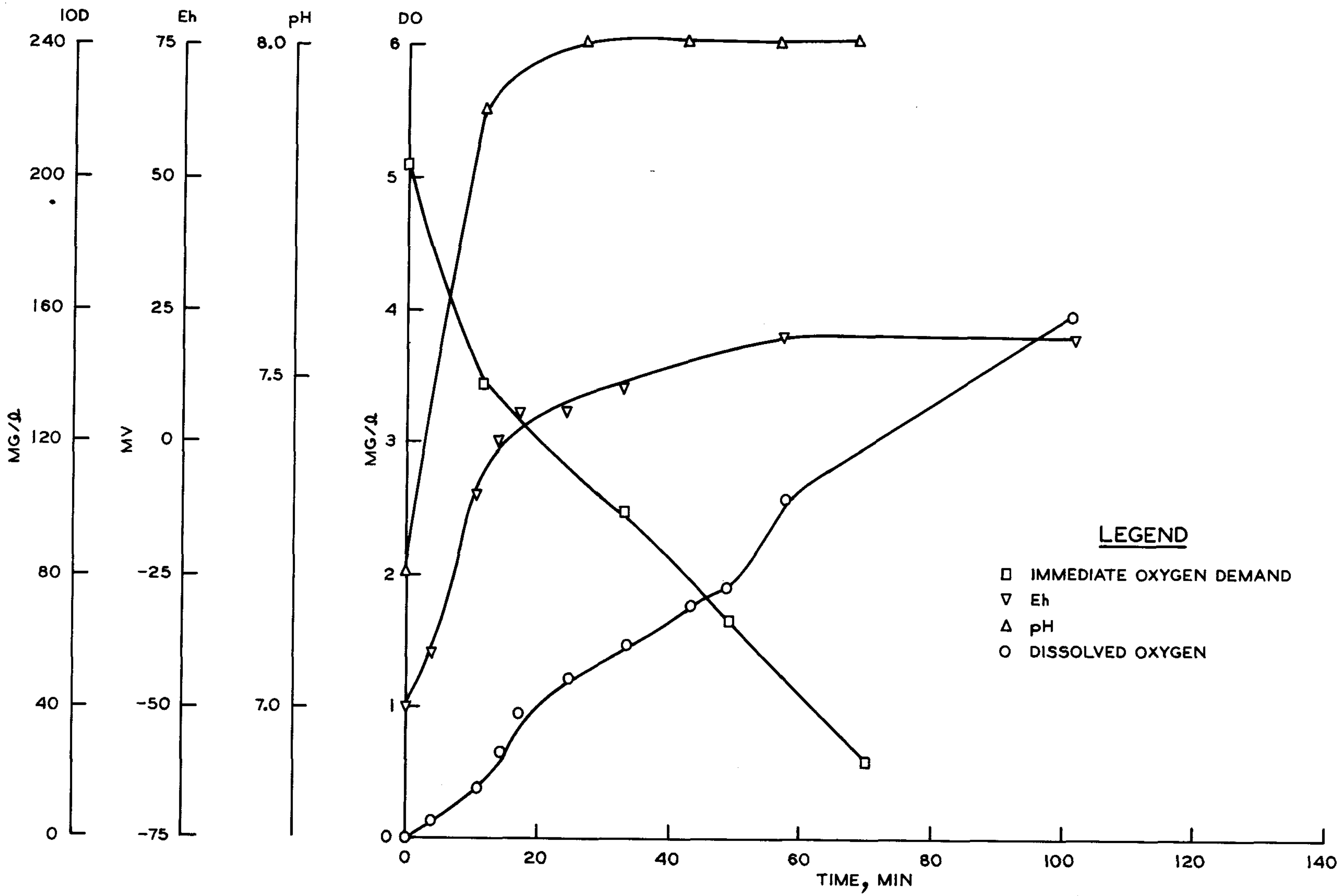


Figure 26. Time-related changes in immediate oxygen demand, dissolved oxygen concentration, pH, and Eh - Chickasaw Creek sediment plus ambient water

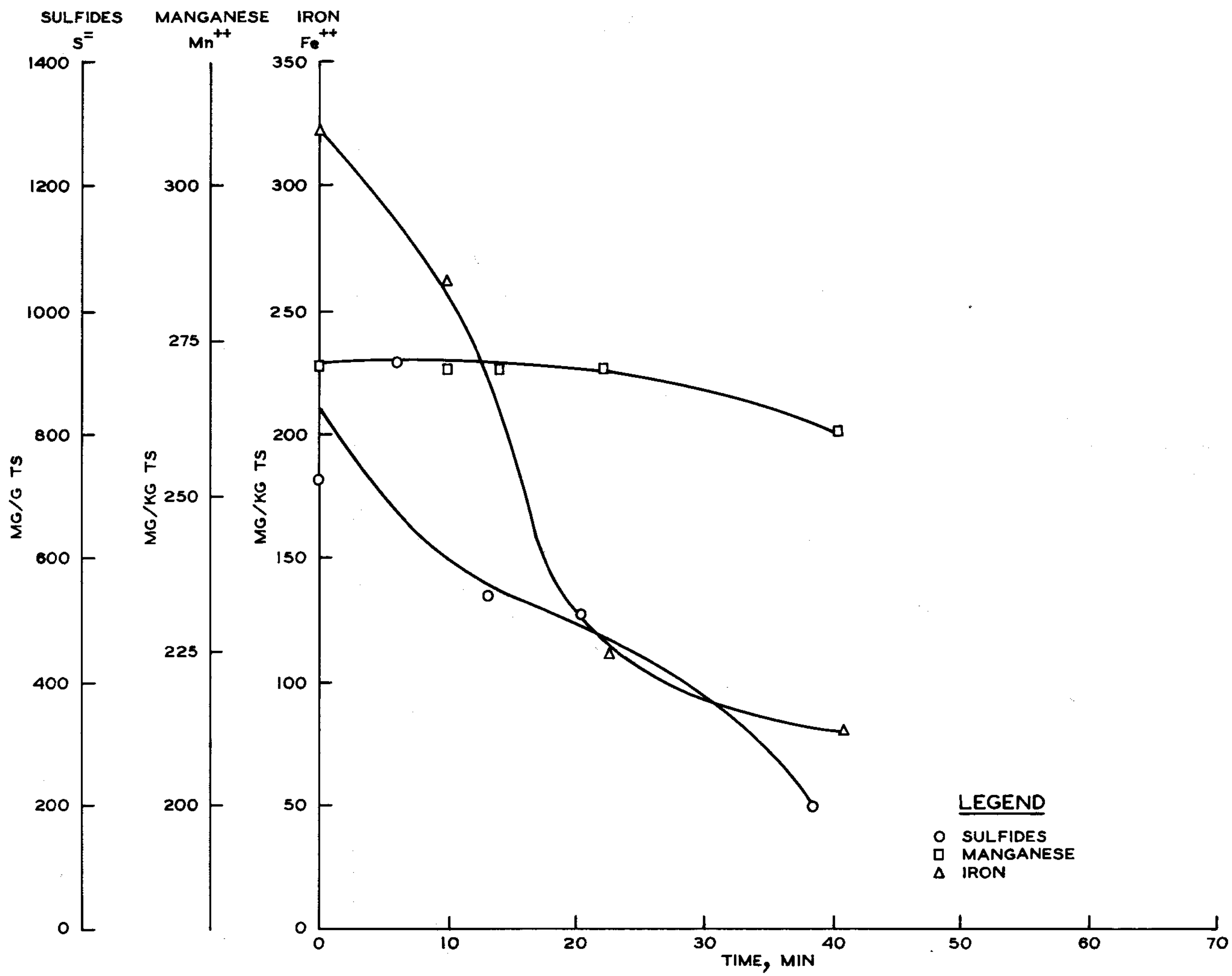


Figure 27. Time-related changes in sulfides, manganese, and iron concentrations - Arlington Channel sediment plus ambient water

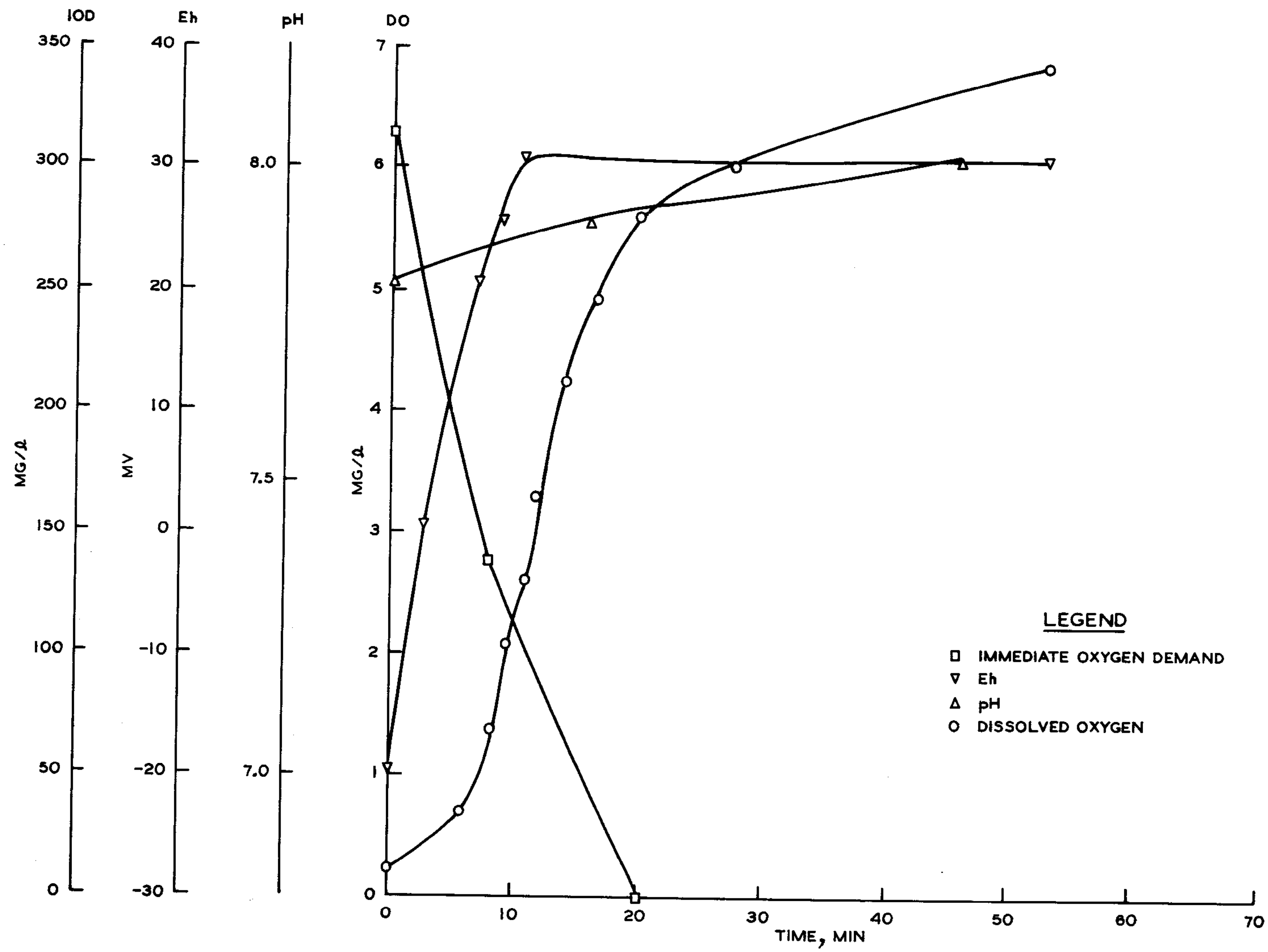


Figure 28. Time-related changes in immediate oxygen demand, dissolved oxygen concentration, pH, and Eh - Arlington Channel sediment plus ambient water

oxidation, but absolute changes were small. Eh changes were moderate and ranged from -50 to +20 mv for Chickasaw Creek and -20 to +30 mv for Arlington Channel; the final Eh values suggest that the suspensions were still in a slightly reduced state. The extractable Fe and Mn data indicate that the soluble ferrous and manganous forms are oxidized to the very poorly soluble ferric and manganic forms. Sulfides, a product of intense reducing conditions and the most reduced form, are oxidized very rapidly and at a lower Eh, pH, and DO. Mn^{++}, present under mild reducing conditions and the least reduced form, did not significantly decrease in concentration until most of the Fe^{++} and $S^{=}$ had been oxidized.

88. Discussion. These data indicate that the reduced forms are oxidized more or less sequentially beginning with the most reduced and more easily oxidized species ($S^{=}$) and with the least reduced species (Mn^{++}) remaining relatively stable until the more reduced species are almost completely oxidized. These data also indicate a capacity of the most reduced forms to poise the chemical system in a more reduced state until at least most of that form has been oxidized. Therefore, the relative concentrations of the various reduced forms would partially determine the amount of time required as well as rate of O_2 supply to oxidize all of the oxygen-demanding species.

89. Many studies have been performed on the release of materials from sediments and it was found that transport of material out of sediment is complex and affected by a large number of parameters.[26] One of the most significant chemicals that could affect the release of contaminants from dredged material is oxygen. A study by Stein and Denison revealed that undisturbed sediment exerted a greater oxygen demand than disturbed sediment.[27] They attributed this to the fact that the undisturbed sediment maintained animal burrows that increased the surface area available for oxygen transfer. McKeown et al. also observed that the oxygen demand of benthal deposits was proportional to the surface area.[28] However, it was observed that the oxygen demand increased with mixing. The fact that the discharge of dredged

material into open water greatly increases the surface area of the sediments lends credence to the conclusion that the IOD observed is predominately chemical in nature (i.e., COD).

90. Effect of aerating to saturation. A second observation made during this phase of the study was that under laboratory conditions, the complete satisfaction of the oxygen demand occurred very slowly. This was suggested by the monitored Eh readings and verified by additional analysis of the samples. After collecting the data discussed above, the samples were aerated until the DO concentration approach saturation for the particular laboratory conditions. The air was then shut off and a significant, rapid drop in the percent DO saturation was observed. This was repeated several times. The results are shown graphically in Figure 29, which was drawn from the strip chart recording of the Arlington Channel aeration study. Two hours of constant aeration did not satisfy the oxygen demand.

Determination of the net oxygen requirements

91. Two methods, oxygen reservoir and BOD bottle methods (which were described in paragraph 50), were used in determining the net oxygen requirements of dredged material from Chickasaw Creek and Arlington Channel. The results are given in the following paragraphs.

92. Oxygen reservoir method.

	Test Results: Chickasaw Creek	Test Results: Arlington Channel
DO_I, mg/ℓ	0.50	0
DO_F, mg/ℓ	13.50	22.1
V_I, ℓ	0.857	0.940
V_F, ℓ	0.707	0.810
V_R, ℓ	0.85	0.85
TS, g/ℓ	34.6	32.4
$V_F - V_I$, ℓ	0.150	0.130
$(DO_F - DO_I)$, mg/ℓ	13.0	22.1

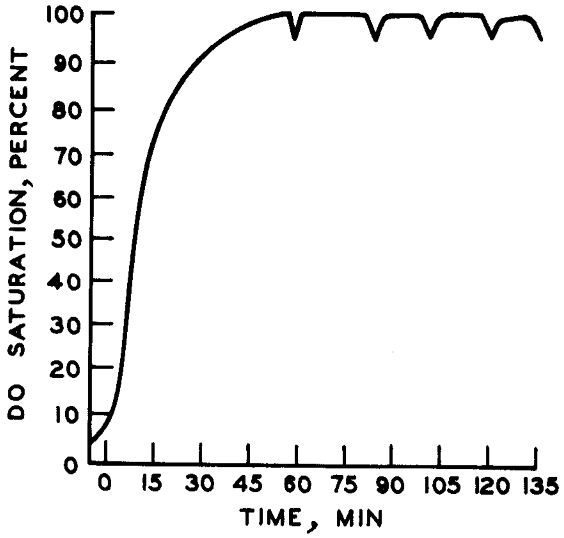


Figure 29. Effect of aerating to DO saturation

	Test Results	
	Chickasaw Creek	Arlington Channel
Time (min):		
Initial	0	0
Final	200	330

93. From the above data the net oxygen requirements were calculated by substitution of terms in equation 8.

$$\text{Oxygen Used } (O_u) = \frac{(V_F - V_I)\left(\frac{32{,}000}{22.4}\right) - (DO_F - DO_I)(V_R)}{(V_R)\ (TS)} \quad (8a)$$

$$\text{Chickasaw Creek} = \frac{0.150 \times \frac{32{,}000}{22.4} - 13 \times 0.85}{0.85 \times 34.6}$$

$$= 6.91 \text{ mg/g of TS}$$

$$\text{Arlington Channel} = \frac{0.130 \times \frac{32{,}000}{22.4} - 22.1 \times 0.85}{0.85 \times 32.4}$$

$$= 6.06 \text{ mg/g of TS}$$

94. BOD bottle method

Arlington Channel Wet Sediment Weight gm	DO_I mg/ℓ	DO_F mg/ℓ
0.76	8.20	5.60
0.71	8.20	5.55
0.32	8.20	6.75
0.71	8.20	5.55
0.69	8.20	5.70

95. The net oxygen required was calculated by substitution of terms in equation 9.

$$\text{Oxygen Used } (O_u) = (DO_I - DO_F) \times \frac{0.3}{W_s} \times \frac{1}{TS}$$

where: TS = Total solids, mg/g sediment, and other units are as listed in subparagraph 50a.

By substitution: $2.60 \times \frac{0.3}{0.76} \times \frac{100}{27} = 3.80$

$$2.65 \times \frac{0.3}{0.71} \times \frac{100}{27} = 4.15$$

$$1.45 \times \frac{0.3}{0.32} \times \frac{100}{27} = 5.03$$

$$2.65 \times \frac{0.3}{0.71} \times \frac{100}{27} = 4.51$$

$$2.50 \times \frac{0.3}{0.69} \times \frac{100}{27} = 4.03$$

$$\text{AVERAGE} = 4.23 \text{ mg } O_2/\text{g TS}$$

96. Discussion. Both methods have limitations as far as accurately measuring the amount of oxygen used by reduced substances is concerned. The closed system with the oxygen reservoir required a long reaction time since a large amount of sediment was used and oxidation occurred only at the oxygen/sediment interface. The modified Standard Methods test may be run more rapidly, but the dilution factor was large and obtaining a representative sample was difficult. Both methods, however, indicate the magnitude of the demand.

97. Application. An idea of the amount of oxygen required for complete satisfaction of the oxygen demand in a dredging operation may be estimated as follows:

Assumptions: Net oxygen demand = 4.23 mg/g TS

Dredge discharge pipe = 24 in.

Q = 16,890 gpm

Dredge slurry = 10% solids = 10 g TS/100 g slurry

Density (δ) slurry = 1.05 g/mℓ

$20^{o}C$, 760 mm Hg

Calculation of oxygen supply rate O_{sr}:

$$O_{sr} = (4.23 \text{ mb/g TS}) \times (10 \text{ g TS/100 g slurry}) \times (1{,}050 \text{ g slurry}/\ell) \times (3.785\ \ell/\text{gal}) \times (16{,}890 \text{ gal/min}) \times \frac{22.4\ \ell}{32 \times 10^3 \text{ mg}}$$

$$= 19{,}875\ \ell/\text{min or } 702 \text{ ft}^3/\text{min}$$

98. It should be recognized that the oxygen supply rate of 702 ft^3/min is an estimate for the entire dredged material oxygen demand. In practice, it may not be necessary to supply a quantity of oxygen sufficient to satisfy the entire demand because of dilution and dispersion at the disposal site. This value indicates that a large volume of oxygen would be required for satisfaction of the total oxygen demand. However, it was shown earlier that the reactions in the laboratory sediment suspensions occur at a slow rate. It has been shown also that when unoxidized sediment was added to receiving water containing on the order of 8 ppm DO, the DO was rapidly depleted. Taking into account the fact that under laboratory conditions the reaction appeared to proceed relatively slowly and considering the settling characteristics of dilute suspensions, such as would be encountered in open-water disposal, it is evident that only a part of the total oxygen demand would be exerted on the receiving water column during the settling time.

99. The use of pure oxygen would greatly speed up the reaction rates. However, during the total oxygen demand studies using pure oxygen at slightly greater than one atmosphere of pressure, the time of complete oxidation was greater than two hours. This was due to the fact that oxygen transfer and utilization was occurring only at the gas-liquid interface where the overall area for transfer was small when compared to the amount of material to be oxidized.

100. Since the reaction rates in the laboratory were such that complete oxidation was observed only after hours of aeration, it became apparent that complete satisfaction of the IOD may not be possible within the slurry residence time of a typical dredge pipe. This led to the DO profile studies.

Dissolved oxygen profiles

101. Results. Figure 30 depicts the effect of a slurry 14 percent solids by weight from the Chickasaw Creek sediment on the DO profile of a 6-ft water column. The DO depleted rapidly at each depth and, as the sediment became concentrated at the bottom of the column, the DO level at the bottom approached zero. Figure 31 represents the DO profiles of another aliquot from the same sediment which had been subjected to 40 psig of pure oxygen for 4 min; the DO concentrations at all depths were enhanced by the saturated condition of the carrier water.

102. The DO profiles of the Arlington Channel sediments are shown in Figures 32-35. The untreated sample contained 20-percent solids by weight and depleted the DO concentration so rapidly that only a few readings could be taken, as shown in Figure 32. Figure 33 depicts the DO profile of another aliquot with the same concentration after treatment with pure oxygen for 2 min at 40 psig. The DO depletions were still quite rapid but were considerably slower than for the untreated sediment. Further treatment of the same material at solids concentrations of 5 and 10 percent by weight are shown in Figures 34 and 35. Both the 5- and 10-percent mixtures were saturated with DO and when introduced to the water column produced an initial enhancement of the ambient DO (those levels occurring in the first few minutes) and the resulting DO depletions were significantly reduced.

103. Discussion. The profile study showed that once the sediment concentrates at the bottom of the column, there is still sufficient reduced materials to cause a severe DO depression. It should be noted that the DO levels in the water column were appreciably benefited by the aeration of the slurry. This implies that oxygen can be applied to the carrier water to saturate it to a level such that there is excess oxygen provided that will temporarily supply the oxygen demand and reduce the IOD to a tolerable level during the passage of the dredged material through the water column. Even in the most severe case (Arlington Channel at 20-percent solids), the DO was maintained at a tolerable level for the first 5 min; and, in field

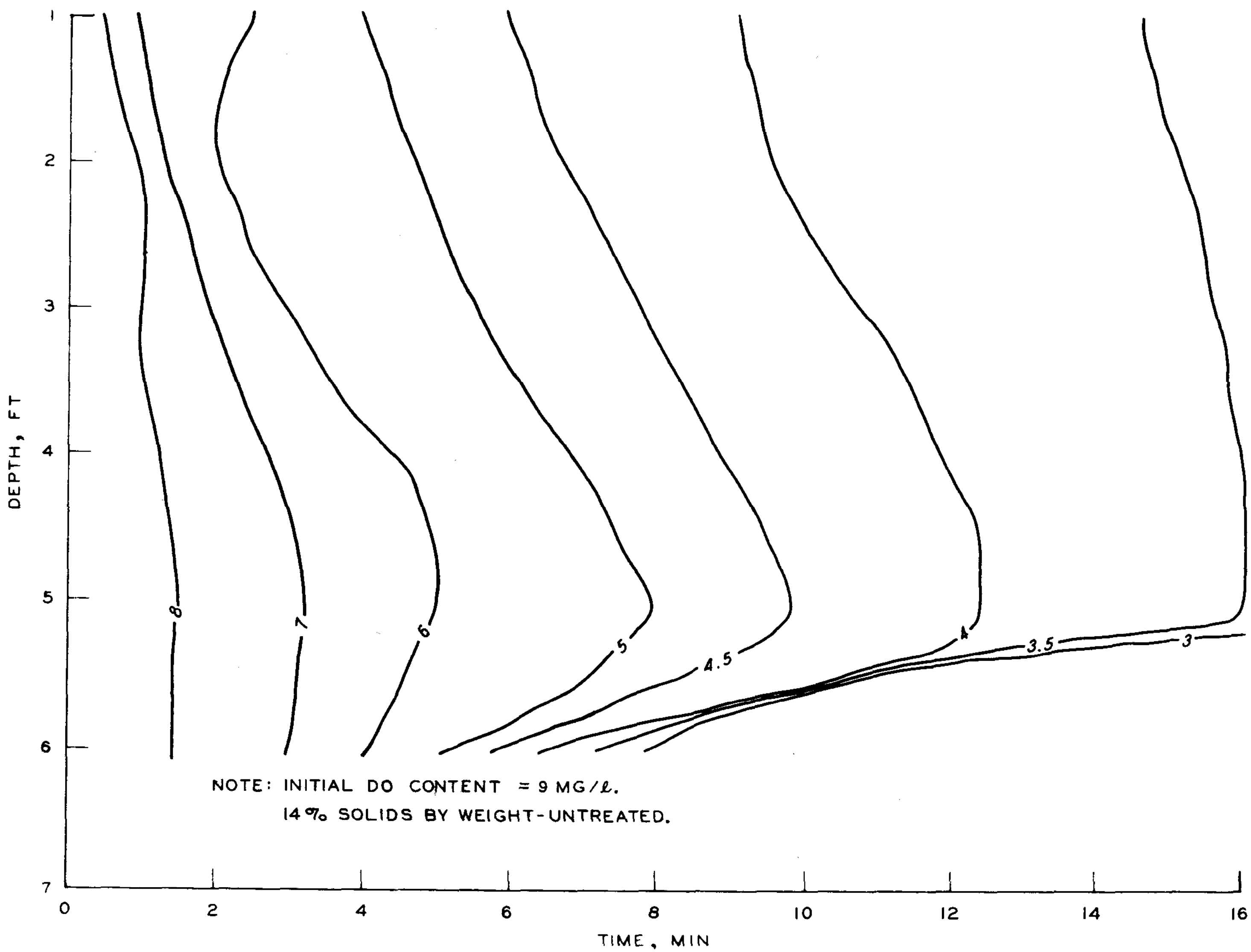


Figure 30. Dissolved oxygen profiles in water column showing effect of introduction of untreated Chickasaw Creek sediment

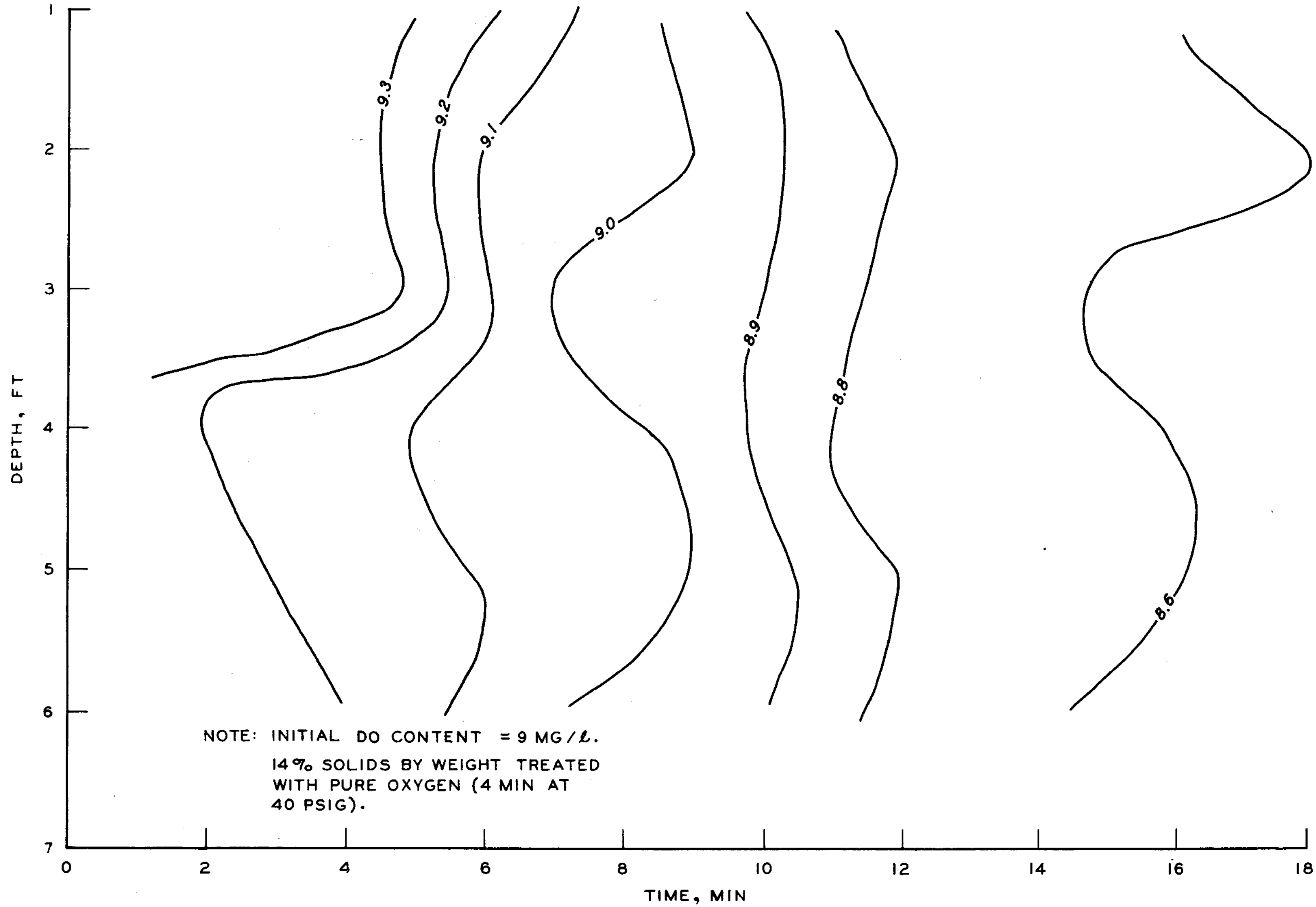


Figure 31. Dissolved oxygen profiles in water column showing effect of introduction of Chickasaw Creek sediment treated with pure oxygen

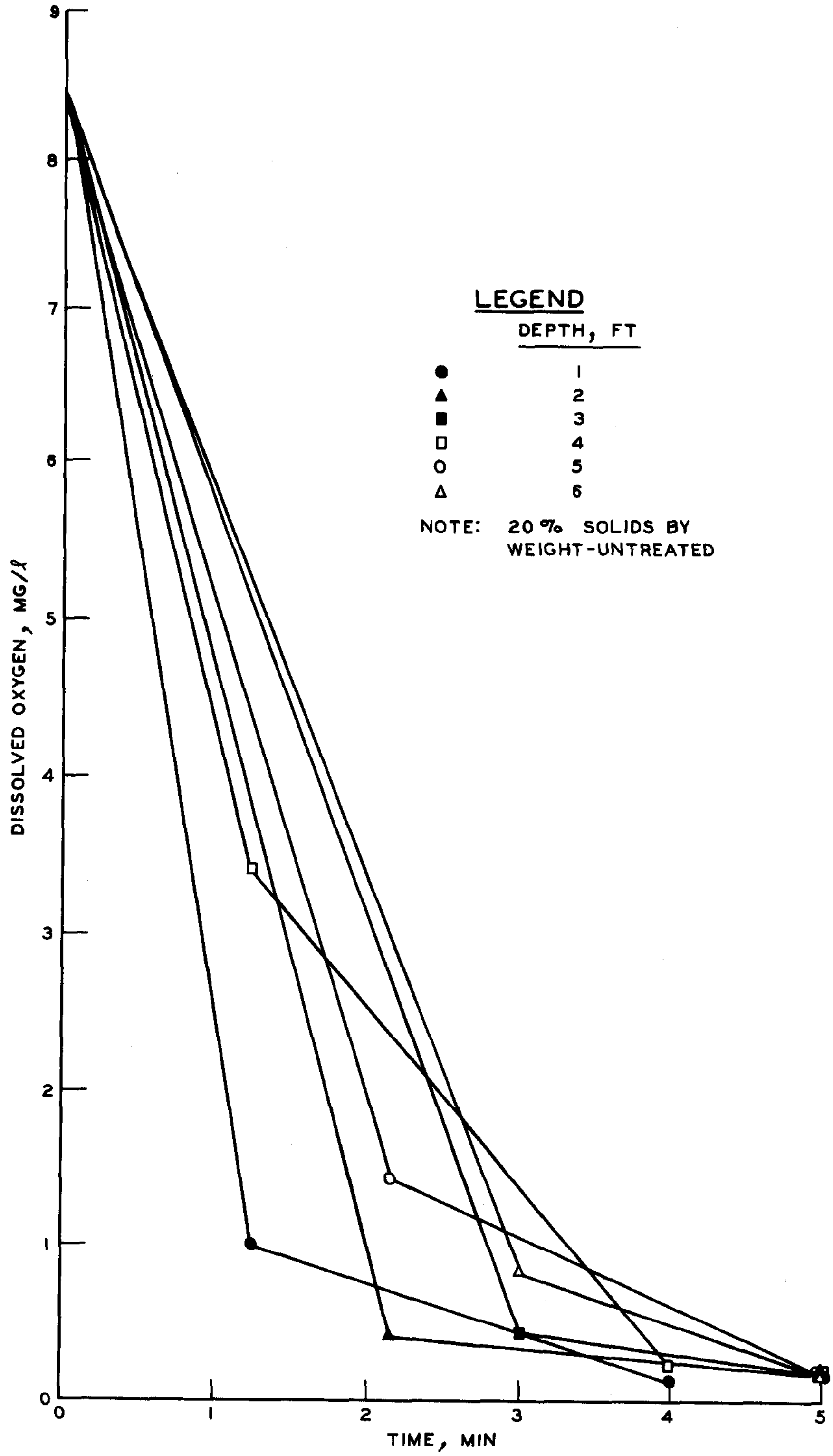


Figure 32. Dissolved oxygen depletion versus time for Arlington Channel sediment (slurry 20 percent solids concentration)

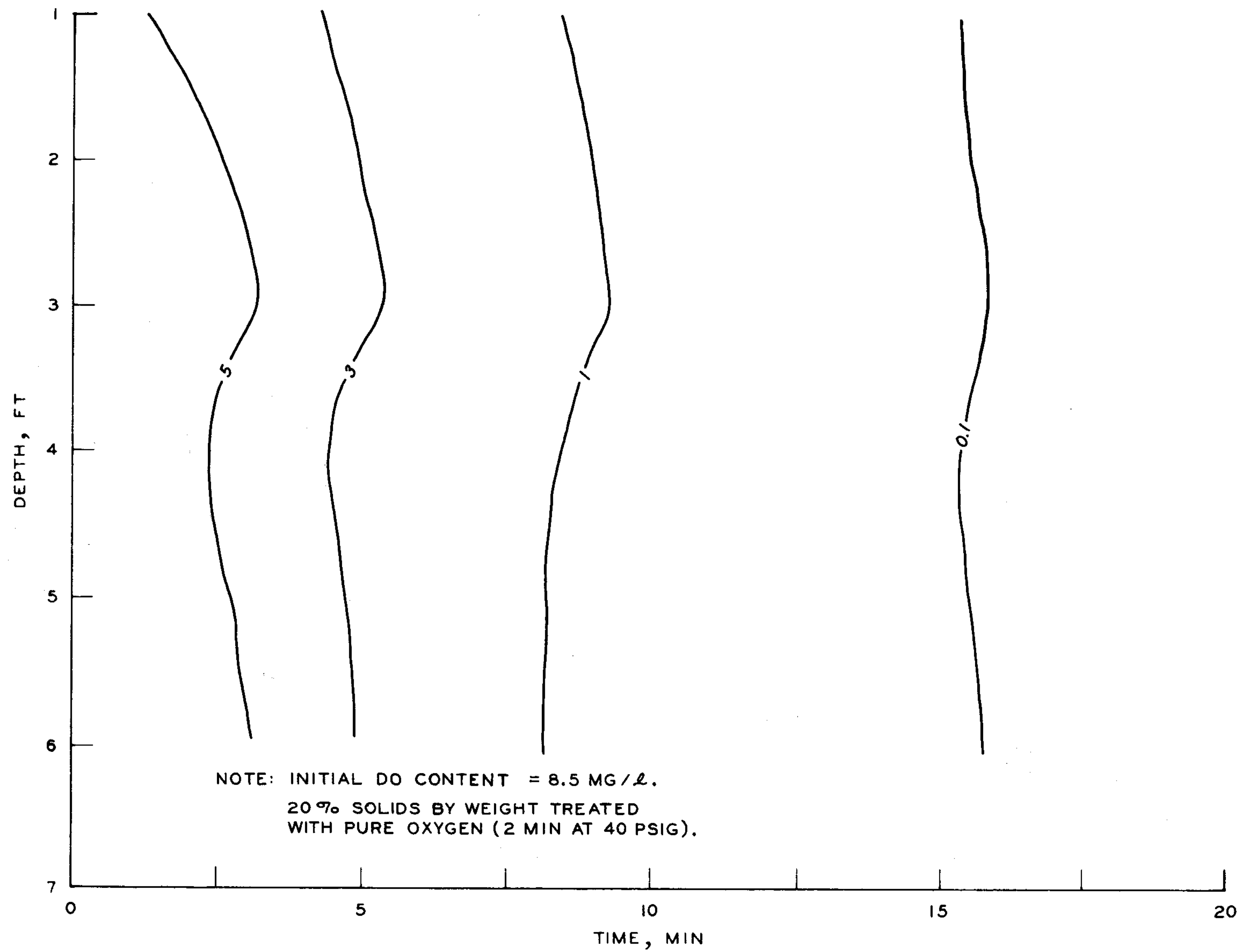


Figure 33. Dissolved oxygen profiles in water column showing effect of introduction of Arlington Channel sediment treated with pure oxygen (slurry 20 percent solids concentration)

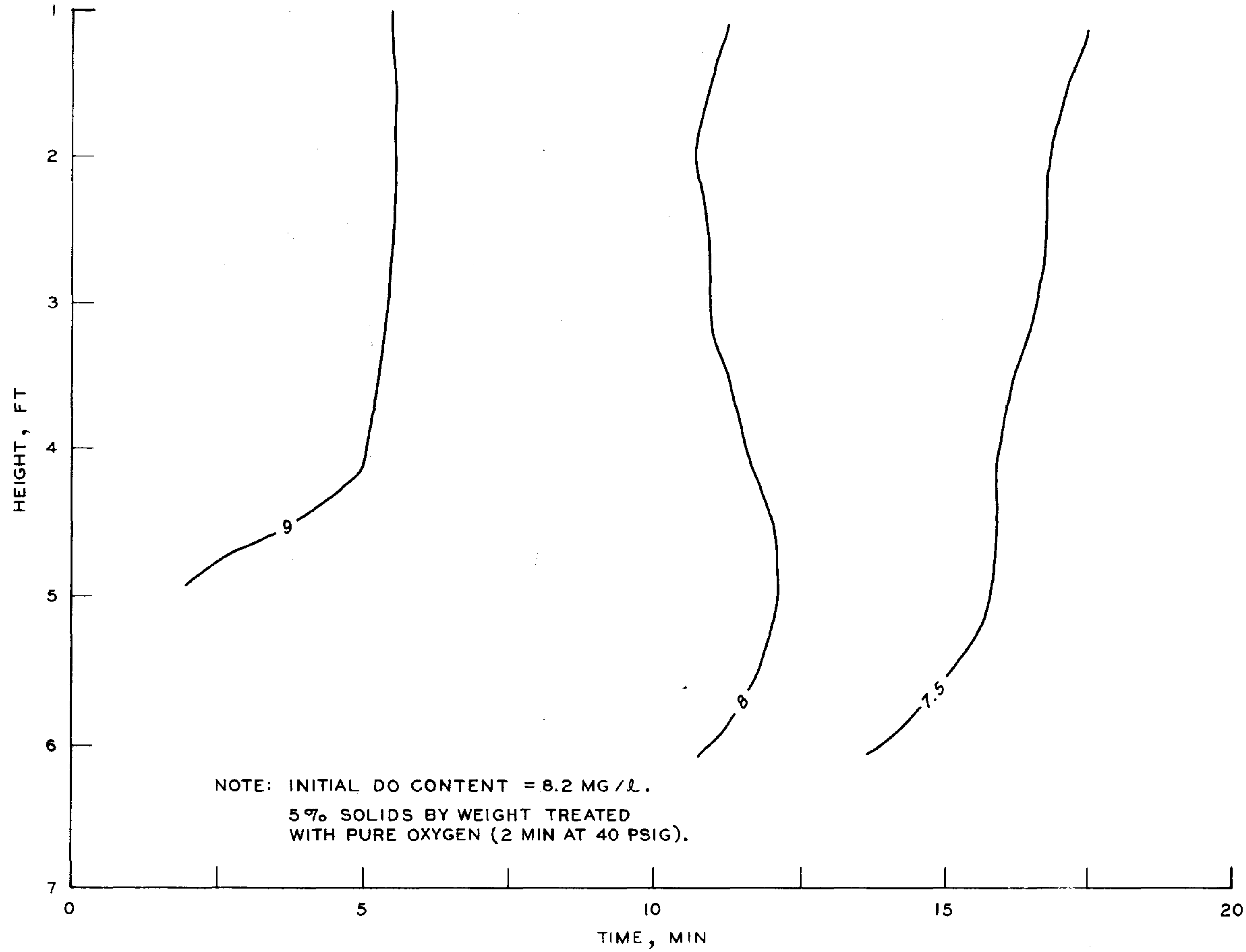


Figure 34. Dissolved oxygen profiles in water column showing effect of introduction of Arlington Channel sediment treated with pure oxygen (slurry 5 percent solids concentration)

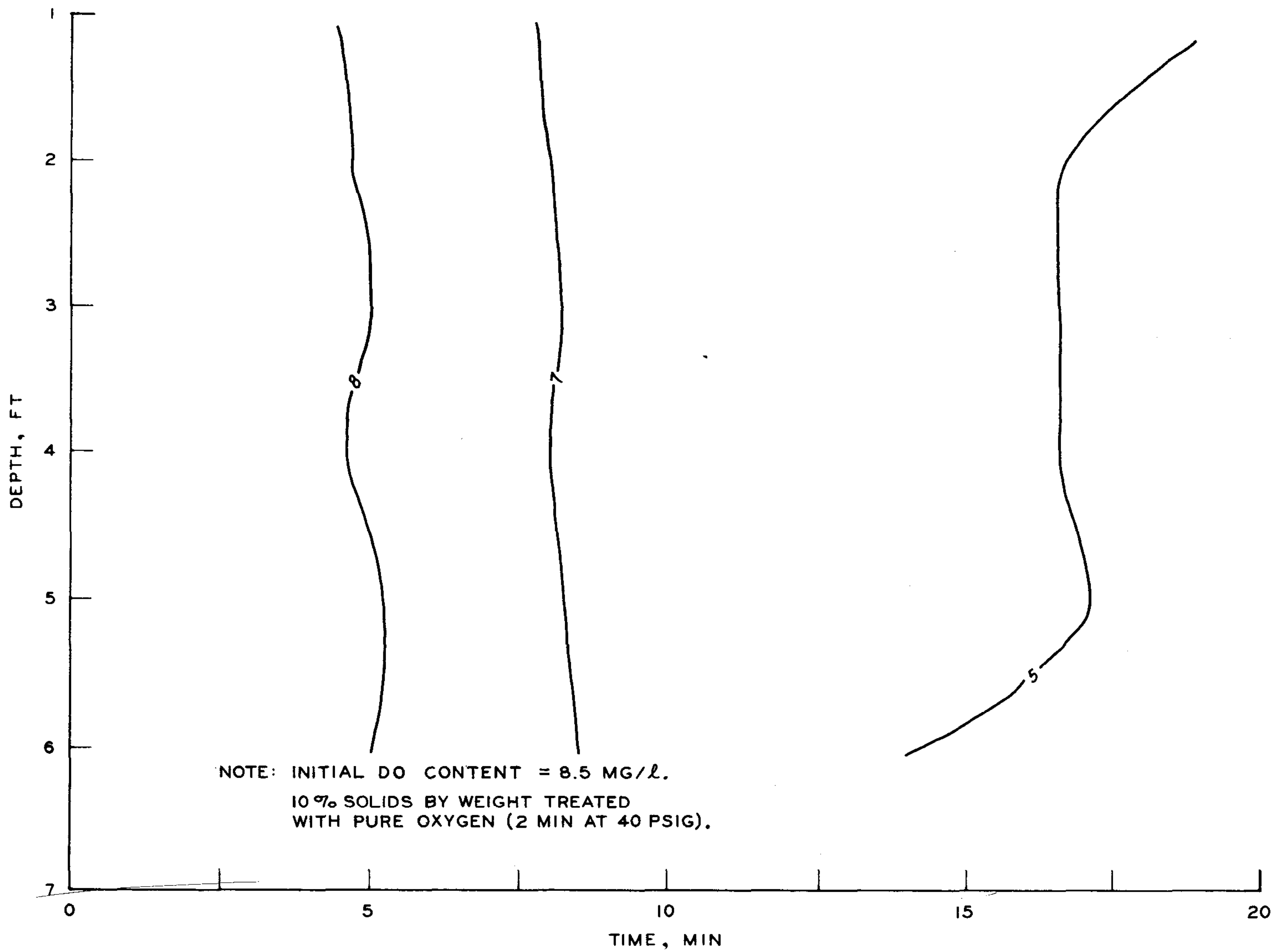


Figure 35. Dissolved oxygen profiles in water column showing effect of introduction of Arlington Channel sediment treated with pure oxygen (slurry 10 percent solids concentration)

conditions, these improvements would have the added benefits of higher dilution and dispersion characteristics of the receiving water.

PART IV: DREDGED MATERIAL TREATMENT SYSTEMS

Systems Considerations

104. The methods developed in sanitary engineering for treatment of municipal and many industrial wastewaters generally consist of separation of solid materials by sedimentation, removal of dissolved organic material by biological treatment, and various physical/chemical processes for removal of specific pollutants. These processes sometimes generate chemically laden organic sludges that must also be disposed of. These sludges are treated further by means such as biological degradation, concentration, dewatering, and incineration.

105. Most sludge handling processes are designed to operate most efficiently when the initial solids concentrations in the sludge are relatively low (0.2 to 5.0 percent). Dredged material usually contains a much higher initial solids concentration (5 to 20 percent), and these solids are predominantly inorganic. Furthermore, it does not appear that dredged material is not usually amenable to biological treatment. Also, the flow rate of dredged material is quite high in comparison to domestic and industrial flow rates and the constituents of the dredged material are highly variable when compared with rather uniform contents of domestic and industrial wastewaters.

106. Many of the conventional waste treatment processes and equipment that engineers are accustomed to using are not applicable for treatment of dredged material. Systems that offer potential for treatment of dredged material are as follows.

In-Line Aeration

107. One of the most significant problems associated with hydraulic pipeline dredges discharging into open waters is the IOD. A method of treatment that has potential for solving the IOD problem

is in-line aeration of the dredge discharge. This can be accomplished by injection of pure oxygen into the dredge discharge line, thereby saturating the dredge slurry with DO. This will greatly reduce or eliminate the DO depletion in the receiving water body attributed to the IOD.

Treatment in Conventional Diked Areas

108. One existing practice for disposal of dredged material on land is simple confinement within large diked areas. Natural sedimentation processes separate the solids fraction from the liquid fraction. The liquid fraction is then discharged into a nearby water body. Where some form of product recovery or simple management of material is practiced, the size required for the diked areas can be reduced.

109. Figure 36 depicts a general treatment scheme incorporating some material management concepts at diked areas. Bulk solids, debris, and other gross material can be separated by screening devices. The remaining materials may consist of gravel, sand, silt, clay, and colloidal matter. These could then be handled by conventional settling tanks for removal of fines and organics and by conventional techniques for removal of specific pollutants.

Factors in containment treatment

110. A report by Hittman Associates, Inc.,[25] extensively covers system concepts that could be applied at containment area facilities for the separation, handling, and drying of dredged material. The report reveals that removal of even the coarsest of materials requires areas so large as to prohibit in-line techniques for solids removal. Figure 37 depicts three grain-size distributions chosen to illustrate the variations that might exist in different dredged material and to show how these distributions would affect the design and performance of conventional containment facilities. Table 3 shows some typical containment basin areas required to achieve various percentages of removal and return water-quality goals based on idealized

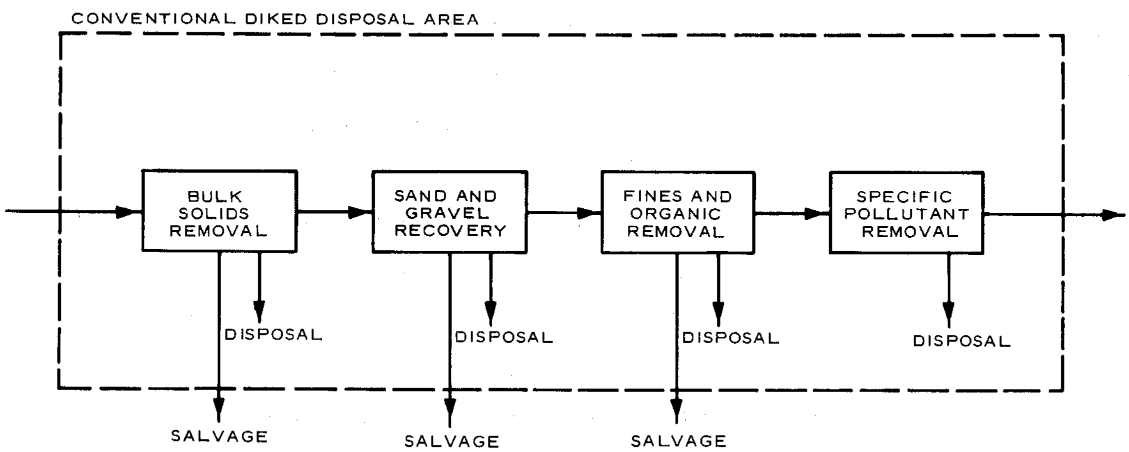


Figure 36. General treatment scheme for a conventional diked disposal area

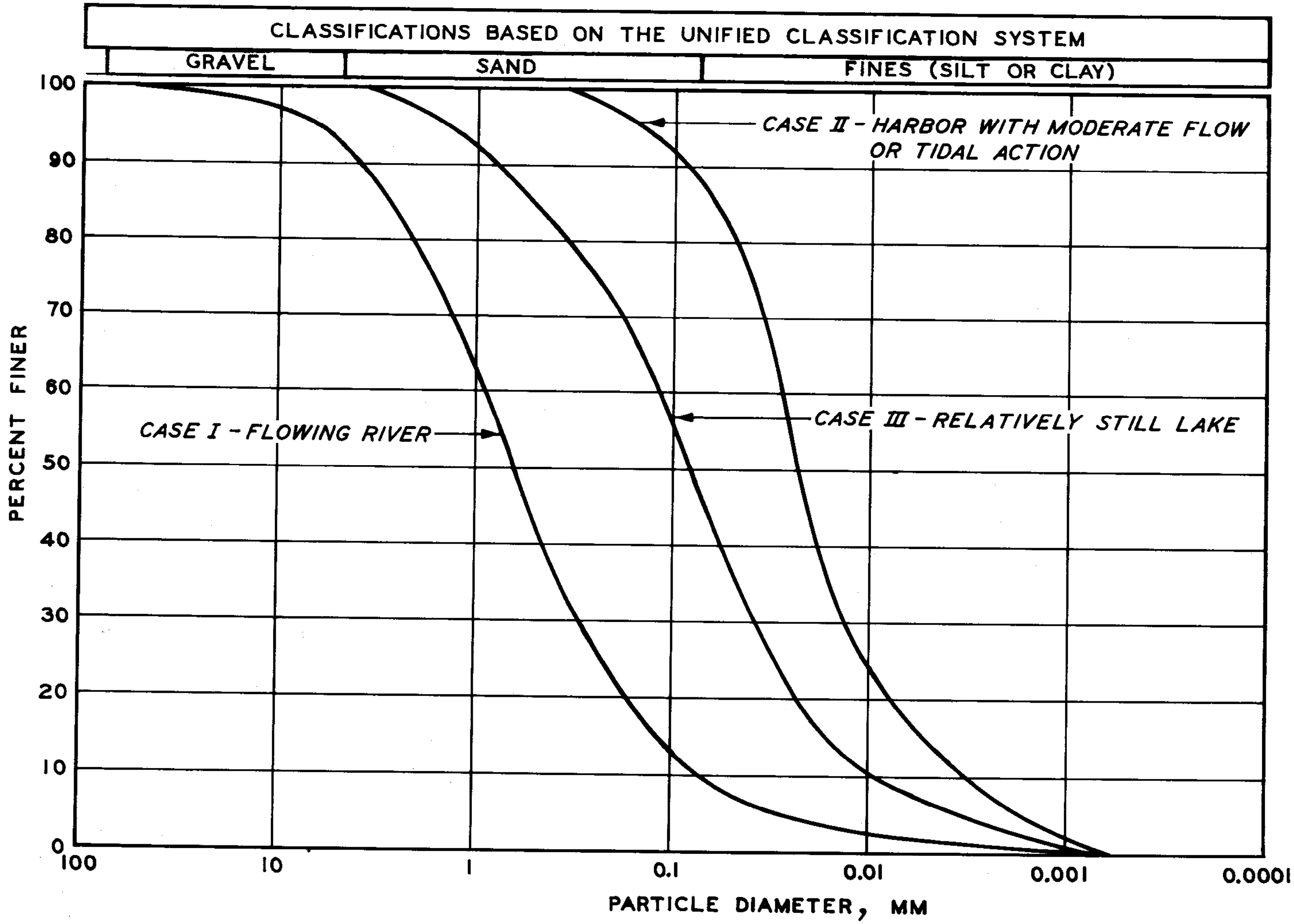


Figure 37. Grain-size distributions of typical bottom deposits selected to demonstrate the variability that might exist in dredged material

settling conditions for the three grain-size distributions given in Figure 37.

Determination of thickener requirements

111. The following calculation is an example of the thickener requirements as applicable to dredged material. Details of the analytical procedure are given in Reference 11. The Fowl River sediment curve at 3-percent solids by weight was used for the example. Figure 38 depicts the analysis curve.

112. The cylinder depth required for the material to settle completely back to the original concentration of the discharge pipe (17 percent) is as follows:

$$H_u = \frac{C_o H_o}{C_u} \text{ or } \frac{(0.03)(36)}{0.17} = 6.35 \text{ cm} \tag{10}$$

where: H_u = Underflow* height, cm

C_u = Underflow slurry concentration

H_o = Initial height of interface, cm

C_o = Initial slurry concentration

Figure 38 indicates that this underflow height is not attainable; the maximum slurry concentration obtainable is:

$$C_u' = \frac{C_o H_o}{H_u} \text{ or } 100 \frac{(0.03)(36)}{7.63} = 14\% \tag{10a}$$

113. Assuming this clarification is to follow a 24-in. dredge pumping at 12 fps for 12 hr per day, the required surface area A becomes:

---

* Underflow is the concentrated slurry containing all particles of fine-sand size and larger that results from hydraulic solids splitting techniques. The overflow from the splitter would contain the particles less than 75μ in size.

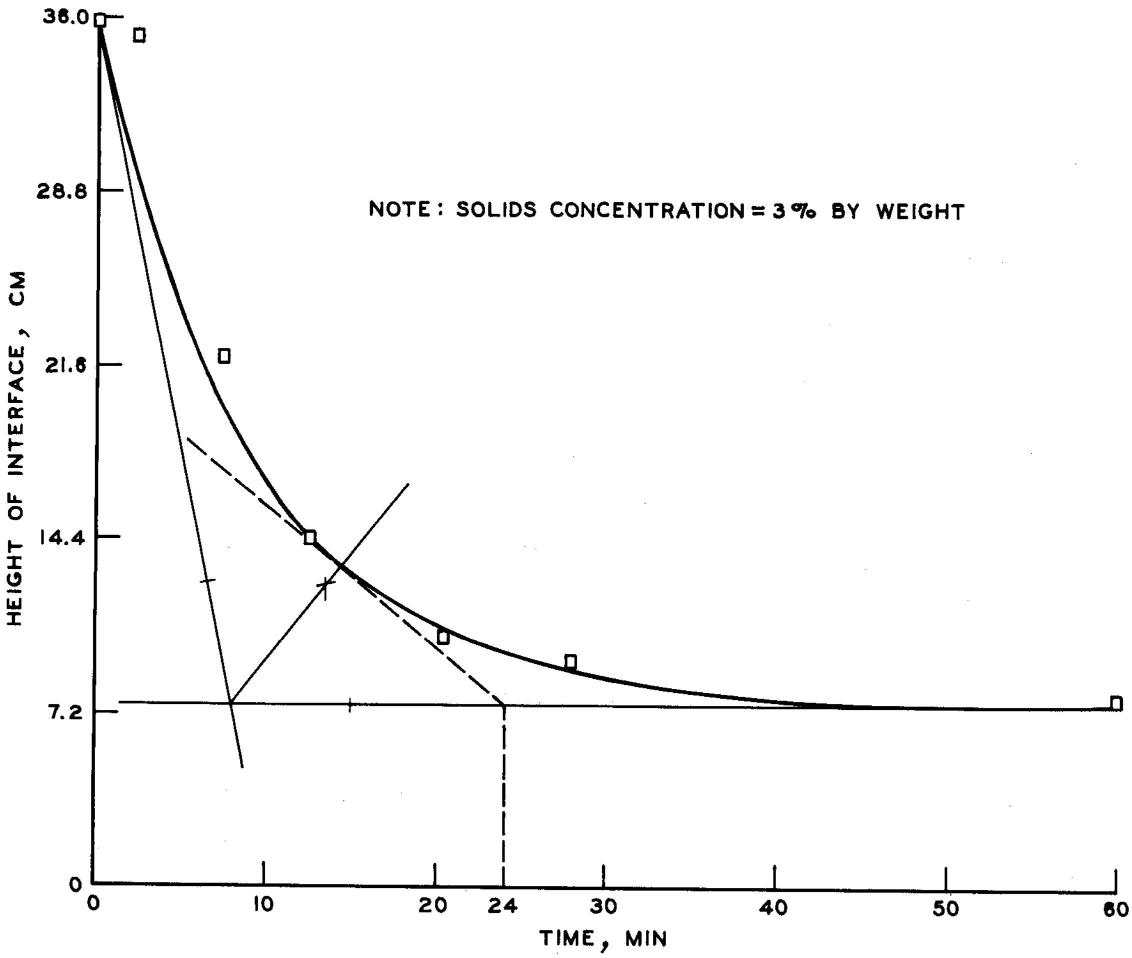


Figure 38. Sedimentation analysis curve - Fowl River

$$A = \frac{Qt_u}{H_o} \quad (11)$$

where: Q = flow rate

t_u = time to reach underflow concentration

If $Q = 0.016890 \text{ gal/min} \times 60 \text{ min/hr} \times 12 \text{ hr/day} \times 1.55 \frac{\text{ft}^3\text{/sec}}{10^6 \text{ gal/day}}$

$t_u = 24 \text{ min} \times 60 \text{ sec/min}$

$H_o = 36 \text{ cm} \times \frac{1 \text{ ft}}{30.48 \text{ cm}}$

By substitution

$$A = \frac{(0.016890)(60)(12)(1.55) \quad (24)(60)}{(36 \div 30.48)} = 23{,}000 \text{ ft}^2 = 0.52 \text{ acre}$$

114. The resulting surface area required is quite large, and it is apparent that any sort of in-line sedimentation process for thickening or clarification of the example dredged material does not appear practical.

Large-Scale Vacuum Filtration

115. Vacuum filtration is a dewatering process used to concentrate sludges to a point where they are amenable to other solids handling procedures. After filtration, sludge concentrations of 20 to 30 percent solids are common with organic sludges and values of 60 percent or more may be obtained with some inorganic sludges.[15]

116. The application of vacuum filtration to dredged material would greatly decrease the time required for separation of the solids and liquid fractions and would allow for mechanical handling of the dewatered dredged material for stockpiling. A simplified process schematic for application of vacuum filtration to dredged material is

shown in Figure 39. In this process the holding pond size will be determined by the dredging and the filtration flow rates. The filtration units can operate continuously during and after the dredging operation. The dewatered dredged material may be stockpiled for further processing such as sand and gravel reclamation, left in place, or used as fill material. The liquid fraction is either discharged directly back to the water body or else treated for specific pollutant removal and then discharged.

Other Dewatering Techniques

117. In the study done by Hittman Associates, Inc.,[25] the dewatering techniques that appeared most promising were a gravity drainage system, rehandling system, surface rewashing, vacuum pumping, electroosmosis, and thickening followed by vacuum filtration.

118. In the gravity drainage concept, a sand/gravel layer is placed in the bottom of a secondary containment basin and the fine-grained materials are allowed to drain through to an underdrain system. This concept would produce some drainage and consequent dewatering until the sand/gravel layer became clogged with the fine-grained material.

119. Simple rehandling of fine-grained dredged material is presently being used by the sand and gravel processing industry as a means of drying and dewatering before truck transport. The main disadvantages of this technique are the relatively large amount of area required and the slow drying times of the material.

120. Surface reworking is a concept where the surface of the deposited dredged material is reworked constantly causing the water to be brought to the surface more rapidly for evaporation. In a recently completed demonstration program, a bulldozer was used to continually agitate the surface of a conventional dredged material containment basin. Consolidation and dewatering of the dredged material was obtained in a much shorter period than if the material were allowed to dewater naturally.

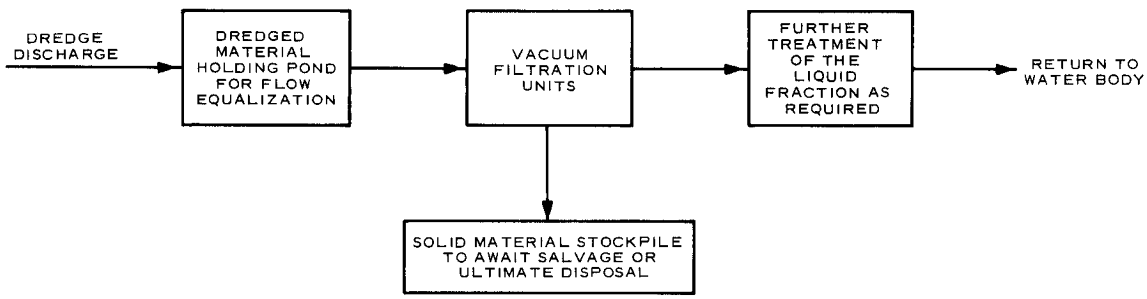


Figure 39. Simplified schematic of vacuum-filtration process

121. Vacuum pumping is a standard method used for dewatering fine-grained soils with high moisture contents. A number of wells and/or well-points are installed, and water is pumped from the wells under a vacuum head. This method has been used successfully to dewater soils from the fine-sand range down to particles that are approximately 5μ in size. The vacuum pumping equipment is commercially available and has been used in a number of instances to dewater fine-grained dredged material.

122. Electroosmotic soil consolidation and dewatering involves a process in which a direct current electric potential is set up in fine-grained soil by means of electrodes. This potential induces the flow of water in the pores of the soil toward the negative pole, or cathode. In a field application of this method, an increase of dewatering rate of 1000:1 over the natural rate was reported. The main disadvantages are that this method yields a relatively slow rate of dewatering and that it is expensive in large-scale applications.

123. A potentially useful concept for dewatering of fine-grained dredged material, which has been investigated for possible use in the restoration of clay disposal ponds in the sand and gravel processing industry, is the use of a thickener followed by filtering in a standard rotating drum vacuum filter. An example system was designed to process 1950 gpm of a clay slurry which was to be removed by pumping from the bottom of a containment basin. The land area required for this system is 600 by 300 ft, which includes space for two thickeners, a vacuum drum filter shelter, and a freshwater make-up pond. This process shows promise as a means for dewatering the fine-grained dredged material remaining after sand and gravel separation.

124. Figure 40 contains a brief summary of the approximate technical range of applicability of the various commonly used soil dewatering techniques.

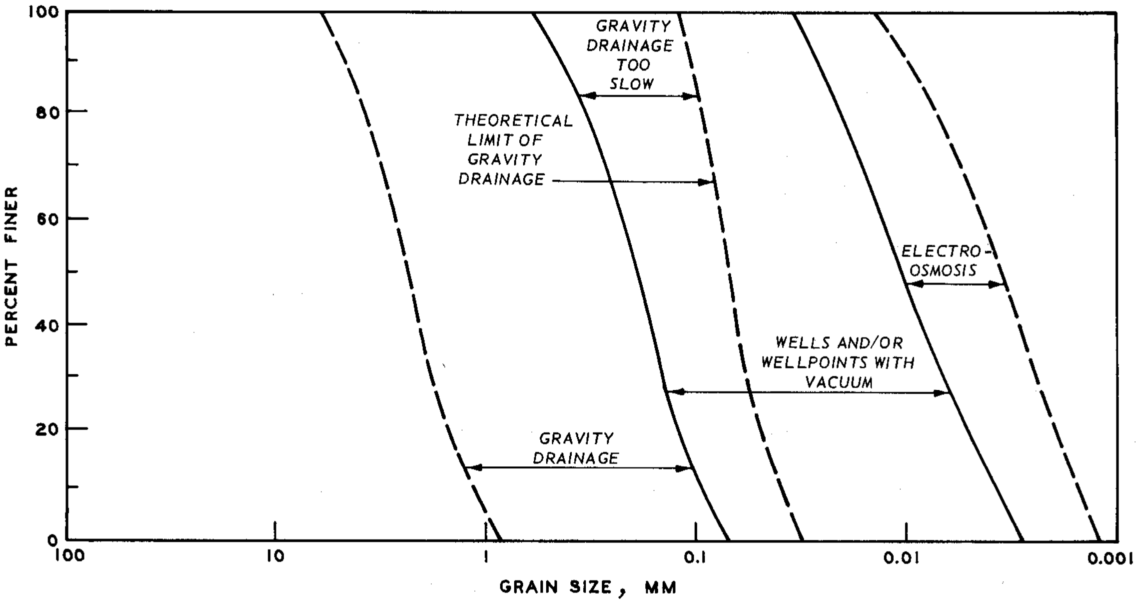


Figure 40. Approximate particle-size range of applicability of various soil dewatering techniques (Moretrench Corp.)

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

General

125. Dredged material may contain various amounts of debris, gravel, sand, silt, clay, and colloidal particles as well as organic matter. The high solids content, magnitude and variability of flow, and the complex nature of dredged material render many conventional wastewater treatment techniques inapplicable and/or impractical for treatment prior to open-water disposal.

Specific

126. Based upon the results of this investigation, the following specific conclusions for the treatment of the dredged material used in this study are believed warranted.

127. Dredged material characterization. Early methods of evaluating the characteristics of dredged material by use of bulk analysis are not adequate for assessing the effect of dredged material disposal on the environment.

128. Biological treatability. The BOD of the dredged material examined during this study represented only a small fraction of the net oxygen demand. This fact, along with the highly variable nature of the dredged material in terms of quantity and chemical characteristics, renders biological treatment ineffective and/or impractical for the areas represented.

129. Chemical treatability. Once the dredged slurry has been separated into solid and liquid fractions, turbidity in the liquid fraction can be reduced by chemical coagulation.

130. Physical treatability.

- a. Specific resistance to filtration. Vacuum filtration has been shown to be an effective means of dewatering dredged material in the laboratory. However, unique filtration equipment may have to be designed to handle materials with initial solids contents as high as those found in dredged material.

b. Sedimentation. The solids portion of dredged material containing relatively clean sand with low organic content settles rapidly. Dredged material with a high organic fraction and/or fine-grained materials requires much more time and minimum turbulence to settle and requires large settling basins to produce solids/liquid separation.

c. Dissolved air flotation. This method of removal of suspended matter from liquids is not effective when applied directly to dredged material slurries.

131. Aeration studies. When the sediment slurries used in this study were introduced to a water column, a rapid depletion of the DO in the water column was caused by oxidation of the highly reduced substances found in the slurry. This effect (IOD) is often associated with disposal of dredged material in open water.

132. DO depletion in the water column can be substantially reduced by saturation of the dredged slurry carrier water with DO. This can be accomplished by supersaturation of the dredge slurry with oxygen in a high-pressure environment.

Recommendations

133. Saturation of dredged material carrier water by injection of oxygen into the dredge discharge line appears to be a feasible method for satisfying the IOD imposed on the receiving water column during open-water disposal of dredged material from a hydraulic pipeline dredge. Laboratory studies should be conducted to determine the most effective means of oxygen introduction and hardware for injection of the oxygen; then a pilot field study should be performed to evaluate the effectiveness of the selected method in satisfying the IOD. The effect of aeration on the release of contaminants should also be examined. The field study could be performed during the scheduled operation of a small pipeline dredge.

134. Product recovery from dredged material disposal sites is feasible. A study should be scheduled at a conventional dike disposal

area to evaluate the most effective means of separating the solid fraction of dredged material for beneficial uses or ultimate disposal. This would be part of another DMRP research task.

135. A laboratory study should be performed to evaluate an experimental vacuum-filtration system for dewatering dredged material. Rapid dewatering of dredged material could greatly reduce the size of containment facilities required for dewatering and ultimate disposal.

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Table 1

Dredged Material Characterization Data

Location	Sample	Total Kjeldahl Nitrogen TKN	Ammonium Nitrogen NH_4-N ppm	Nitrate Nitrogen NO_3-N ppm	Total Phosphorous P-Total ppm	Phosphate Phosphorous PO_4-Total ppm	Mercury Hg ppb	Lead Pb	Zinc Zn	Cadmium Cd	Iron Fe	Sand/Silt/Clay %/%/%	Solids TS/TVS %/%	Cation Exchange Capacity mgq/100g
Mobile Bay														
Fowl River	Ambient water	--	--	--	0.88	0.68	1.2	0.62 ppb	0.35 ppb	0.08 ppb	--	--	--	--
	Dredged supernatant	--	--	--	1.25	1.14	5.3	5.21 ppb	1.03 ppb	0.33 ppb	--	--	--	--
	Dredged sediment	0.128%	40.58	4.3	169.0	2.9	4.1	40.7 ppb	3.63 ppb	5.18 ppb	--	20/55/25	17/10	22.8
Arlington Channel	Ambient water	3.11ppm	1.01	0.21	0.52	0.39	2.4	0.09 ppm	0.95 ppm	0.008 ppm	10.1 ppm	--	--	--
	Supernatant (4:1 mix)	5.37ppm	4.81	0.63	0.94	0.53	0.8	0.06 ppm	0.37 ppm	0.010 ppm	6.2 ppm	--	--	--
	Sediment	0.67%	322.4	26.1	463.8	25.4	61	55.1 ppm	263.5 ppm	4.53 ppm	4.35%	81/16/3	36/11	31.9
Chickasaw Creek	Ambient water	5.6ppm	3.1	0.66	0.19	0.11	2.2	0.08 ppm	0.23 ppm	0.009 ppm	1.14 ppm	--	--	--
	Supernatant (4:1 mix)	77.7ppm	73.5	0.70	1.48	1.31	9.0	0.11 ppm	0.42 ppm	0.016 ppm	5.15 ppm	--	--	--
	Sediment	0.82%	871	6.1	4555	257	170	61.3 ppm	322.5 ppm	3.96 ppm	1.4%	54/33/13	16/69	42.9
Maumee Bay	Ambient water	5.3ppm	1.7	1.9	0.08	0.05	1.1	0.08 ppm	0.10 ppm	0.015 ppm	2.85 ppm	--	--	--
	Dredged supernatant	16.0ppm	2.8	9.6	0.20	0.16	1.2	0.04 ppm	0.11 ppm	0.019 ppm	25.9 ppm	--	--	--
	Dredged sediment	0.089%	21.3	3.1	74.1	10.5	320	32.5 ppm	142.8 ppm	5.75 ppm	2.62%	46/26/28	26/7	6.85
Mare Island Strait	Ambient water	1.40ppm	0.32	8.2	0.25	0.20	1.0	0.61 ppm	0.39 ppm	0.04 ppm	--	--	--	--
	Sediment	0.161%	40.25	20.4	115.0	12.50	74	260 ppm	723 ppm	7.25 ppm	--	--	42/9	31.9
	Supernatant (4:1 mix)	4.52ppm	0.54	2.5	0.41	0.36	1.0	0.52 ppm	0.36 ppm	0.04 ppm	--	--	--	--
	Sediment (4:1 mix)	0.16%	37.79	59.4	128	12.7	82	268 ppm	733 ppm	5.08 ppm	--	--	--	--

Table 2

Characterization of Oxygen Uptake

Source of Sediment	Air Flow Rate ℓ/min	Elapsed Time min	Sulfides $S^{=}$ mg/g TS	Iron Fe^{++} mg/kg TS	Manganese Mn^{++} mg/kg TS	DO mg/ℓ	Eh mv	pH	IOD mg/ℓ
Chickasaw Creek	0.4	0	5	76	45	0	-50	7.2	20.4
		4.13	-	-	-	0.14	-40	-	-
		11.15	-	-	-	0.41	-20	-	14.25
		12.83	-	-	-	-	-10	7.9	-
		14.10	-	-	-	0.68	-10	-	-
		17.09	-	-	-	-	0	-	-
		20.68	-	305	48	-	0	-	-
		24.60	-	-	-	1.22	0	-	-
		28.14	-	-	-	-	0	8.0	9.85
		33.61	-	-	-	1.49	+5	-	-
		43.28	-	-	-	1.76	+5	8.0	-
		48.19	-	-	-	1.90	+10	-	-
		49.10	3.89	-	-	-	+10	-	6.45
		57.16	-	196	43	2.44	+20	8.0	-
		69.00	3.15	-	-	-	+20	8.0	-
		73.12	-	188	42	-	-		-
		86.65	-	-	-	-	-		2.75
		101.00	-	-	-	3.94	+20		-
		118.40	-	-	-				0.00
		127.66	1.73	-	-				
		129.65		235	38				

Note: 1.25ℓ sediment plus 5ℓ ambient water stirred at 300 rpm.

Table 2 (concluded)

Characterization of Oxygen Uptake

Source of Sediment	Air Flow Rate ℓ/min	Elapsed Time min	Sulfides $S^{=}$ mg/g TS	Iron Fe^{++} mg/kg TS	Manganese Mn^{++} mg/kg TS	DO mg/ℓ	Eh mv	pH	IOD mg/ℓ
Arlington Channel	2	0	721	320	270	0.20	-20	7.8	340
		3.1	-	-	-	0.40	0	-	-
		6.06	904	-	-	0.68	-	-	-
		6.75	-	-	-	0.81	-	-	-
		7.50	-	-	-	1.08	+20	-	-
		7.85	-	-	-	1.22	-	-	-
		8.30	-	-	-	1.36	-	-	1.35
		8.80	-	-	-	1.63	-	-	-
		9.85	-	-	-	7.04	+25	-	-
		10.10	-	260	270	-	-	-	-
		10.41	-	-	-	2.31	-	-	-
		11.10	-	-	-	2.58	-	-	-
		11.66	-	-	-	2.85	-	-	-
		12.37	-	-	-	3.40	-	-	-
		13.11	527	-	-	-	-	-	-
		14.43	-	220	270	4.21	-	-	-
		15.63	-	-	-	-	-	7.9	-
		20.69	506	110	270	5.44	-	-	0
		38.10	199	-	-	-	-	-	
		40.51	-	80	260	-	-	-	
		46.30	-	-	-	-	-	8.0	
		53.40	-	-	-	6.80	+30		
		133.37	76	10	210				

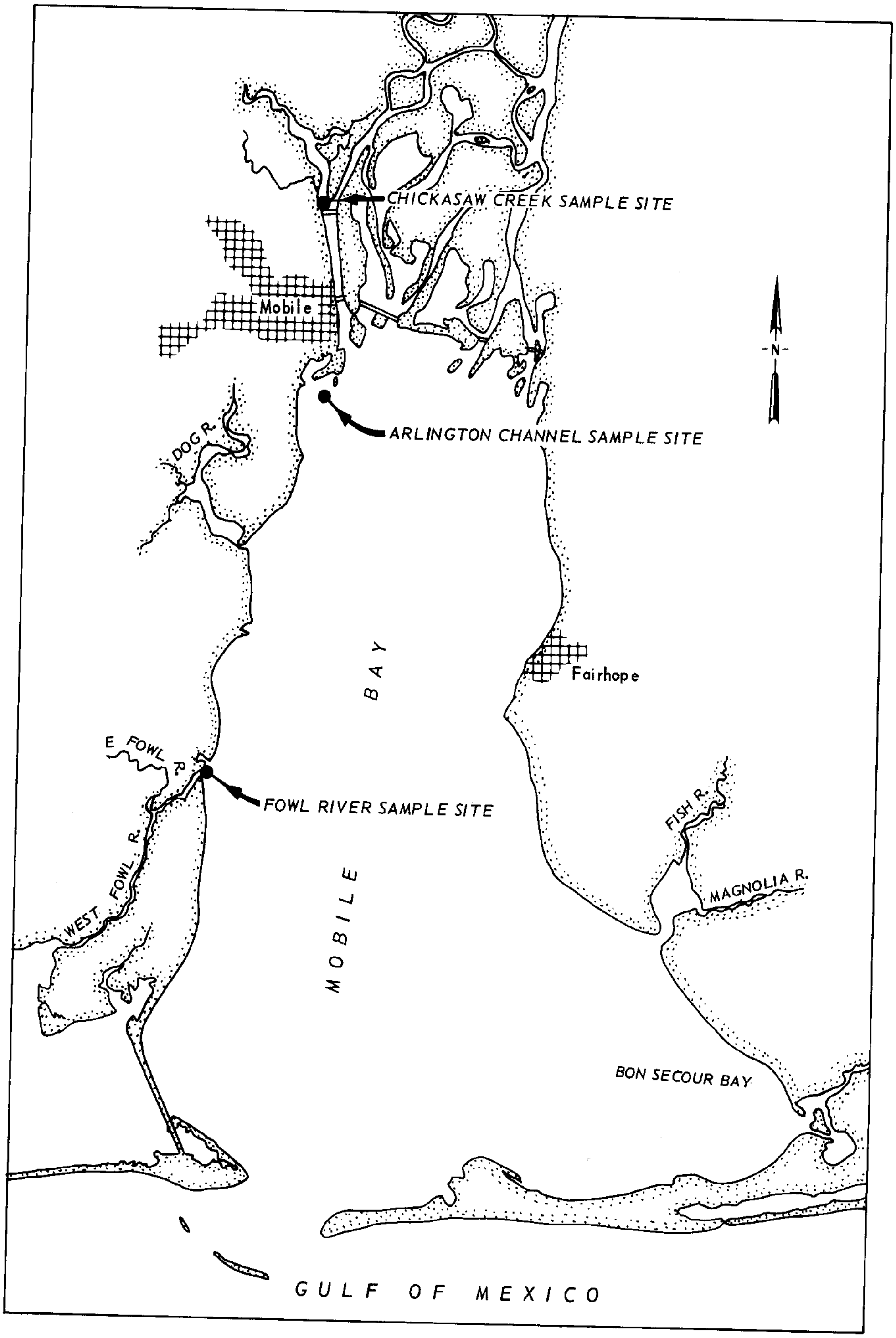
Table 3

Effect of Dredged Material Grain Size on Idealized Containment Basin Area Requirements*

Dredge in.	Capacity cfs	Case**	Basin Area, acres: % Removal 90%	% Removal 95%	Water-Quality Criteria - Suspended Solids, gm/ℓ: 8	4	2	1
8	4.2	I	0.006	0.037	0.021	0.293	1.10	2.10
		II	0.419	2.10	1.11	7.42	14.8	19.7
		III	3.71	8.76	5.67	13.03	37.08	41.92
12	9.4	I	0.014	0.083	0.047	0.656	2.45	4.69
		II	0.938	4.69	2.48	16.6	33.2	44.0
		III	8.30	19.6	12.7	29.2	83.0	93.8
18	21.2	I	0.031	0.187	0.105	1.48	5.53	10.6
		II	2.11	10.6	5.59	37.4	74.9	99.3
		III	18.72	44.2	28.6	65.8	187	212
24	37.7	I	0.055	0.333	0.187	2.63	9.83	18.8
		II	3.76	18.8	9.95	66.6	133	177
		III	33.29	78.7	50.9	117	333	376
30	58.9	I	0.0867	0.520	0.292	4.11	15.4	29.4
		II	5.88	29.4	15.5	104	208	276
		III	52.0	123	79.5	183	520	588
36	84.9	I	0.125	0.750	0.421	5.92	22.1	42.4
		II	8.47	42.4	22.4	15.0	300	398
		III	75.0	177	115	263	750	847

*Taken from reference 25

**See Figure 36 for grain-size distribution for each case



MOBILE BAY AREA

LOCATION MAP

SCALE

5 0 5 MI

PLATE 1

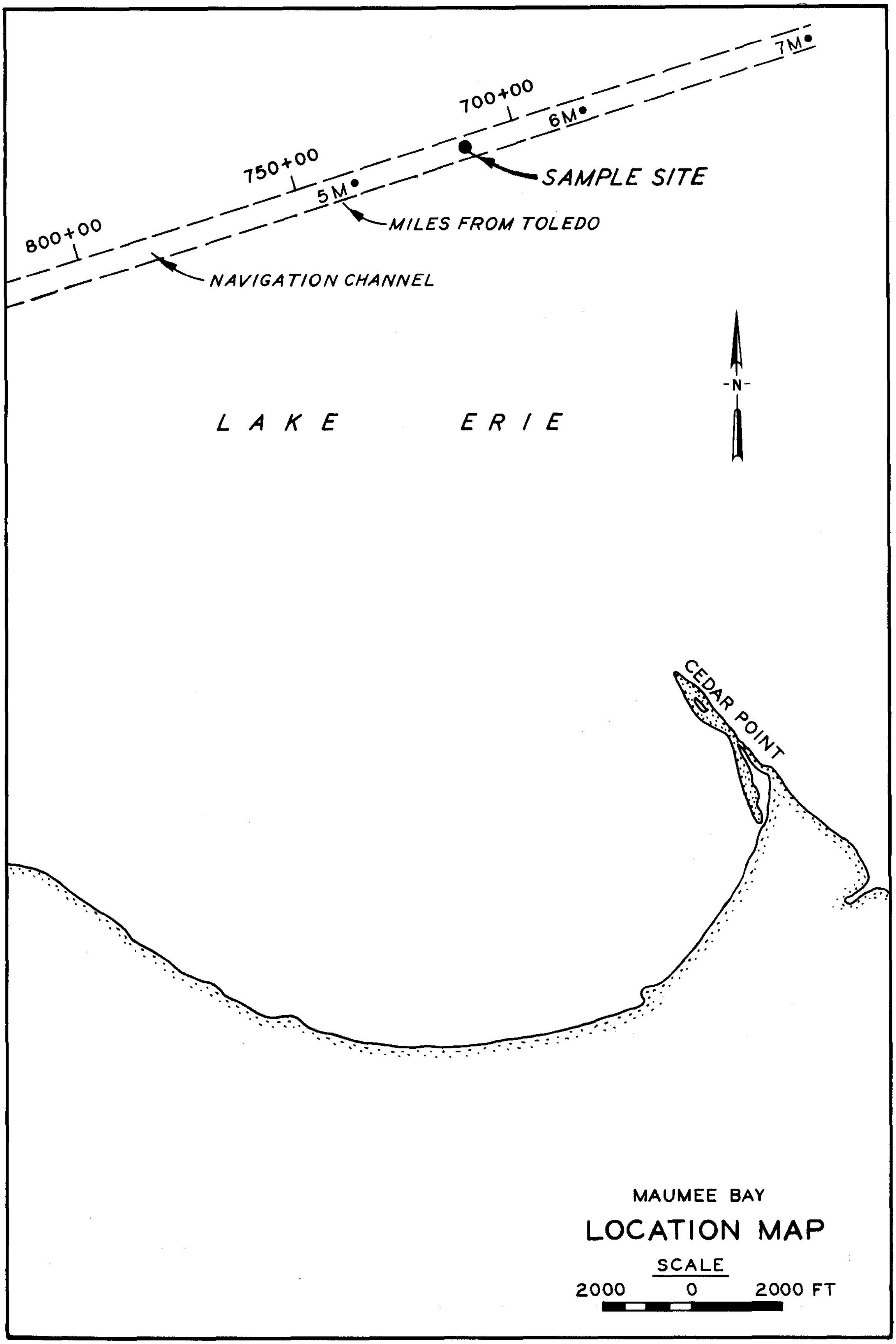
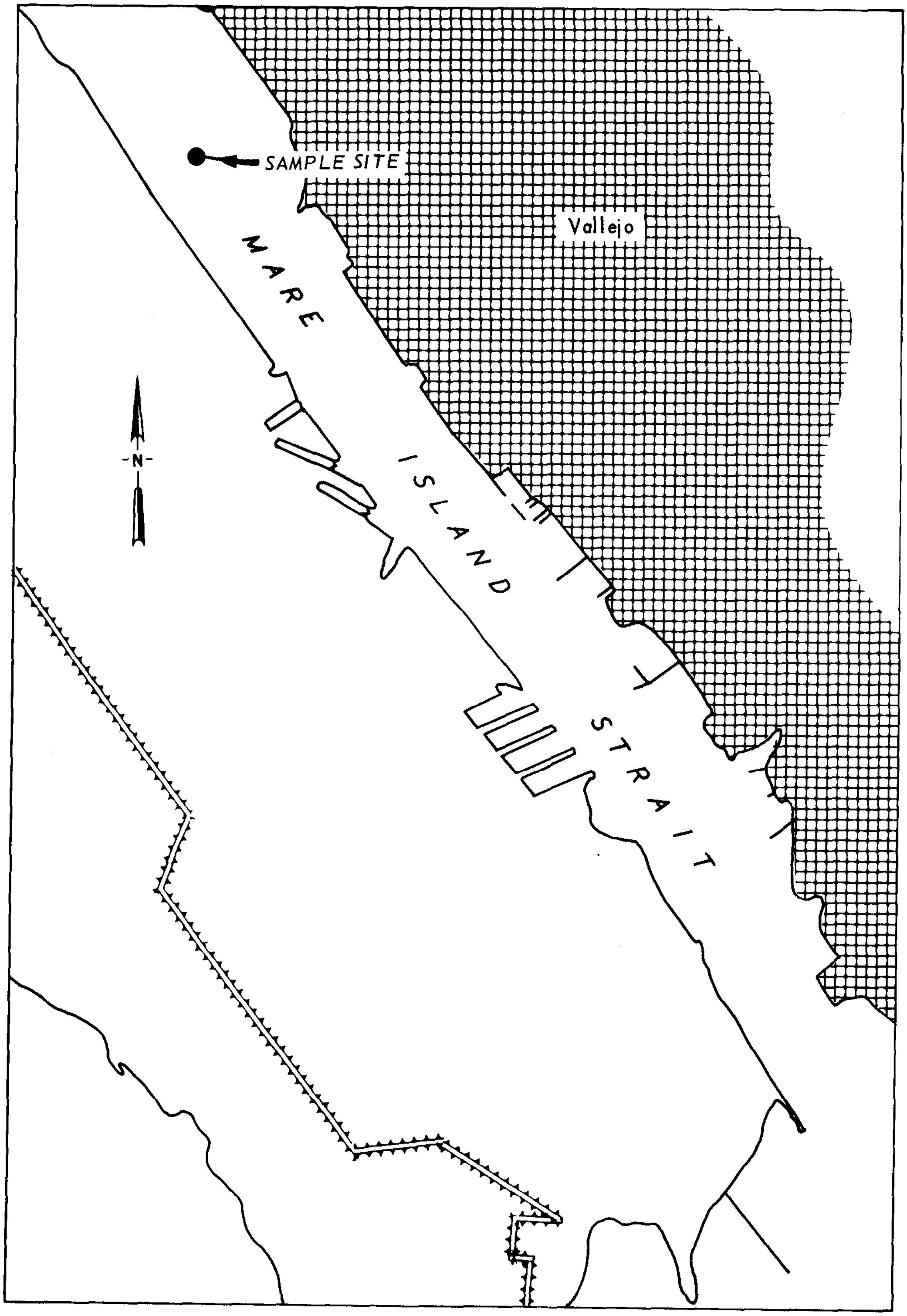

7M
700+00
6M
750+00
5M
SAMPLE SITE
MILES FROM TOLEDO
800+00
NAVIGATION CHANNEL
N
LAKE ERIE
CEDAR POINT
MAUMEE BAY
LOCATION MAP
SCALE
2000 0 2000 FT

PLATE 2



MARE ISLAND STRAIT

LOCATION MAP

SCALE

1000 0 1000 FT

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DMRP Work Unit No. 6B02.
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TA7.W34 no.D-76-2