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DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-39

LABORATORY STUDY OF CHEMICAL COAGULATION AS A MEANS OF TREATMENT FOR DREDGED MATERIAL

by

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1. The technical report transmitted herewith represents the results of one research effort initiated 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 evaluating physical, chemical, and/or biological methods for removing contaminants from dredged material.

2. In recent years, there has been continued concern about 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 became apparent during the planning phases of the DMRP that there could arise situations where it would be necessary to treat contaminated dredged material or the effluent discharged from containment areas before it could be returned to open water. Therefore, Task 6B was developed to meet this possible need.

3. Initial studies within Task 6B and other DMRP tasks indicated that most contaminants in effluents are associated with the solid phase of the material returned to the waterway. Therefore, if solids could be effectively removed from the effluent, most water-quality standards could be met. Other studies within Task 6B indicated that the use of chemical flocculants might be a viable method for improving the solids removal from the effluents of containment areas. The Environmental Engineering Program of the University of Southern California conducted a laboratory study under Work Unit 6B07, the first of two studies to evaluate the performance of flocculants and to develop guidelines for their use with dredging operations. The study, reported on herein, was designed to determine the effectiveness of flocculants under laboratory conditions. The second study, conducted under Work Unit 6B08 by the Environmental Engineering Division of the Waterways Experiment Station's Environmental Effects Laboratory and Jones, Edmunds and Associates, Inc., of Gainesville, Florida, was designed to apply the results of the laboratory study to the development of guidelines for the field application of flocculants.

4. The laboratory study found that conventional coagulants such as alum and ferric sulphate are unsuitable for use in the treatment of effluent from containment areas due to the large doses and pH control that are required to achieve acceptable effluent quality. There is also the problem of carryover of trace metals from these conventional coagulants. On the other hand, the study indicated that polymers can be effective in removing solids from the effluent. Rapid removal of solids and contaminants was observed immediately after flocculation. When a detention time of a few minutes is provided, the concentration of contaminants in the treated effluent can be drastically reduced from the parts-per-million range to the parts-per-billion range. Pertinent factors such as salinity and initial turbidity level were also studied in relation to the level of salinity and initial turbidity in the suspensions. A suspension with high salinity and low initial turbidity is easy to clarify because of rapid floc formation.

5. Methods were developed to provide a technique to screen the large number of polymers available on the market to narrow the number effective for use with specific sediments. Parameters of gross sediment content such as chemical oxygen demand, total organic carbon, and particle size of sediments were found to be well correlated with optimum dosage requirements. Therefore, these parameters should be useful in the initial selection of the optimum polymer dosage.

6. There is no significant difference in the physical properties of resettled sediments with and without polymer treatment in terms of plastic limit, liquid limit, and plasticity index. However, a slight increase in the coefficient of permeability for the polymer-treated sediments was observed. An assessment of long-term mobilization of chemical constituents from the polymer-flocculated particles was conducted to gain additional insight concerning the possibility of release of contaminants to the water column. In most cases the polymer-treated particles do not show any significant difference in release of contaminants from that of untreated samples.

7. As stated previously, the results of this study are being used to develop final guidelines for the use of flocculants to treat effluent from containment areas. The results of the study reported herein will be useful in determining the potential effectiveness of polymers for improving effluent quality from confined disposal areas.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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~~T~~trace metals, chlorinated hydrocarbons, and biostimulants which are found to be enriched in fine particulates of contaminated sediments. When different types of sediments are resuspended, it has been found that the extent of redissolution is very small. However, contaminants attached to the particulates can be transported along the waterways downstream from the disturbed areas. In confined areas, proper treatment and rapid removal of those suspended particulates (Continued) over

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~~20. ABSTRACT (Continued)~~

from the water column will not only lessen the oxygen demand, but will also reduce the input of contaminants into the receiving water. ←

With the exception of sandy types of sediments, total concentrations of trace metals and biostimulants from the resuspension of contaminated sediments after two hours of sedimentation (without any pretreatment) are mostly in the ppm range. In some cases, these concentrations may exceed the allowable discharged requirement imposed by regulatory agencies. In this study, extensive laboratory experiments were carried out to screen commercially available polymers and conventional coagulants, such as alum and ferric sulfate, for the removal of suspended particles. It has been found that these conventional coagulants are unsuitable for this use due to the large dosages (in the range of 30 to 40 ppm) and pH control that are required to achieve acceptable effluent quality. There is also the problem of carry-over of trace metals from these conventional coagulants. Furthermore, polymers affect pH to a minor extent, thereby eliminating the need for pH adjustment of the treated effluent.

Among fifty types of polymers evaluated in this study, some high molecular weight cationic polymers (such as Betz 1160 and Hercofloc 815.3 and 849) and anionic polymers (such as Calgon WT-3000 and Betz 1120) were found to be very effective for the treatment of the resuspensions tested in the laboratory. Rapid removal of contaminants was observed immediately after flocculation. When a detention time of a few minutes is provided, the concentration of contaminants in the treated effluent can be drastically reduced from the ppm range to the ppb range.

Pertinent factors such as salinity and initial turbidity level of resuspensions were also studied in relation to the optimum dosage of Betz 1160 polymer. It was found that the optimum dosage of a polymer is closely related to the level of salinity and initial turbidity in the resuspensions. A suspension with high salinity and low initial turbidity usually requires less polymer. However, a suspension with higher turbidity is easier to clarify; i.e., fast floc formation.

Parameters of gross sediment content such as COD, TOC, and particle size of sediments <5 μm were also found to be well correlated with optimum dosage requirements of Calgon WT-3000, a high molecular anionic polymer. Correlation coefficients of 0.93, 0.95, and 0.97, respectively, were found in this study. Therefore, parameters of contaminated sediment content such as TOC, COD, and particle size of sediments <5 μm could be useful in the initial selection of the optimum polymer dosage.

There is no significant difference in the physical properties of resettled sediments with and without polymer treatment in terms of plastic limit, liquid limit, and plasticity index. However, there is a slight increase in the coefficient of permeability for polymer-treated sediments.

An assessment of long-term mobilization of chemical constituents from polymer-flocculated particles was also conducted to gain additional insight concerning the possibility of release of contaminants to the water column. In most cases, the polymer-treated particles do not show a significant difference in the release of contaminants and stimulants from that of the untreated sample.

PREFACE

The work described in this report was performed under Contract No. DACW39-76-C-0039, entitled, "Flocculation as a Means for Water Quality Improvement from Disposal of Dredged Material in Confined Areas," dated December 1, 1975, between the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, and the University of Southern California, Los Angeles, California. The research was sponsored by the Environmental Effects Laboratory (EEL), WES, under the Dredged Material Research Program (DMRP) Work Unit 6B07. The study was part of DMRP Task 6B, "Treatment of Contaminated Dredged Material," of the Disposal Operations Project (DOP).

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This report is the result of experimental work performed to evaluate the effectiveness of various flocculants in separating suspended particulates and associated chemical constituents from water columns to reduce the discharge of contaminants to receiving waters from disposal of dredged materials in confined areas.

The research was conducted under the supervision of Dr. Kenneth Y. Chen, Director, Environmental Engineering Program, USC. This report was a basis for the dissertation of Dr. Chun-Chiang Wang, who performed most of the laboratory and data analysis. Individuals who contributed to different portions of the laboratory operations were: George [illegible], Lata [illegible], Jeffrey Stone, Tzu-Pei [illegible], and Mark Montgomery. The editorial assistance of Bert [illegible] is greatly appreciated.

The contract was monitored by Mr. Thomas K. Moore, Manager of Task 6B, and Mr. Daniel E. Averett, EEL, under the direct supervision of Mr. Charles C. Calhoun, Jr., Manager, DOP, and the general supervision of Dr. John Harrison, Chief, Environmental Effects Laboratory, WES. The Contracting Officer was [illegible] J. Stoltzman.

The Directors of WES during the study and preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. The Technical Director was Mr. F. R. Brown.

PREFACE

The work described in this report was performed under Contract No. DACW39-76-C-0038, entitled, "Flocculation as a Means for Water Quality Improvement from Disposal of Dredged Material in Confined Areas," dated December 31, 1975, between the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, and the University of Southern California, Los Angeles, California. The research was sponsored by the Environmental Effects Laboratory (EEL), WES, under the Dredged Material Research Program (DMRP) Work Unit 6B07. The study was part of DMRP Task 6B, "Treatment of Contaminated Dredged Material," of the Disposal Operations Project (DOP).

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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
microns	0.000001	meters
inches	25.4	millimeters
feet	0.3048	meters
miles (U.S. statute)	1.609344	kilometers
square feet	0.09290304	square meters
cubic yards	0.7645549	cubic meters
acres	4046.856	square meters
gallons	3.785412	cubic decimeters
pounds (force) per square inch	6.894757	kilopascals
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
centipoises	0.001	pascal-seconds

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* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

LIST OF NOTATIONS

Technical Terms

Chemical oxygen demand	COD
Double distilled (water)	D.D.
Dissolved oxygen	D.O.
Heated graphite atomizer	HGA
Immediate dissolved oxygen demand	IDOD
Moisture content	M.C.
Nephelometric turbidity units	NTU
Polychlorinated biphenyls	PCB's
Total dissolved sulfide	$\Sigma S(-II)$
Total Kjeldahl nitrogen	TKN
Total organic carbon	TOC
Total volatile solids	TVS

SUMMARY

Trace metals, chlorinated hydrocarbons and biostimulants are found to be enriched in fine particulates of contaminated sediments. When different types of sediments are resuspended, it has been found that the extent of redissolution is very small. However, contaminants attached to the particulates can be transported along the waterways downstream from the disturbed areas. In confined areas, proper treatment and rapid removal of those suspended particulates from the water column will not only lessen the oxygen demand, but will also reduce the input of contaminants into the receiving water.

With the exception of sandy types of sediments, total concentrations of trace metals and biostimulants from the resuspension of contaminated sediments after two hours of sedimentation (without any pre-treatment) are mostly in the ppm range. In some cases these concentrations may exceed the allowable discharged requirement imposed by regulatory agencies. In this study, extensive laboratory experiments were carried out to screen commercially available polymers and conventional coagulants, such as alum and ferric sulfate, for the removal of suspended particles. It has been found that these conventional coagulants are unsuitable for this use due to the large dosages (in the range of 30 to 40 ppm) and pH control that are required to achieve acceptable effluent quality. There is also the problem of carry-over of trace metals from these conventional coagulants. Furthermore, polymers affect pH to a minor extent, thereby eliminating the need for pH adjustment of the treated effluent.

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Pertinent factors such as salinity and initial turbidity level of resuspensions were also studied in relation to the optimum dosage of Betz 1160 polymer. It was found that the optimum dosage of a polymer is closely related to the level of salinity and initial turbidity in the resuspensions. A suspension with high salinity and low initial turbidity usually requires less polymer. However, a suspension with higher turbidity is easier to clarify; i.e., fast floc formation.

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An assessment of long-term mobilization of chemical constituents from polymer-flocculated particles was also conducted to gain additional insight concerning the possibility of release of contaminants to the water column. In most cases, the polymer-treated particles do not show a significant difference in the release of contaminants and stimulants from that of the untreated sample.

LABORATORY STUDY OF CHEMICAL COAGULATION AS A MEANS OF TREATMENT FOR DREDGED MATERIAL

PART I: INTRODUCTION

Need for Corps Research

1. The disposal of dredged material in upland disposal areas or in enclosed dike areas has increased in recent years. A common problem associated with such a practice is the possibility of discharge of contaminant-laden effluents into the receiving waters.

2. The need for the deposition of dredged material in confined areas may arise primarily from the lack of satisfactory alternatives; it may also arise from the need for the creation of new land or other productive use.

3. Prior to 1970, most dredged material was deposited in open waters at selected disposal areas located sufficiently near the dredging sites to minimize dredging costs, but far enough away to avoid interference with other beneficial uses of the water body. In recent years, however, because of the concern for the protection of the aquatic habitat and water quality, the practice of open-water disposal of dredged material has been reduced drastically.

4. Recent studies on the release of soluble trace contaminants during open-water disposal have demonstrated that the dissolution reaction is negligible (Chen, et al., 1976; May, 1973; and Windom, 1972). In most cases, the majority of contaminants are associated with suspended particulates. Therefore, the removal of the particulate fraction should result in a significant reduction of the contaminant load into the receiving waters.

5. This study is directed towards improving the quality of effluents from contaminated dredged material in confined disposal areas by reducing the concentration of suspended

particulates in the effluent.

6. Dredged material disposal in confined areas will result in the overflow of the effluent to nearby waterways. If contaminant levels in the effluent are high and there is lack of sufficient dilution, this practice could be detrimental in localized areas. Most of the trace contaminants associated with dredged material (especially in the colloidal particle size range) would be present in the effluent that could possibly enter the most sensitive areas of a water body; for example, the nearshore waters in which larval forms may be present. These are areas with relatively lower mixing than open waters, where, generally, the contaminants are rapidly dispersed. Therefore, in the disposal of contaminated dredged material in a confined area, effluent quality should be considered.

7. The current method of treating dredged material within a confined area consists principally of the deposition of material within an earthen basin. The purpose is to obtain good separation of solid and liquid fractions and subsequent discharge of the liquid. Such a procedure can effectively prevent the contaminated sediments, if any, from reaching the receiving waters.

Relationship of Dredging Operations to the Problem

8. The amount of turbidity or suspended solids resulting from the disposal of dredged material is relatively small in comparison with that generated from natural erosion, resuspension, and wastewater discharge. However, due to the highly localized nature of confined disposal, the potential environmental impact cannot be overlooked.

9. During hydraulic dredging and subsequent discharge into the confined area, sediment and water are vigorously intermingled before discharge. During this process the fine-grained sediment may be resuspended. While the extent of

redissolution is very small, contaminants attached to the particles can be transported by the effluent to the receiving waters. The ecological significance of these particles cannot be well defined at present. Nevertheless, trace metals and chlorinated hydrocarbons associated with suspended particles, including macromolecular organic complexes, may pose some problems due to the possible biological uptake.

10. At present, there is no specific numeric standard on a national basis regulating effluent discharge from a confined disposal area. The California State Water Resources Control Board promulgated an ocean water plan with specific numeric limitations for the discharge of sewage effluents in 1972 (CSWRCB, 1972); however, the plan does not apply to dredging operations. The standard for sewage effluent is based on a dilution ratio of sewage to seawater of 1:100. It is not known whether such a dilution is attainable in the situation of confined disposal under most circumstances.

11. Table 1 lists several effluent quality standards of 1973 (Murphy and Zeigler, 1974) and 1975 (Krizek, et al., 1976) adopted for the operation of various dredging activities. Interim guidelines were imposed by the EPA (1975) to govern discharge of dredged or fill material into navigable waters. An interagency manual to be prepared by the U.S. Army Corps of Engineers and the Environmental Protection Agency will define tests, procedures, etc., necessary to evaluate such discharges.

12. The resuspension of fine particles will result from the disturbance of sediments through dredging operations. Since most water quality standards do not differentiate between soluble and particulate fractions, disposal operations involving contaminated dredged material would either require a long detention time or treatment in order to meet the effluent water quality standards.

13. In addition, a large fraction of trace metals in dredged material is in the form of insoluble sulfides. Upon

resuspension of sediments in aerated water, the effects of oxidation and dilution will solubilize a certain amount of trace metals (Lu, 1976). Rapid removal of suspended particulates from water columns will lessen the oxygen demand and reduce the total input of trace metals into the receiving waters.

Objectives of the Study

14. The purpose of this study was to evaluate effective means for the reduction of contaminants in effluent discharged from confined disposal areas. Specifically:

a. To investigate the effectiveness of various flocculants (both conventional coagulants and polyelectrolytes) for the removal of fine-sized fractions of dredged material which are likely to remain in suspension, and to determine the optimum dosage required for adequate flocculation of the fines. The effectiveness of each flocculant is determined from the settling characteristics of flocculated particles and residual turbidity of the effluent.

b. To correlate the characteristics of sediments with the type and dosage of flocculants. All of the sediment samples used in this study are characterized in terms of total organic carbon content (TOC), grain-size distribution, total organic nitrogen, trace metals concentration, chlorinated hydrocarbons, sulfide, total phosphorus, and salinity. The correlation of sediment characteristics with treatment requirements will provide some guidelines in the preliminary selection of type and dosage of flocculants.

c. To evaluate the removal efficiency of trace contaminants and nutrients in water columns with and without polymer treatment. Sediment-water mixtures are treated with optimum dosage of polymer. The removal efficiency of trace contaminants and nutrients is evaluated at different time periods in comparison with a control column. The behavior of flocculated particles and the efficiency of pollutant removal by selected polymers are evaluated.

d. To evaluate the treatment of effluents with turbidity levels higher than 1000 nephelometric turbidity units. In small-size disposal areas, retention times are usually short and high turbidity effluents may result. Flocculation with a higher polymer dosage may be needed to treat these supernatants.

e. To assess the distribution of trace metals, nitrogen and phosphorus species, as well as total organic carbon at different depths of the settling columns. Concentration of trace metals, different forms of phosphorus and nitrogen, as well as organic carbon in different sizes of sediments need to be examined to evaluate the removal potential by sedimentation alone.

f. To compare the characteristics of flocculated sediments vs. resettled sediments. Flocculation provides for the agglomeration of fine particles into bigger flocs. The grain-size distribution for the polymer-treated and untreated sediments are evaluated. The "percentage of flocculation" at various particle sizes is calculated to evaluate the effectiveness of the polymer in flocculating the sediment slurries. For the purpose of evaluating the effectiveness of flocculation, the falling-head method is used to determine the coefficient of permeability of treated and untreated sediments.

g. To study the effect of salinity on the treatment of supernatants. Ionic strength has significant effects on the flocculation process. Effluents with different salinities may be encountered in the confined disposal of dredged material. Different solid concentrations at different salinity levels are evaluated to determine the optimum polymer dosage and corresponding residual turbidity. Correlations between the optimum dosage of specific polymers and salinity levels are expected.

h. To study the possibility of leaching contaminants from flocculated sediments. Flocculation and sedimentation of suspended particles within the disposal area will concentrate contaminants in surface layers of the resettled sediments or in relatively small areas. In many instances, the resettled sediment will remain in contact with the supernatant for a long period of time. An assessment of long-term mobilization of chemical constituents from flocculated sediments is needed to gain additional insight concerning the possibility of the release of contaminants to the water column after suspended particulates are flocculated.

PART II: LITERATURE REVIEW

Treatment of Dredged Material

15. Although the research effort expended on the effectiveness of various flocculants for treatment of dredged material is limited, results of some field studies are available.

16. In a Delaware River study (U.S. Army Corps of Engineers, Philadelphia District, 1969), analysis of suspended solids in Delaware River dredged sediments revealed that 10% (by weight) were organic matter. The remaining 90% passed through a 200 mesh screen (0.74 mm), and 30% were finer than 0.001 mm. The settling rate of suspended solids finer than 0.001 mm (colloidal range) is very slow, e.g., the settling velocity of a 0.001-mm-diameter discrete particle, as computed by Stokes' Law, is approximately 0.003 m/hr.

17. Laboratory and field tests directed towards improving the sedimentation of dredged mixtures in hopper dredges by the addition of chemical precipitants, polyelectrolytes, and ion exchange were conducted by Dow Chemical Co., Rohm and Haas Co., Drew Chemical Co., and Rutgers University. However, none of the additives evaluated showed any significant improvements in settling rates (U.S. Army Corps of Engineers, Philadelphia District, 1969).

18. In a San Francisco Bay Area study (U.S. Army Corps of Engineers, Portland District, 1973), flocculants were tested to study their effectiveness in increasing the sedimentation of dredged material in hoppers. The dredging areas chosen in this study were high in silt materials. In connection with this study, laboratory tests of hopper samples with coagulants were conducted by the Calgon Corporation. The results showed that the addition of 0.56 ppm Calgon Coagulant Aid #225, a cationic polymer, gave a settled volume of 136 ml in five minutes (jar test), compared with an untreated set-

tled volume of 60 ml in five minutes.

19. Onboard hopper tests were also conducted in the San Francisco Bay Area study. In the Mare Island strait area, aboard the hopper dredge, BIDDLE, the addition of 2.5 ppm and 5 ppm of Calgon Coagulant Aid #225 to the hopper dredged slurry increased the sediment retention rate by 19.8 yd^3 and 41.4 yd^3 per pumping minute, respectively. The average retention rate without polymer treatment was 135 yd^3 per pumping minute.

20. A second test aboard the dredge, HARDING, was performed at three locations in the San Francisco Bay Area, viz., the Mare Island Strait, Alameda, and Point Molante. Calgon Coagulant Aid #225, diluted with seawater from the sanitation lines on the dredge, was added to the dredged slurry on the suction side of each pump. With a polymer dosage up to 4 ppm, no significant improvement in settling rates was observed. Failure to increase the settling rates in this study has been attributed to inadequate mixing between flocculant and slurry; however, standard jar tests on grab samples from each test location also showed little effect in improving the settling rates.

21. The effectiveness of flocculants in treating: (a) dredged slurry within the hopper bin; (b) overflows from hopper dredges; and (c) suspended solids in effluent at on-shore disposal operations was studied in the Great Lakes area (U.S. Army Corps of Engineers, Buffalo District). For the treatment of dredged slurry within the hopper bin, Dow Chemical Purifloc C-31 and Separan AP-23 polymers were evaluated. Polymer was added through the intake pipe to facilitate the mixing of flocculant and dredged slurry before spilling into the hopper bin. The direct spraying of coagulants into the hopper during filling operations was also performed. Neither method produced significant improvement in settling rates.

22. For the treatment of overflows from hopper dredges, the optimal concentrations of Dow Chemical Separan AP-273

and Purifloc C-31 were applied from a perforated 2-inch pipe above the overflow discharge trough. The suspended solids and turbidities were significantly reduced. There were also reductions in ortho-phosphates.

23. For the treatment of suspended solids in effluents at onshore disposal operations, the study was divided into two portions; optimal application of flocculants was determined from laboratory testing of samples obtained from the Pennsylvania disposal area, followed by in-situ treatment at the Riverside disposal area.

24. Samples of effluents from the Pennsylvania disposal area were taken at different time periods after the cessation of pumping operations. Various concentrations of Purifloc C-31 and Separan AP-273 polymers combined with other chemicals such as clay, alum, and $FeCl_3$ at various pH levels were tested to determine optimal dosage. Separan AP-273 was not effective in reducing turbidity. The effectiveness of Purifloc C-31 in reducing turbidity in combination with other chemicals is summarized as follows:

a. additions of caustic chemicals were detrimental;

b. additions of acid were helpful;

c. additions of hectorite clay were very beneficial;

d. ferric chloride induced floc was light and settled slowly;

e. ferric chloride combined with Purifloc C-31 yielded a 99% suspended solid removal. The use of Dow Chemical Purifloc C-31 without chemical addition reduced the turbidity level from 1500 to 70 JTU units.

25. In-situ treatment at the Riverside disposal area was conducted by diking a 1.9-acre part of the disposal area to provide a clarification pond. The supernatant from the main area was discharged into this area through a 250-foot-long corrugated metal trough in which mixing of the flocculant and effluent occurred. The chemical dosages used in the

treatment were 33 ppm of $FeCl_3$ and 7.5 ppm of Purifloc C-31. This procedure reduced the turbidity from 130 to 30-40 JTU. Suspended solids were reduced from 60 mg/l to 10-25 mg/l; phosphates decreased from 0.16 to 0.10 mg/l.

26. The Dow Chemical Company (1969) performed a study to evaluate the use of synthetic polymers for the treatment of effluent from an unidentified dike disposal area. The results showed that the most effective coagulation was accomplished with ferric chloride and Dow Polymer Purifloc C-31.

27. Betz Laboratories (Gerstemeier and Quinn, 1974) studied the effectiveness of Betz 1130 flocculant (highly anionic acrylamide copolymer). Testing was carried out in conjunction with the Georgia Department of Transportation. Dredged material from the South Brunswick River was utilized as fill material for a highway construction project. A comparison of treated vs. untreated samples showed that the use of Betz 1130 polymer significantly increased the settling rate. As a result, the water quality of effluent discharged to the Brunswick River was improved. There were also indications that less water and more solids remained in the landfill when flocculants were used. The testing period, however, was not sufficient to obtain statistical evidence to substantiate these preliminary results.

Synthetic Polyelectrolytes: Flocculation Mechanisms

28. Synthetic polymers have the characteristics of polymers and electrolytes; they have been called "polymeric electrolytes" or "polyelectrolytes".

29. A polyelectrolyte is a molecule with a high molecular weight, ranging on the order of 50,000 to several million. Molecular weights of this order result in a thread-like particle whose greatest dimension, its length, can be measured in terms of a fraction of a micron to as much as 10μ.

30. Synthetic polyelectrolytes generally are classified according to the charges on substituent groups along the polymer backbone. They may be cationic, anionic, or nonionic. Polymers with negative charges are termed anionic; positive charges are cationic; and if no charge is associated with polymers, they are called nonionic. The charges which develop on the polymers are due to ionization of certain groups extending from the chain at specific sites.

31. Because of the great variety of monomers available as starting material and the additional varieties that can be obtained by varying the molecular weight, charge, density, and ionizable groups, there is a great assortment of polyelectrolytes available.

32. Michaels (1954) suggested that the most effective polyanionic polymers contain a mixture of ionic and unionized hydrophilic groups. The ionized groups keep the polymer in an extended position; this leads to particle bridging and flocculation.

33. Most soils and finely divided solids carry a negative charge in an essentially neutral aqueous environment. Therefore, cationic polyelectrolytes would be effective flocculants for such systems as suggested by Hedrick and Mowry (1952); Michaels and Lambe (1953); and Ruehrwein and Ward (1952).

34. Simha, et al. (1954) and Frisch (1954 and 1955) have developed a theoretical model of polymer adsorption, in which the polymer molecule is attached to the adsorbent surface by a fraction of the total number of segments comprising the polymer chain, while pendent loops extend into the solution. As the fraction of attached segments is reduced, the Simha and Frisch adsorption isotherm approaches the well-known Langmuir isotherm. When the polymer molecule is attached to the adsorbent surface by only one segment, it becomes identical with the Langmuirian model.

35. Ruehrwein and Ward (1952) were the first investigators to propose a polymer-bridging mechanism for the flocculation of highly concentrated clay suspensions. Later, LaMer and Healy (1963) developed a mathematical model for this mechanism.

36. The bridging theory postulates that polymer molecules attach themselves to the surface of the suspended particles at one or more adsorption sites, and that part of the chain extends out into the bulk of the solution. When these extended chain segments make contact with vacant adsorption sites on other suspended solids, bridges are formed.

37. The particles are thus bound into small packets which can grow to a size limited only by the shear gradient imposed by the degree of agitation in the system and the amount of polymer initially adsorbed upon the surfaces of the particles. If too many adsorption sites are occupied by polymer segments, bridging will be completely inhibited. Conversely, if too few adsorption sites are occupied, the bridging may be too weak to withstand the shearing forces imposed by the condition of agitation.

38. The attachment of the polymer molecule to the adsorbent surface may occur by chemical or physical attractions, depending upon the characteristics of the polymer chain and adsorbent surface.

39. For cationic polymers, Ruehrwein and Ward (1952) and Olphen (1963) have suggested that the polymer molecule is adsorbed on the faces of the clay particulate via cation-exchange mechanism.

40. The adsorption of anionic polymers by clay particles has been studied by Michaels (1954); Michaels and Morelos (1955); Mortensen (1961); and Holmes and Toth (1957). The adsorption mechanism is considered to be either hydrogen bonding, anion exchange, or chemical reaction with cations on the clay surface. Mortensen (1961) has also shown that anions in

the solution compete with polymeric anions for adsorption sites on the clay particle.

41. Warkentin and Miller (1958) have demonstrated that the configuration of the polymer molecule at the liquid-solid interface can influence the bridging action of the polymer and the long-chain anionic polymers can remove turbidity more effectively than can short-chain polymers of the same degree of hydrolysis.

42. Mortensen (1959) discovered that the adsorption of anionic polymers on kaolinite clay increased with sodium chloride concentration of the suspension. Increase in ionic strength generally promotes particle destabilization and would promote coagulation and subsequent flocculation by polymers.

43. Studies involving the adsorption of the nonionic polymers onto negatively charged surfaces are few in number. Fontana (1963) has studied the adsorption of a copolymer of ethylene oxide onto silica surfaces and has shown by infrared techniques that a sizeable fraction of polymer segments were attached to the silica surface via hydrogen bonding of the other oxygen atoms in the polymer chain to the silanol groups on the silica surface. A hydrogen bonding mechanism has also been invoked by Howard and McConnel (1967) to explain the adsorption of polyethylene oxide onto silica surfaces from various types of solvents. Birkner and Edzwald (1969) have studied the flocculation of dilute clay suspensions with nonionic polymers and concluded that a polymer bridging mechanism could possibly be invoked to explain the polymers' role in the destabilization reaction.

PART III: EXPERIMENTAL

Collection of Sediment and Water Samples

44. Sediment and water samples were collected by personnel from the U.S. Army Engineer Waterways Experiment Station from active dredging areas. Samples were sealed in 4-gallon polyethylene pails and bottles. These samples were packed in ice chests and transported by aircargo to the Los Angeles International Airport and immediately picked up by personnel from U.S.C. Environmental Engineering program.

45. All sediment and water samples were stored in a constant-temperature, constant-humidity chamber. Because of possible changes in the sediment characteristics during storage due to chemical and biological activities, all samples for a given series of tests were taken from the storage chamber and processed at the same time, including the untreated blank samples for control purposes. Because freezing may disrupt the physical structure of the sediment and drastically change its settling characteristics, sediment samples were not frozen at any time.

46. Seawater used in this study was collected from a chosen reference station about three miles outside the breakwater of Los Angeles Harbor (33°41.5'N, 118°14.5'W), in 4-gallon polyethylene containers which were thoroughly precleaned with acid and rinsed with demineralized, glass-distilled water.

Reagents, Apparatus, and Sample Treatment

47. Due to the very low levels of trace metals in the seawater background, meticulous cleaning procedures and high-purity reagents were used to eliminate all possible losses and contamination.

48. No glassware was used in this study for metal analysis. All containers were made of Teflon, quartz, polypropylene, and polyethylene materials (Robertson, 1968; NSF, 1973; Struempler, 1973; King, et al., 1974).

49. A demineralization and double-distillation unit was used to produce water suitable for this study. The demineralized, glass-distilled water was regularly extracted for analysis of trace metals to insure the absence of contaminants.

50. All labware was soaked in 5% acid for several days, followed by soaking in demineralized-redistilled water for several days, and then rinsed several times with high quality double-distilled water. All reagents were of the highest quality obtainable; for example, ultrapurified acid and double-distilled methyl isobutyl ketone.

51. Because a 0.45 μm membrane filter is not effective in removing some particulates (Gibbs, 1973; Chen and Wang, 1974), a 0.05 μm membrane filter was used for the separation of soluble and particulate fractions. The filter paper was soaked in 5~10% ultrapurified nitric acid for two days and then rinsed several times with demineralized-redistilled water before use.

52. A syringe pressurized filtration technique and glove bag setup were used to keep air away from the sample. Caution was used to prevent possible water-soluble contributions from the membrane filters by discarding the first few ml of filtrate (Robertson, 1968; Burrel and Gunnerwood, 1969; Rattonetti, 1974).

Preparation of Polymers

53. The polymer product, in general, is available in various forms according to its function (nonionic, anionic, or cationic) and molecular weight. Ease of preparing the stock solution should be considered an important parameter in

selecting a suitable polymer for any particular application.

54. Solutions of dry powder polymers are required for effective application. However, these long-chain polymers are difficult to dissolve; if care is not exercised in solution preparation, problems of incompletely dispersed, jelly-like agglomerates will result. Stock solutions of powder form polymers were prepared by slowly adding the polymer to water.

55. The exact molecular weights of polyelectrolytes such as those used in this study are extremely difficult to determine. However, it is believed that all powder polymers and many liquid polymers have molecular weights of 3,000,000 or higher. There are several basic variables that influence the performance of these polymers. The most important ones are: ionic character, level of ionic function, molecular weight, and molecular linearity.

56. Solutions of high ionic strength will decrease the solubility of polyelectrolytes. Therefore, the effectiveness of polyelectrolyte solutions will be diminished if high ionic strength water is used to prepare stock solutions of these polyelectrolytes. The procedures used are described as follows.

Powder form polymer

57. Place 1000 ml of deionized-redistilled water in a 1-liter beaker. Agitate the water to create a distinct water vortex in the beaker using a magnetic stirrer. Very slowly transfer a 10-g sample of powder polymer into this water vortex. Increase the mixer speed to maintain the water vortex during dry-powder addition. Allow the hydrated sample to stir at a moderate speed for a specific time as shown in Appendix A. If maximum viscosity and maximum flocculating efficiency are desired, violent agitation during the dissolving process should be avoided. Because some polymers deteriorate with age, the 1% stock solution was useful for only limited

periods of time and was discarded after one week.

58. In general, several hours of mixing were required to dissolve powder flocculants. Higher temperatures can hasten the dispersion of polyelectrolytes; however, temperatures above 120°F are not recommended. The difficulty in dissolving the powder polymers might present some problems in field operations and therefore reduce their use as primary coagulants.

Liquid form polymer

59. A 10% stock solution was prepared in a beaker with a magnetic stirrer similar to that used to dissolve the powder polymer.

60. The stock solutions (prepared from both powder and liquid form polymer) were then further diluted to a final concentration of 0.1% and used throughout the study.

61. Liquid polymers furnished by manufacturers, in general, present no mixing problems. The molecular weight of anionic flocculants is generally the highest, followed by nonionic polymers, and finally cationic polymers. Anionic reagent solutions are, consequently, more viscous for the same weight percent solutions.

Particle Size Distribution

62. Particle sizing by vacuum membrane filtration method may be inaccurate due to clogging (Faisst, 1976). Therefore, the pipette method (Royse, 1970) was used in this study.

63. All the dredged material used in this study was analyzed for textural composition. The sediments were thoroughly mixed and dispersed in deionized-redistilled water and then separated into five fractions: Larger than 62.5 μm, 4 to 6 μm, 2 to 4 μm, 0.5 to 2 μm, and smaller than 0.5 μm by pipette method (Royse, 1970). Percentages of sand, silt, and clay material were calculated (Table 4).

64. Since the addition of a dispersing agent (sodium hexametaphosphate) to dredged sediment can break up flocculated clay particles, the resulting grain-size distributions are not representative of the true particle size of the materials that are pumped into a disposal area. Therefore, no dispersing agent was used in this study.

65. Representative samples were collected from: (a) Anchorage Basin in the Cape Fear River Mouth, Wilmington, North Carolina; (b) James River, Richmond, Virginia; (c) Calcasieu River, Louisiana; and (d) Mobile Bay, Alabama. The distribution of trace metals and biostimulants in various size fractions was determined for each sample.

Jar Test Experiment for Sediment Slurries

66. No two dredged material samples are exactly alike nor do they contain the same contaminants. Therefore, no single prescription of coagulant can be expected to perform satisfactorily in the treatment of different dredged materials. A jar test is the easiest means of selecting the treatment process most likely to overcome the problems needing correction (Black, et.al., 1957; Cohen, 1957; Griffith and Williams, 1972; Kawamura, 1976). When properly carried out, the jar test gives a systematic comparision between the "control sample" and the use of specific coagulants at various concentrations.

67. The jar test was performed using a multiple stirring apparatus, equipped with 1" by 3" stirrers and a variable speed mixing control, at room temperature.

68. A mixture of sediment and seawater was placed in a 1-liter beaker. A total of six 1-liter beakers were placed on the mixing stand. One mixture served as a control with no polymer added; the rest were subjected to different dosages of the same polymer.

69. The sediment-seawater slurries were homogenized by mixing at approximately 80 rpm for five minutes. Rapid and uniform coagulant dispersion is required for maximum turbidity removal (Griffith and Williams, 1972). The desired polymer dosage in the form of a 0.1 percent polymer solution was poured into the mixtures simultaneously and mixed for five minutes at 100 rpm. The rate of mixing was then reduced to 20 rpm and mixing continued for 20 minutes more.

70. The stirring mechanism was removed from the beakers and the particles were allowed to settle for 10 minutes. In order to observe the settling characteristics of the flocculated particulates, the floc levels were measured at the beginning of slow mixing and at the end of both slow mixing and settling.

71. Samples for turbidity measurements were removed at 5 cm below the liquid surface, in 5-ml increments, withdrawn with a pipette from beakers 1 through 6, then in reverse order from 6 back to 1, until 25 ml from each beaker was obtained.

72. Following collection of samples, turbidity measurements were immediately taken with a Hach 2100A Turbidimeter previously calibrated against a standard turbidity suspension.

73. In every jar test series, one blank sample (control sample) was evaluated in conjunction with samples of the same material treated with varying amounts of polymers. Due to the difficulties in obtaining representative samples, and possible changes due to chemical and biological activities during storage, the properties of a particular material were not necessarily identical for different test series performed at different time periods. Therefore, a "control" blank sample was used as a reference point for each test series.

74. The optimum polymer dosage was selected on the basis of turbidity removal compared with the blank.

Turbidity-Mass Concentration (s.s.) Study

75. In the routine laboratory monitoring of water quality, the determination of suspended solids is time consuming and impractical. Turbidity is strictly an optical property of the medium and bears little direct relationship to the concentration of the suspended particulates (McCluney, 1975). However, the value of turbidity measurements in water quality monitoring would be enhanced if a relationship between turbidity and concentration of suspended materials for specific sediments could be established.

76. Turbidity was used as a primary water quality parameter throughout this study in the evaluation of the effectiveness of polymer flocculation. Therefore, an effort was made to develop a correlation between turbidity and mass concentration for the Mobile Bay sediment slurry used in this study.

77. The following procedures were followed to obtain data for suspensions of Mobile Bay sediment in deionized-redistilled water.

a. 150 g of Mobile Bay sediment was transferred to a 4-liter, 3" I.D., plexiglass cylinder.

b. The cylinder was then shaken vigorously for 5 minutes to ensure the homogeneity of the slurry.

c. The sediment was allowed to settle for a specific time.

d. 200 ml of the suspension was removed at different depths.

e. The mass concentration of the suspended solids was obtained for each sample (retained on 0.05 μm filter).

f. The particle size distribution of the suspended solids in each sample was calculated.

g. The turbidity of each sample at consecutive dilutions was determined using a Hach 2100A laboratory turbidimeter.

Zone Settling Velocity Studies

78. All zone settling tests, in which the particles or aggregates settle as a blanket with a distinct interface between the settling slurry and the clarified supernatant, were performed in 1000-ml cylinders (approximately 14 inches high).

79. Representative sediment samples were mixed with waters of varying salinity. Two different slurries with sediment/water ratios of 1 to 4 to simulate dredged material slurry and 1 to 10 to simulate effluent from containment areas were prepared. Before the flocculant was added, the slurries were homogeneously dispersed by manually inverting the cylinder 30 times in two minutes.

80. The optimum dosage of polymer (derived from previous standard jar test) was put into a series of cylinders in which a different number of invertings was performed to determine the best turbidity removal and fastest zone settling velocity.

81. After the flocculant and slurry were mixed, the cylinder was placed in front of a lighted panel where the interface height was measured at different time intervals. A 25-ml sample was removed by pipette at 2 inches below the surface of the supernatant liquid at different time intervals. The turbidity of the sample was then determined immediately. No turbidity measurement was taken if there was insufficient supernatant liquid available at that specific sampling time.

Soil Characteristics Study

82. Soil properties such as the liquid limit, plastic limit, and sticky point of settled sediments with and without polymer treatment were measured. The procedures are described as follows.

Liquid limit

83. The liquid limit is determined by measuring the

water content and the number of blows required to close a specific groove for a specific length in a standard liquid limit device. In other words, the liquid limit (L.L.) is the minimum water content at which the soil will flow under a specified small disturbing force. The disturbing force is defined by the conditions of the test. Detailed experimental procedures are listed as follows:

a. A representative sample of the soil to be tested is homogenized (with double-distilled water, if necessary) to a putty-like consistency.

b. A portion of this sample is placed in the brass cup of the liquid limit device and leveled to a depth of 1 cm.

c. The sample is divided by the grooving tool along with the center line cam follower.

d. The height of drop of the device is adjusted to exactly 1 cm.

e. The crank is turned at the rate of two rotations per second until the divided sample coalesces at the bottom of the groove along a distance of ½ inch.

f. A portion of the soil is removed from around the groove area and its water content is determined.

g. The number of blows and moisture data are recorded.

h. A "flow curve" representing the relationship between the water content and corresponding number of blows is plotted on a semilogarithmic graph with water content as the ordinate on the arithmetic scale, and the number of blows as the abscissa on the logarithmic scale.

84. The water content, expressed as a percentage of the weight of the oven-dried soil, corresponding to the intersection of the flow curve with a 25-blow abscissa is the liquid limit of the soil.

Plastic limit

85. Plastic limit is defined as that water content at which a 1/8" (3 mm) diameter thread of soil begins to crack

and crumble under continued rolling by hand. Detailed experimental procedures are listed as follows:

- a. A representative 15-gram sample of the soil to be examined is shaped into a ball in the palm of the hand.
- b. The ball of soil is rolled between the palm of the hand with sufficient pressure to form the soil into a 1/8-inch-diameter thread.
- c. This is repeated until the soil can no longer be rolled into a 1/8-inch-diameter thread.
- d. The water content of the broken threads is determined.

86. The water content expressed as a percentage of the weight of oven-dried soil is the plastic limit.

Sticky point

87. The sticky point is defined as the moisture content of a drying clay paste when it just fails to stick to the fingers or to a nickel spatula drawn across the surface. However, personal variances in the experimental procedure yield inconsistent results. Therefore, the "sticky point" experiment was eliminated from this study.

Permeability Study

88. The falling-head method was used in this study to determine the coefficient of permeability of treated and untreated sediments.

89. There are commercially produced permeameters of a standard size, but their mold volume (500 ml) is not a practical size for use with zone settling studies of 1:4 and 1:10 sediment/water ratios. For the measurement of coefficient of permeability of sediments from zone settling studies, a laboratory designed permeameter was used (Figure 1). It has a mold volume of 60 ml, which permits the use of 1000-ml graduated cylinders for the zone settling studies.

90. In order to best represent the field condition, it

is desirable to test for permeability with the sediment in an undisturbed state. The test sediment is allowed to settle for two days after its zone settling velocity has been measured. The supernatant is then carefully decanted. A core of sediment is removed from the 1000-ml graduated cylinder by placing a tube of the same diameter as the permeameter into the cylinder, applying a vacuum and sealing the end. The tube with the enclosed core sample can then be removed undisturbed. It is then placed over the permeameter and then the vacuum is released. By gravity the core slides into the permeameter mold. The mold is then placed into a Sattorius membrane filter device and sealed with paraffin to prevent leakage.

Study of Salinity Effect on the Treatment of Supernatants

91. Ionic strength has profound effects on the flocculation process. Effluents with different salinities and turbidity levels may be encountered in the confined disposal of dredged material. Correlations between the optimum dosage of specific polymers, salinities, and turbidity levels were investigated.

Selection of polymer

92. The selection of Betz 1160 polymer for the treatment of supernatants is based on preliminary experiments in which Betz 1160 showed the most effective turbidity removal under different salinity and turbidity levels for the material considered in this study. A 0.1% stock solution was prepared and used throughout this experiment.

Preparation of solutions with different salinity levels

93. Since the treatment of supernatants may take place in both fresh and saline water, these environments were simulated in the test program. A 0.45 μm filtered background seawater with a salinity of 33 o/oo was used in the preparation of solutions with different salinities. The following table shows the ratio of seawater and dilution water

(deionized-redistilled water) used to prepare solutions of varying salinity.

Prepared Solution Salinity	Ratio of Seawater/Deionized-Redistilled Water
0 o/oo	Deionized-Redistilled Water Only
3.0 o/oo	1:10
5.5 o/oo	1:5
8.2 o/oo	1:3
16.5 o/oo	1:1
33.0 o/oo	Filtered Seawater Only

Preparation of solutions with different salinity and turbidity levels

94. Solutions with different salinity and turbidity levels were initially obtained by sampling the supernatants resulting from mixing one part of sediment with four parts of water of varying salinity at different time periods. This procedure proved to be impractical because of the tremendous amounts of supernatant required for this study.

95. An alternative method was used to obtain solutions with different turbidity levels by preparing a "stock" turbidity solution. The "stock" turbidity solution was obtained by siphoning the supernatant of a 1/4 sediment/water slurry after overnight settling. Various amounts of the stock turbidity solution were added to waters of different salinity to obtain the desired turbidity and salinity levels.

Experimental conditions

96. The experimental setup for this study is shown in Figure 2. A Heidolph RZR 10 variable speed stirrer (Polyscience Corp.) was used. A 400-ml beaker with a three-blade stirrer was positioned at the midpoint of the solution.

97. A 30-second premixing of the sample was performed to assure homogeneity before the specific polymer dosage was

added. Residual turbidity of the supernatant which was siphoned below the water surface was measured after five minutes of settling. Formazin was used for the calibration solution. The turbidity is expressed in Nephelometric turbidity units (NTU). The following experimental conditions were followed throughout this experiment.

Experimental Conditions for the Study of Salinity Effects

Turbidity Level of Supernatants (NTU)	Stirring Speed (rpm)	Stirring Time (sec.)	Time of Settling (min.)	Residual Turbidity of Control Blank (NTU)
100	770	60	5	78 - 89
250	770	60	5	186 - 210
540	770	30	5	400 - 480
1000	550	30	5	750 - 850
2000	550	30	5	1800 - 2000
5000	550	30	5	4000 - 4500

Laboratory Polymer Screening Study for Supernatants

98. A total of forty-five different polymers were evaluated in this study. The characteristics of these polymers, such as viscosity, pH, bulk density, etc., are listed in Appendix A.

99. Preliminary studies showed that if a polymer is effective for turbidity removal at low salinity levels, it is also likely to be effective at high salinities.

100. Two salinity levels of 2.5 o/oo and 8.0 o/oo, and two turbidity levels of 200 NTU and 1000 NTU, were prepared for this study. A 0.1% polymer solution was also prepared. The experimental setup and procedures are the same as those described in the section on salinity effect. The criteria used in evaluating the effectiveness of various commercially available polymers were the character and rate of settling of the flocs, and the residual turbidity.

Column Studies: Short-Term and Long-Term Studies

101. A 3' length, 6½" I.D., 1/8" thick, plexiglass column was used in this study. Compressed air bubbling units are located near the base of the column for mixing.

Short-term study

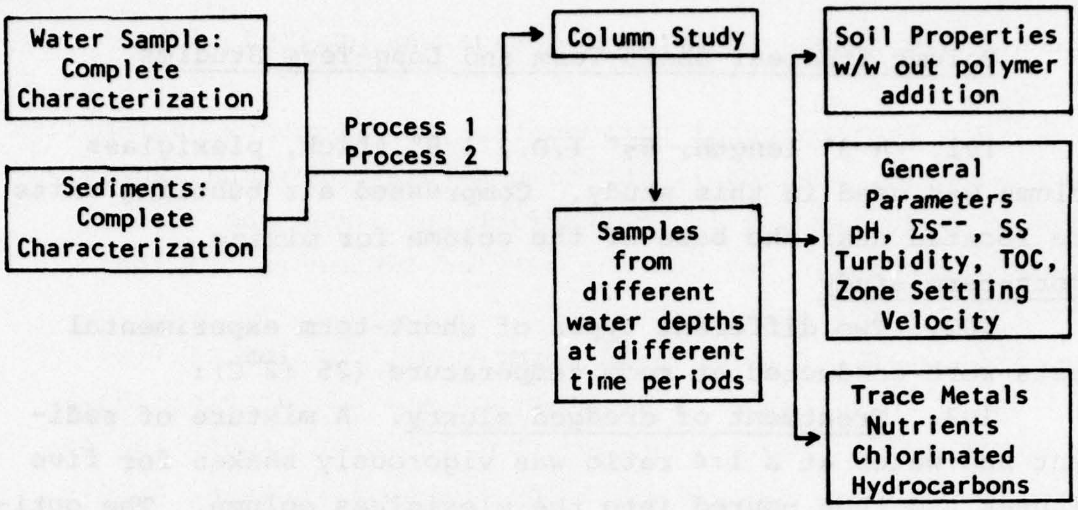
102. Two different types of short-term experimental tests were conducted at room temperature (25 ±2^{o}C):

103. Treatment of dredged slurry. A mixture of sediment and water at a 1:4 ratio was vigorously shaken for five minutes and then poured into the plexiglass column. The optimum dosage of the selected polymer was added to the water column containing a mixture of sediment/water (3 liter/12 liter). A control column was prepared in exactly the same manner without polymer addition.

104. Treatment of a simulated diked area effluent. Simulated turbidities of 1000, 500, 250, and 100 NTU (Nephelometric turbidity unit) were prepared for the purpose of evaluating the effectiveness of selected polymers in the column study. The same experimental procedures previously described for the treatment of dredged slurry were used.

105. Water samples were withdrawn from the column with a 50-ml plastic syringe at different water depths at various time intervals. General water quality parameters, nutrients, chlorinated hydrocarbons, and trace metals were analyzed. Zone settling information was also recorded.

106. The flow chart for this study is shown in the following figure:



Process 1: Mixture of sediment/water at 1:4 ratio. Vigorously shake for 5 minutes, then pour mixture into plexiglass column. Add selected polymer at optimum dosage; bubble with purified air until big flocs form.

Process 2: Turbidities of 1000, 500, 250, and 100 NTU are chosen as simulated supernatants. Pour supernatant into the plexiglass column; add selected polymer at optimum dosage. Bubble with purified air until big flocs form.

Long -term study

107. An assessment of long-term mobilization of chemical constituents (nitrogen, phosphorus, and trace metals) from flocculated sediments was conducted. A resettled sediment (untreated) was also evaluated to compare the effect of polymer treatment on the release of contaminants to the overlying water.

108. Selection of sediment-water samples and polymer. The level of contaminants in both sediment and background water from Mobile Bay, Alabama, was found to be quite high in comparison with other sites surveyed. Sediment and water from this site were used for the release study.

109. Previous screening experiments in evaluating the effectiveness of various polymers in the treatment of dredged slurries as shown in Tables 12 and 13 indicate that Calgon WT-3000 is the most effective for the treatment of the sampled

dredged slurries. An optimum dosage was applied in this study.

110. Environmental parameters. Environmental parameters such as redox potential, pH, temperature, pressure, activities of organisms, etc., may affect the level and rate of pollutant release between the settled sediments and the overlying interfacial water.

111. Since the chemical forms and the valence of all elements are affected by their redox state, Garrels (1954) and Bohn (1971) have suggested that the redox potential be used as an indicator for defining the environmental condition. The pH of the solution will also influence the direction of the alternation process, such as precipitation, dissolution, and redox reactions (Bostrom, 1967; Stumm and Morgan, 1970).

112. Since the dissolved oxygen level might be the only controllable factor in a field situation, the most important objective of this experiment was to study the effect of the D.O. concentration of the overlying water on the release of nutrients and trace metals from polymer-treated and untreated sediments.

113. No external control of pH was made in this study. The D.O. level was used as the environmental controlling factor. The aerobic column was purged using pure O_2. Both aerobic and anaerobic sites were maintained in the dark to prevent O_2 production by the growth of algae.

114. The environmental conditions for this study are summarized in the following table:

Environmental Variables	Aerobic (Polymer-Treated)	Anaerobic (Control and Polymer-Treated)
Light Exposure	None	None
D.O. Controlling gas	O_2	N_2
D.O. Level	2.5~3.5 ppm	0 ppm
Residence Time (days)	70 days	70 days
Temp.	$20\text{-}21^{\circ}$C	$20\text{-}21^{\circ}$C

115. Experimental setup. A mixture of sediment and background water from Mobile Bay, Alabama, at a 1:4 ratio (v/v) was shaken vigorously for five minutes in a glove bag. The well-mixed slurry was then poured into the plexiglass column. An optimum polymer dosage of 10 ppm Calgon WT-3000 was added to the column; compressed air was injected at 2 psig to promote floc formation. The columns were then closed and maintained airtight in order to avoid any interchange with the atmosphere. Direct sunlight was excluded by wrapping the columns with aluminum foil.

116. Three long-term tests were conducted in a constant-temperature room ($20\text{-}21^{\circ}$C) under different environmental conditions. The setup for the three plexiglass columns is shown in Figure 3. The three plexiglass columns are hereafter referred to as columns no. 1, 2, and 3.

- a. Column #1: Control column without polymer treatment; Dissolved oxygen = 0 ppm.
- b. Column #2: Polymer-treated column; Dissolved oxygen = 0 ppm.
- c. Column #3: Polymer-treated column; Dissolved oxygen = 2.5 to 3.5 ppm.

117. Nitrogen gas was connected to columns #1 and 2 throughout the experiment. Ultrapurified O_2 gas was kept in contact with column #3 under appropriate partial pressure

throughout the experiment to maintain the desired D.O. level.

118. Experimental conditions and sampling schedule. Due to the high IDOD of the sediment, the water in the test columns became deoxygenated (anoxic) immediately after the introduction of the slurry. The D.O. and $S(-II)_T$ for the three columns at different time periods up to 70 days were measured.

119. The interfacial water samples for this leaching study were taken approximately 1¼ inches above the surface of the sediment (Figure 3). The analyses of these interfacial water samples include:

a. Trace metals: Ag, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn.

b. Environmental parameters: pH, D.O., $S(II)_T$

c. Biostimulants: NH_3-N, organic-N, orthophosphate, total phosphorus.

Analytical Methods

Analysis of general parameters of sediments (see Table 5)

120. Methods used in this study for the analyses of general parameters of sediments are summarized as follows.

121. Moisture content (M.C.). Dry sample at 103°C until a constant weight is obtained. % moisture content =

$$\frac{\text{wet weight} - \text{dry weight}}{\text{wet weight}} \times 100.$$

122. Total volatile solids (TVS). Ignite dried sediment sample at 550°C for 15 minutes. TVS (mg/kg) =

$$\frac{\text{mg dry weight} - \text{mg residue} \times 1000}{\text{mg dry weight}}$$

123. Immediate dissolved oxygen demand (IDOD). Modified procedures listed in Standard Methods (APHA 1971) were followed. Oxygen-saturated water with a specific salinity analogous to that of the sediment was used in place of distilled water; H_3PO_4 was used instead of H_2SO_4 (expressed as ppm of dry sediment).

124. Nitrogen. Weigh about 2 grams of sediment sample in a kjeldahl flask and add 180 ml of double-distilled water. The procedure in Standard Methods was followed to determine NH_3-N and organic-N (expressed as ppm N of dry sediment).

125. Total phosphorus. Digest 0.2 to 0.3 gram of sediment sample in a Teflon beaker with a $HF + HNO_3 + HClO_4$ solution until dry. Cool and dissolve the sample in about 20 ml of distilled water and neutralize with 1N NaOH. If necessary, the neutralized solution is filtered. Transfer the filtrate to a 100-ml volumetric flask and add make-up water to 100-ml mark. Add 2 ml molybdate acid to 50 ml of digested solution and mix. After exactly five minutes, measure the absorbance of the solution vs. a blank at a wavelength of 690 μm using a 5-cm cell (expressed as ppm P of dry sediment).

126. Acid-soluble sulfide. Place zinc acetate solution into two absorption flasks and connect in series. Purge the system with N_2 gas for 20 minutes. Transfer 5-10 g of sediment into a 1-liter reaction flask and add 500 ml of distilled water and 10 ml of conc. H_2SO_4; connect to the absorption flask. Mix thoroughly and pass N_2 through the sample for one hour. Add 10 ml of iodine solution and 2.5 ml of conc. HCl to the absorption flasks and mix thoroughly for about 15 minutes. Back-titrate with 0.025N sodium thiosulfate titrant, using starch solution as an indicator (expressed as ppm S of dry sediment).

127. Total organic carbon (TOC). Weigh about 5 g of sediment in a 150-ml beaker. Adjust pH below 2 by adding 1:1 HCl; bubble N_2 through the sample for 10 minutes. Dry the sample at 70-100°C. Weigh a portion of 0.5 - 1 g of dry sample in a special TOC crucible. Determine TOC content using LECO TC-12 Automatic Carbon Determinator (expressed as percent C of dry sediment).

Analysis of general parameters of water samples

128. Analyses for pH, D.O., and total dissolved sulfide in the solution phase were performed primarily according to procedures described in Standard Methods, 14th edition. Parameters such as pH, D.O., and total dissolved sulfide were determined immediately after sampling. If prompt analysis was impossible, nitrogenous species were acidified with sulfonic acid (100 µl in 100-ml sample) and stored at 4°C (Proctor, 1962). Samples for orthophosphate and total phosphorus were quick-frozen at 0°C (Collier and Marvin, 1953). Information regarding the analysis of organic nitrogen, dissolved silica, ammonia, nitrite, nitrate, orthophosphate, and total phosphorus is listed in the following table:

Parameters Factors	Volume of Sample Needed	Analysis Method	Method for Sample Preservation
NH_3-N, NO_2^--N	100 ml	By Riley, et al., (1972)	100 µl H_2SO_4 in 100- ml sample
Organic-N	50 ml	Kjeldahl Method (Standard Method, APHA, 1971)	100 µl H_2SO_4 in 100-ml sample
Ortho-phosphate Total phosphorus	100 ml	Amino-naphthol Sulfonic Acid Method (APHA, 1971)	quick frozen
Dissolved Silica	20 ml	Heteropoly Method (Standard Method, APHA, 1971)	0.3 ml of 1.0 M HCl in 100-ml sample
NO_3^--N	50 ml	Modified Brucine Method by Jenkins and Medsker, 1964	100 µl H_2SO_4 in 100-ml sample

129. A Beckman Model 915A Total Organic Carbon Analyzer (with a Beckman Ten-Inch Potentiometer Recorder) was used for the analysis of total carbon (organic carbon plus carbonate carbon) and inorganic (carbonate carbon). For the determination of total organic carbon (TOC), the above two analyses are performed on successive identical samples; the TOC

is the difference between the two values obtained.

Analysis of trace metals

130. In this study, a Perkin-Elmer Atomic Absorption Spectrophotometer Model 305B with a heated Graphite atomizer Model 2100, and a deuterium arc background corrector were used for trace metal analysis.

131. For gross sediment samples, with the exception of Hg, the trace metal samples were prepared by acid digestion (Ultrex HNO_3-$KMnO_4$-HF).

132. The analysis of trace metals in seawater (or saline water) is quite difficult, mainly due to the problems of:

a. matrix effects
b. contamination
c. adaptability to multi-element determinations
d. preparation of standard backgrounds

133. Various techniques have been proposed for solving these problems (Mansell and Emmel, 1965; Brooks, et al., 1967; Burrel and Gunnerwood, 1969; Sachdev and West, 1970; Fernandez and Manning, 1971; Burrell, 1968; Pans, 1971 and 1973; Segar, 1971; Segar and Gonzales, 1972; Yanagisawa, et al., 1973; Barnard and Fishman, 1973; Edinger, 1973 and 1974; Edinger, et al., 1974; Dudas, 1974; Kinrade and Van Loon, 1974).

134. Analytical procedures and optimum operating conditions for the Perkin-Elmer 305B HGA AA are summarized as follows.

135. APDC-MIBK extraction--6N ultrapurified HNO_3 back-extraction followed by HGA (Heated Graphite Atomizer) determination. This method is applied to samples with very low trace metal concentrations (usually less than a few ppb) and to samples which have a complex matrix background. It is well known that the quantity of metal extracted is strongly dependent on the pH of the solution, and the chelating agents will often alter the pH of the solution (Brooks, et al., 1967; Pans, 1971 and 1973; Edinger, 1973; Dudas, 1974; Kinrade and

Van Loon, 1974).

136. In this study, a stable citrate buffer which did not interfere with the extraction process was used in the final extraction procedure. Six steps involved for each extraction were developed as follows:

- a. 100 ml of an aqueous sample solution is poured into a 250-ml polyethylene bottle (or Teflon separatory funnel).
- b. 2 ml of a purified citrate buffer is added and the pH of the solution is checked to insure that it is around 5.0 (the buffer is 1.2M sodium citrate and 0.7M citric acid).
- c. 2.5 ml of chelating solution is added (this is 1% W/V of APDC and DDDC in water).
- d. 10 ml of MIBK is added.
- e. The polyethylene bottle (or separatory funnel) is shaken for 1 minute by a Burrel wrist shaker, Model 75, and is then allowed to settle for 10 minutes.
- f. After the waiting period, the aqueous phase is drained and the organic phase is collected.

137. Seven metals in this study were extracted by this procedure: Ag, Cd, Cu, Fe, Ni, Pb, and Zn. It was found that the injection of the organic solvent MIBK was not reproducible enough, mainly due to the instability of its organic structure. The MIBK phase was immediately back-extracted with 6N ultrapurified HNO_3. This aqueous phase is much easier to inject into the graphite furnace and the trace metals in 6N HNO_3 will remain stable for a long period of time, whereas the MIBK complexes are known to deteriorate.

138. HGA direct injection method. This method is suitable for concentration ranges of trace metals from a few ppb to several hundred ppb. Equipment and injecting procedures are the same as the previous method without the extracting process. The concentrations of Cr, Fe, and Mn in saline water samples in this study were obtained by direct injection into the HGA. In the analysis of these elements, the

deuterium arc background corrector and charring temperatures of 1250°C are needed to remove the matrix effects. The standard solutions used to obtain the calibration curve are prepared in the same background "clean saline water". "Clean saline water" was obtained by passing the reference seawater through a 0.05 μm membrane filter, followed by extraction with MIBK-APDC to remove impurities. This clean saline water was then used to prepare the standard solutions and calibration curves. In this manner, any possible error due to different matrix species in the sample was minimized.

139. Operation of HGA at the optimum operating conditions is essential for reliable results since the charring and atomizing temperatures and times are very sensitive for many elements. Numerous combinations of settings were attempted. Modifications are necessary over those recommended in "Analytical Methods for AA Spectroscopy using the HGA Graphite Furnace" provided by Perkin-Elmer.

140. Even by using the HGA method, the sensitivity of the atomic absorption method in trace metals determination could be suppressed or enhanced by the presence of different matrices in the samples. Therefore, selection of an extracting method and optimum combinations of AA settings is very critical in the determination of trace metals, especially in dealing with saline water. A summary of working conditions of trace metals in this study is listed in Tables 2 and 3.

141. Flame atomic absorption method. This method is suitable for concentrations of trace metals in the range of several hundred ppb to a few ppm. A Perkin-Elmer Atomic Absorption Spectrophotometer, Model 305B, with flame atomizer and deuterium arc background corrector was used for the analyses. High concentrations of trace metals in gross sediment samples (or sediment extracts) are determined by this method.

Analysis of chlorinated hydrocarbons

142. The extraction, separation, identification, and quantification of chlorinated hydrocarbons were performed in accordance with the published literature (Hubbard, 1964; Mills, 1968; Reynolds, 1969; Armour and Burke, 1970; Official Method of Analysis of the Association of Analytical Chemists, 1970; Schultzmann, et al., 1971). Detailed operation procedures are described as follows.

143. Extraction. Two hundred and fifty ml of Acetonitrile (pesticide quality, Matheson, Coleman & Bell) was added to the glass-stoppered flask containing 10 g of wet sediment (in the pesticide fractionation experiment, 250 ml of the sample solution was used), which was then shaken for one hour. The flask was kept at room temperature overnight. The sample was again shaken for two hours and then filtered through 5 g of Celite (Celite 545, Sargent Welsh) media on Whatman No. 4 filter paper under slight vacuum. At this time, another 100 ml of Acetonitrile was added to avoid the possible loss of chlorinated hydrocarbons on the container walls, Celite, or residue. The filtrate was then transferred to a 1000-ml separatory funnel containing 200 ml of double-distilled water and 10 ml of saturated NaCl solution. Eighty ml of petroleum ether (pesticide quality, Matheson, Coleman & Bell) was used to clean the concentrator and was added tc the separatory funnel. The process was then repeated. After the third extraction the aqueous phase was discarded, and all the petroleum ether extracts were collected into a Kuderma-Danish concentrator. After the extraction, petroleum ether was concentrated to approximately 5 ml and then eluted on the prepared activated florisil column.

144. Florisil column elution. A chromatograph tube (450 x 28 mm) with a removable frittered glass and Teflon stopcock was packed with 15 g of activated florisil (60/100 mesh, GC grade, Sargent Welsh) which had been stored at 130°C

and topped with 15 g of anhydrous sodium sulfate (reagent grade, J.T. Baker) to absorb water from the extract. The column was then washed with 70 ml of petroleum ether. The petroleum ether extract (concentrated to approximately 5 ml) was added when the petroleum ether sank through the top surface of the anhydrous sodium sulfate. Sequential elutions were then carried out, first with 175 ml of petroleum ether, next with 100 ml of 6 vol % ethyl ether-94 vol % petroleum ether mixture (6 + 94), and finally with 150 ml of 15 vol % ethyl ether-85 vol % petroleum ether mixture (15 + 85). During the elution, the flow rate was controlled by a Teflon stopcock at approximately 2 ml/min. In the florisil column elutions, polychlorinated biphenyls (PCB's) and most of the DDE were recovered in petroleum ether, most of the other organochlorine compounds in 6 vol % ethyl ether-94 vol % petroleum ether mixture, and endrin and dieldrin in 15 vol % ethyl ether-85 vol % petroleum ether mixture. Each eluted sample was again concentrated and the extract final volume measured. If sulfur is present in large amounts in the samples, the extract should be treated with mercury to remove sulfur as mercuric sulfide before injecting into the gas chromatograph.

145. Identification and quantification. Standards of DDT series were supplied by Supelco, Inc., PCB Standards (Arochlor) by Monsanto Chemical Co., and aldrin and dieldrin by Shell Chemical Co., all at 99.0 - 99.5% purity.

146. A Hewlett-Packard Research Gas Chromatograph, Model 5750, equipped with Ni^{63} electron capture detector was used. The glass column (1220 x 4 mm) was packed with 5% QF-1 (Chromosorb W-HP, 80/100 mesh, Sargent Welsh). The carrier gas used consists of purified 95% argon and 5% methane.

147. The sample components were identified by comparison of retention times of unknown peaks to the known peaks of reference standard solutions and were quantified by comparison of the peak height of an identified component with

the corresponding peak of the component in the reference standard solutions. In addition to the reference standard solutions of single components, multicomponent reference standard solutions with different series of combinations of concentrations and components were prepared.

148. Preliminary sample injections were always performed to test whether pre-concentration or dilution of a sample was required, as well as the series of reference standard solutions to be used. The efficiencies of recovery after spiking 10 g of wet sediment with 0.1 - 1.0 μg of chlorinated hydrocarbons were 85 - 99% for DDT homologs, 85 - 94% for dieldrin, and 93 - 102% for PCB's.

PART IV: RESULTS AND DISCUSSION

Characterization of Sediments

149. A total of seven sediments collected from different parts of the country have been studied. Gross chemical compositions of each sediment were analyzed for the possible correlation of sediment characteristics to the final selection of polymer type and dosage. The compositions of these sediments are given in Tables 5 and 6. Trace metal analyses were performed for silver, cadmium, chromium, copper, iron, lead, manganese, nickel and zinc. The concentrations of chlorinated hydrocarbons are given in Table 7. Textural composition of the sediments in terms of percentage of sand, silt, and clay is listed in Table 4. The classification of sediment type is based on the Corps of Engineers Triangular Classification Chart shown in Figure 4.

150. The particle size distribution of dredged material is an important physical property associated with confined disposal operations. Coarse-grained dredged material settles rapidly, and with adequate detention times, has little effect on the effluent water quality. However, the tendency for colloidal formation by fine-size particles will result in long residence times and could contribute to the contaminant load of the discharged effluents.

151. The particle size distribution curves for the sediments are shown in Figures 5 and 6. The weight percent of particles smaller than one micron ranges from 1 to 18 percent. Fine particles are usually associated with high concentrations of contaminants and have very slow settling velocities resulting in long residence times. Removal of particulate fractions should result in a significant reduction of the contaminant load in the discharge effluent. Tables 5 and 6 show that the total organic carbon, nutrients, and trace metals content of

each sediment decrease with increasing sand percentage.

Evaluation of Conventional Coagulants in the Treatment of Dredging Slurries and Supernatants

152. Alum and ferric sulfate were studied in the standard jar test for the treatment of slurries with sediment/water ratios of 1 to 4 and 1 to 10. Results of the standard jar test using a clay-silt sediment (Sediment #7) are given in Tables 8 and 9. Floc heights at the beginning of slow mixing and the end of slow mixing are also presented. The data show that the resulting flocs settle very slowly. Also, very high dosages of flocculants (up to several thousand ppm) were needed to obtain a significant reduction of turbidity. The results indicate that alum and ferric sulfate are not effective coagulants for the direct treatment of sediment-water mixtures.

153. Alum and ferric sulfate were further evaluated in the treatment of supernatants having a turbidity level of approximately 1000 NTU. The minimum dosage of coagulant was determined by the standard jar test. A concentration of 20 ppm (as Al and Fe) was found to be the minimum dosage for both alum and ferric sulfate (Table 8).

154. Another set of standard jar tests was performed and the minimum dose of coagulant was added. The pH was adjusted over a range of 3 to 9 by using 1N NaOH or H_2SO_4. The residual turbidity was then plotted against pH to determine the optimum pH. Another series of standard jar tests were performed at the predetermined optimum pH to obtain the optimum dosage.

155. Experimental results on the treatment of a relatively turbid effluent (approximately 1000 NTU) using alum and ferric sulfate are presented in Figures 7 and 8. The data show that a pH of 9.0 - 9.5 and a dosage of 25 ppm are required for optimum ferric sulfate treatment. A residual

turbidity of 32 NTU was observed. Alum requires a pH of 8.5 to 9.0 and a dosage of 50 ppm; residual turbidity was 8 NTU.

Distribution of Trace Metals and Biostimulants in Different Size Fractions of Sediments

156. Confinement of dredged material in diked areas has been widely used for many years (Murphy and Zeigler, 1974). With the exception of those operations where dewatering of the dredged slurries takes place by evaporation, all confined areas are equipped with some kind of sluicing device to divert the supernatant from the disposal area.

157. Because of the possible ecological impact, the quality of effluents discharged from the containment area into the receiving water is of great concern to both regulatory agencies and dischargers. The effluent quality is affected by many factors, such as the nature of the dredged material, the size of the disposal area, the operating conditions that prevail within the area, and the method of discharge. The concentrations of particulates in the effluents are of major concern because of their high pollutant-bearing capacity. Concern over the discharge of trace metals and biostimulants is expressed because of possible toxicity and eutrophication problems.

158. The available literature provides limited information of the particle size distribution of trace metals and biostimulants in dredged sediments. The distribution of contaminants in various size fractions is significant because it provides for an approximation of what percent removal of suspended solids would be required to meet applicable water quality standards. The particle size distributions versus TKN, TOC, and T-P, respectively, are shown in Figures 9 - 11.

159. Table 10 shows the particle size distribution of trace metals, TOC, T-P, and TKN in four dredged sediments.

The particle size distribution was divided into three ranges: >50 μm; 5-50 μm; and <5 μm, which correspond to the grain size limits used in differentiating the sand, silt, and clay fractions.

160. The particle size distribution patterns for sediments #4 and #6 are quite similar (Figure 6). Approximately 38% of the particulate matter is smaller than 5 μm, and 80% is smaller than 50 μm. The particle size distributions versus trace metals for these two sediments show a similar pattern (Table 10). For sediment #5, 97% of the particulates are larger than 50 μm. The distribution of trace metals in the remaining 3% (<50 μm) ranged from 62% to 93% of the total quantity. The particle size distribution of sediment #7 lies between those of sediments #4, #6, and #5, in which 55% of the particulates are larger than 50 μm (Figure 6). The distribution of trace metals in the four sediments shows a large variation: 2-38% >50 μm (rapid settling) and 10-80% <5 μm. T.O.C. ranged from 9-37% >50 μm; 21-32% <5 μm. T-P: 12-74% >50 μm; 10-34% <5 μm. TKN: 15-50% >50 μm; 21-30% <5 μm. The data show that a significant portion of trace metals, T.O.C., T-P, and TKN is associated with fine-grain particulates. The slow settling velocity of these particulates precludes plain sedimentation as a feasible method of treatment.

The Effect of Salinity on Polymer Flocculation

161. The effect of salinity on flocculation efficiency was investigated for both dredged slurries and simulated diked area effluent. For simulated diked area effluent, initial turbidity levels from 100 to 5,000 NTU were used. Betz cationic polymer 1160 was selected after preliminary screening studies. The results are summarized in Table 11.

162. The relationship between the optimum dosage and

salinity of the solution at different initial turbidity levels is presented in Figure 12. The data show that the optimum dosage decreases with increasing salinity from 0 to 8 o/oo. Salinities greater than 8 o/oo have negligible effects on the optimum dosage. The thickness of the double layer is a function of the ionic content of the solution and decreases with increasing concentration of electrolytes. At higher salinity levels, the bulk solution has a higher ionic strength; the diffused double layer is compacted to a smaller thickness and does not extend as far into the solution. Therefore, for colloidal systems with high ionic strength, the repulsive interaction is smaller than for systems containing a lower ionic strength. Consequently, less polymer (cationic Betz 1160) is needed in destabilizing the colloidal system. The Van der Waals forces of attraction are, however, less affected by changes in ionic content.

163. References in the literature indicate that multivalent cations, Ca^{2+} and Mg^{2+}, influence the flocculation of colloidal dispersions. Birkner and Edzwald (1969) demonstrated that Ca^{2+} and Na^{+} influenced flocculation of clay by non-ionic polyethylene oxide. Teot and Daniels (1969) showed Al(III) and Fe (III) were effective in promoting flocculation of polystyrene latex and dilute sewage solids with anionic hydrolyzed polyacrylamide and with anionic sodium polystyrene sulfonate. McGarry (1970) found that alum improved the flocculation of pond algae with cationic polymers and a similar result was observed by Thorup, et al. (1970) during the flocculation of viruses with cationic polymers. These cations may serve the purpose of compressing the thickness of the double layer of the clay particles, thereby reducing interparticle repulsive forces.

164. Figure 13 shows the relationship between residual turbidity and salinity for different initial turbidity levels

at optimum dosage. The results show that the residual turbidity decreases with both increasing initial turbidity levels and salinity at optimum dosage. The data suggest possible interparticle bridging for polymer-suspended solids interactions.

165. The effect of initial turbidity levels in the degree of turbidity removal is a purely kinetic phenomenon; increasing the turbidity level increases the probability of interparticle collisions, leading in turn to more favorable conditions for interparticle bridging.

166. Higher turbidity removal in the presence of higher salinity may be explained on the following basis. The added ionic strength forms an ion cloud around the positively charged polymer molecule. The ion cloud diminishes the repulsive force between polymer molecules so that they can be adsorbed more closely together on the suspended solids surface. This allows for a closer packing of polymer on the suspended solids surface and increased polymer stretching and bridging.

167. The relationship between initial turbidity levels and optimum polymer dosage at different salinities is shown in Figure 12. The data show that the optimum dosage for a given salinity increases with increasing initial turbidity levels.

168. The dependence of dosage requirements on turbidity reduction, or better, on the amount of surface to be covered by the adsorbing polymer, has been demonstrated by LaMer and Healy (1963) and Tenny and Stumm (1965). Stoichoimetry for the destabilization of kaolinite clay suspensions with cationic polymer PDADMA was also reported by Black, et al. (1965). Due to the complex nature of the simulated supernatants, no stoichoimetric relationship between the initial turbidity and optimum polymer dosage was observed.

169. The effect of salinity on optimum dosage for dredged slurries with sediment/water ratios of 1 to 4 and

1 to 10 is presented in Tables 12 and 13, and Figure 14.

170. Sediment #7 which was collected at Mobile Bay, Alabama, was used for the preparation of slurries. The optimum dosage and residual turbidity at various salinities for the three most effective types of polymer (Betz 1120, Betz 1160, and Calgon WT-3000) are given in Tables 14 to 18. Solutions with salinities of 0, 2.5, 8.0, 16.0, and 33.0 o/oo were evaluated.

171. The test results show some general trends for the three polymers evaluated: (1) the optimum dosage decreases with increasing salinity; (2) the residual turbidity decreases with increasing salinity; (3) the optimum dosages for Betz 1120 and Calgon WT-3000 anionic polymers are much lower than for Betz 1160 cationic polymer.

Turbidity Versus Suspended Solids Concentration

172. Turbidity has been defined by Fair and Geyer (1966) as a measurement of the interference presented by suspended matter to the passage of light. The use of turbidity as an indicator for water quality management has the advantages of being a simple and rapid procedure. The interference between the suspended solids and the passing light in the process of turbidity determination is complex in nature. The interference may be a function of the shape, size, number, and index of refraction of the suspended matter.

173. McCluney (1975) has indicated that: (1) turbidity is strictly an optical property of the medium; (2) the use of the term turbidity is ambiguous; (3) instrument calibration may be misleading and incorrect; (4) optical instruments in current use provide an inferred and not a direct measurement of suspended solids; (5) the use of turbidimeters must be supported by ancillary measurements which demonstrate that the optical data are correlated with the concentrations of the materials to be monitored; and (6) a transfer function,

not a single-point calibration, is required to connect optical readings from a given instrumentation to actual mass concentrations of suspended solids.

174. In this study, turbidity measurements were used as an indicator of the effectiveness of the polymer flocculation process. In general, supernatants contain a wide range of particle sizes; therefore, turbidity removal may have a relatively limited physical significance. An effort was made to establish a relationship between turbidity and suspended solids, since the suspended solids concentration expresses the actual amount of materials removed.

175. Figure 15 shows the empirical correlation between the two parameters for sediment #6 supernatant. The data indicate an approximate continuous function for a specific sediment sample. In actual practice, sampling of the entire dredging area would be required to develop calibration curves for turbidity levels and concentrations of suspended solids.

General Characteristics and Purity of Polymers

176. All the synthetic polymers evaluated in this study are water soluble with high molecular weights. Appendix A lists all the pertinent data, such as ionic nature, form, concentrations and pH of solutions, and the approximate time needed for complete dissolution.

177. Stock solutions of Betz 1160, Betz 1120, and Calgon WT-3000 polymers were prepared in deionized-redistilled water. These 0.1 percent stock solutions were analyzed for trace metal content. The purity (in terms of trace metal content) of these polymers was confirmed. For all trace metals analyzed (Ag, Cd, Cu, Cr, Mn, Ni, Pb and Zn), the concentrations were mostly undetectable or below the sub-ppb range. Total carbon and total organic carbon contents were also analyzed for these prepared stock solutions. Data on TOC, IOC and T.C. for Betz 1120, Betz 1160, and Calgon WT-

3000 polymers are given in Table 19.

Laboratory Screening of Polymers

178. It is extremely difficult to prescribe a specific type, dosage, and application of flocculant due to wide variations in the nature of dredged material. It is necessary to carry out a series of laboratory screening tests with different types of polymers in order to determine the optimum dosage for specific application.

179. Polymers will, in general, coagulate colloidal particles within a pH range normally encountered in dredged slurries and effluents; however, certain polymers may be most effective at a specific pH value (Crook and Pollio, 1972). pH control during dredging operations would probably not be economically feasible. Therefore, no pH adjustment was attempted in this study. The results show that the pH of slurries and supernatants after polymer addition did not deviate significantly from the initial pH. Other important variables such as polymer molecular weight and solution properties may also affect polymer flocculation reactions. Polymer screening tests were performed on both dredged slurries and supernatants to evaluate flocculation efficiency.

Screening of polymers in the treatment of different sediment slurries

180. The flocculants can be categorically classified into three groups: anionic, nonionic, and cationic. Anionic polymers are those which exhibit an electronegative charge as opposed to the cationic type, which is electropositive. The nonionic polymers, as the name implies, are essentially neutral.

181. Approximately fifty different polymers from five different chemical companies (Calgon Co., Nalco Chem. Co., Betz Co., Union Carbide Chem., and American Cyanamid Co.)

were screened to determine their effectiveness as coagulants in the treatment of sediment slurries using the standard jar test. Many polymers, for example, WT-2860, WT-2640 (Calgon products), 81C-09, 72C-25, and Nalcolyte 607 (Nalco Chem. Co. products), to name a few, exhibited extremely high dosage requirements (up to 1000 ppm) to obtain adequate clarification of the sediment slurries. Therefore, they were eliminated from further study in this project. Effective polymers were selected for further testing to evaluate the flocculation effectiveness at different polymer dosages.

182. Table 20 summarizes the optimum dosage range (standard jar test) for 13 polymers used in the treatment of five sediment slurries with sediment/seawater ratios of 1:4. Sediment #4 was also evaluated with a sediment/seawater ratio of 1:10. The optimum dosage for the other four sediments with 1:10 ratios could not be determined due to insufficient sediment material. The detailed experiment data are listed in Tables 21-26. In order to judge the effectiveness (settling characteristics) of each polymer, floc heights at different time intervals (i.e., at the beginning and the end of slow mixing and at the end of settling) were recorded. Percent removal in residual turbidity compared with that of a control sample was also calculated.

183. Among the polymers evaluated for the treatment of dredged slurries, it was found that for the Betz products, Betz 1120 and Betz 1150 produced the best effluent quality at the end of the settling period. Moreover, these two polymers also showed larger and denser floc formation. Consequently, much faster settling of coagulated flocs was observed in the standard jar test, compared with the other Betz products evaluated. Polymer WT-3000 from Calgon Co. showed results comparable to those for Betz 1120.

184. Polymers obtained from Nalco Chem. Co. and

Union Carbide were also evaluated. High residual turbidity with only slight clarification of sediment slurries was observed. The rate of floc formation was observed to be very slow. Long settling times (up to 2 hours) and extremely high dosages (up to 1000 ppm) must be provided to obtain clarification of sediment slurries. In some cases, an activator (to bring the polymer to maximum efficiency) was required to prepare some of the Nalco products (72-D-13 and 81-C-09). This makes the preparation of stock solutions impractical, especially in field studies.

185. Textural composition of sediment #5 (James River, Richmond, Virginia) is shown to contain 1.0% clay and 97% sand. This sediment settles rapidly without any polymer addition. Treatment with different polymers showed no significant reduction of residual turbidity (in both sediment/seawater ratios of 1:4 and 1:10).

186. It is interesting to note that the optimum dosage for slurries with a sediment/seawater ratio of 1:10 is only approximately one-third of the polymer dosage required for slurries with a sediment/seawater ratio of 1:4.

Screening of polymers in the treatment of supernatants

187. A total of forty-five different polymers received from different manufacturers were evaluated for the treatment of supernatants. Some of the polymers were not available until the latter part of the project; therefore, the experiments were carried out in two stages. The first stage included the evaluation of seventeen different polymers. Results for the optimum dosages and corresponding residual turbidities for these polymers in the treatment of supernatants with salinities of 33 o/oo at four different initial turbidity levels are summarized and presented in Figures 16 and 17.

188. For the treatment of supernatants in the first stage study, it was found that the most effective polymers

were Betz 1160, Betz 1150, and Calgon WT-3000.

189. In the second stage screening of polymers in the treatment of supernatants, all forty-five polymers were evaluated (including 17 from the first stage study). The results of the second stage polymer screening study for supernatants with two turbidity concentrations (200 and 1000 NTU) and two salinity levels (2.5 and 8.0 o/oo) are presented in Tables 27 and 28.

190. For the treatment of supernatants, the most effective polymers in reducing turbidity are: cationic polymer (Hercofloc 815.3 and 849; Betz 1160 and 1150) and nonionic (Calgon WT-2690, Magnifloc 905N).

Correlation of the Characteristics of Sediments with Type and Dosage of Flocculants

191. Many different types of polymers were used to treat sediment slurries at sediment/water ratios of 1:4 and 1:10. Among those polymers evaluated, Betz 1120 and Calgon WT-3000 were the most effective in reducing turbidity at low dosage levels. Other polymers evaluated also proved to be effective; however, the extremely high dosage required (up to 100 ppm) may deny their economical use. Betz 1120 and Calgon WT-3000 polymers are both anionic and showed comparable results in reducing turbidity levels in the treatment of sediment slurries. The correlation between sediment characteristics and optimum polymer dosage was developed for Calgon WT-3000 polymer. Betz 1120 polymer would show similar relationships. The relationships between general parameters such as particle size distribution, TOC, and COD and Calgon WT-3000 optimum dosage for sediment slurries with a sediment/seawater ratio of 1:4 are presented in Figures 18 and 19.

192. The correlation coefficients between the optimum

polymer dosage and selected parameters are presented in the following table:

Parameters	Particle Size			TOC	TKN	COD	T-P	TVS	IDOD	Oil & Grease	Total Sulfide
	<50μ	<25μ	<5μ								
γ	0.75	0.95	0.97	0.95	0.95	0.93	0.88	0.78	0.51	0.26	-0.33

193. Among the indicated parameters, the correlation between percent particle size finer than 5 μm and optimum dosage is excellent ($\gamma = 0.97$). The correlation between T.O.C., COD, and TKN concentrations and optimum dosages is also very good as indicated by the correlation coefficients of 0.95, 0.93, and 0.95, respectively. The data also indicate that parameters such as total sulfide content, IDOD, and oil and grease content are not satisfactory indicators for the correlation of optimum polymer dosage.

194. Figures 18 and 19 indicate that the optimum polymer dosage increases with increasing levels of contaminants. This correlation is expected, due to the fact that high concentrations of contaminants are usually associated with fine particles, and optimum dosage is related to particle size distribution (Figure 19). It is concluded that the particle size distribution of sediments less than 5 μm is the most promising indicator for approximating the optimum polymer dosage.

Effects of Polymer Treatment on the Soil Characteristics of Coagulated Sediments

195. General soil characteristics, such as void ratio, porosity, specific gravity, density, liquid limit, plastic limit, and plasticity index for polymer-treated and nontreated sediment #7 are presented in Table 29. The data show that no

general trends can be established for these general soil characteristics between the polymer-treated sediment and nontreated sediment subjected to various mixing conditions.

196. The determination of these soil characteristics involved oven-drying of the settled sediment at 103°C; this procedure may destroy the physicochemical structure of the polymer-coagulated sediment. Also, experimental procedures for the measurement of these soil characteristics are difficult to control and vary from person to person. It is concluded that none of the general soil determinations are valid and thus they cannot be used as a useful parameter in evaluating the effectiveness of a specific polymer. Therefore, no further experiments on soil characteristics for the remaining six sediments were performed.

197. The coefficient of permeability is a constant proportionality relating to the ease with which a fluid passes through a porous medium. Two types of tests are typically used to determine permeability: 1) constant head; and 2) falling head. The falling-head method is generally used for relatively impervious soils, such as clays, where the flow rate is very small (10^{-4}cm/sec). Conversely, the constant-head method is used for larger grained solids with flow rates greater than 1 cm/sec.

198. The falling-head method was used to test the coefficient of permeability of sediments with and without polymer addition. Permeability (K) values are standardized to K_{20^oC} by the use of a viscosity correction table. The permeability coefficients (K_{20}) for polymer-treated and nontreated sediments are presented in Figure 20.

199. Polymer-coagulated sediments #4, #6, and #7 show an increase in permeability of 38 to 46% over the nontreated sediments. In general, any change in permeability greater than 10% should be considered as significant, instead of attributing it to experimental variation. The larger the value

of K, the greater the flow rate; therefore, polymer-treated sediments will have increased drainage rates compared with nontreated sediments.

200. After the short-term column study, each supernatant was carefully decanted from the resettled sediment. Particle size analysis was carried out on the settled sediments. Table 30 shows the grain size distribution of settled sediments (after 72 hours) for both polymer-treated and nontreated sediment #7. It was found that for the settled sediment sample with polymer treatment, a lower value of "percent finer" was obtained for each respective particle size, indicating the agglomeration of fine particles into bigger flocs. The grain size distribution curve for the polymer-treated sediment lies below that of the untreated sediment.

201. The "percentage of flocculation" at various particle sizes was also calculated to evaluate the effectiveness of the polymer in flocculating the sediment slurries (Table 30). The "percentage of flocculation" is defined as: % Flocculation = $\frac{U-T}{U}$, where U equals the percent finer than a given specific size (D) for untreated sediments, and T represents the percent finer than the particle size (D) for the polymer-treated sediment.

202. The salinity effect upon the particle size distribution of the resettled sediment was also evaluated. Table 31 shows the results of the particle size distribution of resettled sediment #7 at 2.5, 8, 16, 33 o/oo salinity. Ten ppm of Betz 1120 was used in the treatment of this slurry having a 1:4 sediment/water ratio. In most cases, higher salinity solutions provide for better flocculation and result in larger and denser flocs.

Effect of Polymer Flocculation on Sedimentation

203. Apart from advection due to fluid flow, the most important particle transport mechanisms in containment areas (plain sedimentation) are gravitational settling and diffusion. The relative significance of the two mechanisms for a given suspended particle depends largely on its size. Diffusion can be a dominating factor for small size particles.

204. Streeter (1962) showed that the ratio of the displacement of a suspended particle in a given time period due to diffusion in relation to that of gravitational settling is as follows:

$$\frac{x_d}{x_g} = \frac{8.29}{\rho_s - \rho} \left(\frac{KT\mu}{t}\right)^{0.5} \frac{1}{d^{2.5}} \qquad (1)$$

where x_d and x_g = displacements of the suspended particle in time t due to diffusion and gravitational settling, respectively; ρ_s and ρ = specific gravities of the suspended particle and water, respectively; K = Boltzman Constant; T = absolute temperature; μ = dynamic viscosity of water; and d = particle diameter.

205. Equation 1 indicates only the relative order of magnitude of x_d and x_g; the relative significance of the two mechanisms varies with particle size as well as the settling period. The longer the period, the less pronounced the diffusion effect for a given particle size.

206. As expected, the effect of diffusion decreased rapidly with the increase of particle size. If a difference of two orders of magnitude or more between x_d and x_g is considered to be sufficient to ignore the significance of the lesser one, the limiting particle sizes with gravitational settling dominating will be about 1.4 μ for t = 1 hr,

0.5 μ for t = 5 days; and 0.4 μ for t = 20 days. These same figures also indicate the practical limit of the removal of suspended particles that can be attained by gravitational settling.

207. For particulates settling in environments where the Reynolds number

$$R = \frac{\rho d V_s}{\mu g}$$

is less than 1, Stokes' Law holds

$$V_s = \frac{1}{18} \frac{\rho_s - \rho}{\mu} d^2 \qquad (2)$$

where V_s = particle settling velocity;
g = acceleration of gravity;
ρ_s = specific gravity of particulate;
ρ = specific gravity of water;
μ = dynamic viscosity of water;
d = particulate diameter.

208. For natural materials, ρ_s varies from close to 1.0 g/cm^3 for some organic material to 2.65 g/cm^3 for typical siliceous minerals to about 4.0 g/cm^3 for garnet sands. For Stokes' Law settling, V_s is proportional to d^2. Therefore, particle diameter is the most sensitive parameter.

209. In a typical diked containment area, the dredged material slurry is pumped into the disposal site at one point and the supernatants are discharged at a point approximately opposite the inflow point. Factors such as the concentration and nature of the inflow slurry, the size of the disposal area, the relative location of the influent and effluent pipes, the degree of channelization in the flow, the detention time of the fluid, the direction and velocity of the wind, and the extent of vegetation may influence the concentration and nature of the suspended solids in the

effluent.

210. In the absence of any documented and sophisticated analysis, the use of Hazen's sedimentation theory to estimate the proportion of sediment particles in different sizes that will be retained by discrete sedimentation in a disposal area may provide a first-order approximation of sedimentation in a dredged material containment facility.

211. Fair and Geyer (1966) introduced the following simplifying assumptions to devise a framework for the formulation of sedimentation in a continuous-flow basin:

a. Within the settling zone of the basin, sedimentation takes place in a quiescent container of equal depth.

b. The flow is steady and upon entering the settling zone, the concentration of each size is uniform throughout the cross section normal to flow.

c. A particle that settles out is not resuspended.

212. The proportion, E, of particles that are removed in a horizontal-flow basin is given (Hazen, 1904; Fair and Geyer, 1966) by the expression:

$$E = \frac{V_s}{Q/A} \qquad (3)$$

where Q is the mass rate of flow and A is the surface area of the basin. Therefore, for discrete particles and unhindered settling, the efficiency of a basin is solely a function of the settling velocity of the particles, and the surface area and rate of flow through the basin; it is independent of the depth of the basin and the detention period.

213. Factors such as: (a) eddy currents caused by the inertia of the incoming fluid; (b) wind-induced currents; (c) thermal convection currents; and (d) density currents, may reduce efficiency of a settling basin. Therefore, according to Hazen's theory, the proportion, E, of particles

removed in a real basin where currents reduce the efficiency is:

$$E = 1 - \left[1 + \frac{1}{n}\frac{V_s}{Q/A}\right]^{-n} \qquad (4)$$

where n is a performance coefficient for the basin and ranges from unity (very poor performance) to infinity (ideal plug flow).

214. For a particle size of 100 μ or less, the Reynolds numbers are less than unity, and therefore Stokes' Law (Equation 2) is reasonably applicable in the sedimentation region of a disposal area.

215. For a specific gravity of solids equal to 2.67 and a water temperature of 20°C, Equation 2 can be simplified to:

$$V_s = 9,000\ d^2 \qquad (5)$$

where V_s is in cm/sec when d is expressed in cm.

216. Since the efficiency of settling in a real disposal area will be reduced by currents, among other factors, the use of Equation 4 with a performance coefficient of unity (to be conservative) in conjunction with Equation 5 yields an expression for the removed portion, E, of the particles with diameter, d:

$$E = 1 - \left[1 + \frac{9,000\ d^2}{Q/A}\right]^{-1} \qquad (6)$$

where Q/A and d are expressed in cm/sec and cm, respectively. Therefore, when the discharge and surface area of a disposal facility are known, the percentage of particles of various sizes that are removed from suspension by sedimentation can be computed from Equation 6.

217. The removal efficiency of suspended particles

predicted by Equation 6 for different particle sizes of 10 μ, 5 μ, 2 μ, 0.5 μ, and 0.1 μ versus a wide range of surface loadings is plotted in Figure 21. In Figure 22 the removal efficiencies are plotted against the suspended particle size for various surface loadings. The amount of suspended solids of a given size that will settle out of suspension in the disposal area can be estimated from this equation. For example, for a surface loading of 10^{-5} cm/sec, about 80% of the 0.7-μm particles will be removed.

218. The experimental results for both polymer-treated and non-treated columns of sediment slurries and resuspensions are graphically presented in Figures 23 and 24. Settling velocity is also expressed in equivalent overflow rate to facilitate the practical interpretation.

219. As indicated in Figure 23, for the sediment slurries without polymer treatment, there is a slow rate of suspended solids reduction down to about 70 gal/day/ft^2 (2.8 m/day). The rate decreases from this point on. On the average, the efficiencies of plain settling in removing suspended solids without any polymer addition are about 50% at 4 to 8 gal/day/ft^2 (0.16 to 0.32 m/day), 30% at 20 to 25 gal/day/ft^2 (0.80 to 1.0 m/day), and 10% at 70 to 75 gal/day/ft^2 (2.8 to 3.0 m/day) for slurries with sediment/water ratios of 1:4 and 1:10, respectively.

220. The significant portion in extended sedimentation will be the lower end of the curve up to approximately 70 gal/day/ft^2. Apparently, the removal efficiency of suspended solids will be extremely low if no flocculant is used.

221. For the slurries with optimum treatment, in terms of both type and dosage of polymer, very high overflow rates could be applied and still remove a high percentage of solids (Figure 23). For example, with an overflow rate of 100 gal/day/ft^2, efficiencies of 83 and 95% for suspended solids removal could be achieved for slurries with sediment/water ratios of 1:4 and 1:10, respectively.

222. Figure 24 plots the results for suspensions with initial turbidities of 1100, 570, 270, and 150 NTU. The highest removal efficiency was obtained for suspensions with 1100 NTU. For suspensions with low initial turbidity, a lower removal efficiency can be expected (Figure 24). In comparing the suspensions with polymer treatment to those without polymer treatment, a significantly high removal efficiency is observed for polymer-treated suspensions. This occurs even when a high overflow rate is applied.

223. In most cases, the contaminants are found to be particulate-associated in this study. The removal of suspended solids and turbidity shown in Figures 23 and 24 shows that better quality can be expected from polymer-treated effluent.

224. Other pertinent findings of this study are summarized as follows:

a. For a specific removal efficiency of suspended solids or turbidity, the required design overflow rate can be calculated from the calibrated curve derived from the batch column study.

b. If a specific removal efficiency has to be met by an extended sedimentation process (without any polymer coagulation) for a sediment slurry (or resuspended sediments), the necessary detention time is about 9.4 days (225 hrs) if water depth of the diked area is 5 ft (1.5 m) at a design flow rate of 4 gal/day/ft^2 (0.16 m/day) (Figure 24).

c. Extended sedimentation efficiency at different design overflow rates could be predicted for a specific type of slurry or suspension. Assuming an original suspension turbidity of 570 NTU, with an overflow rate of 20 gal/day/ft^2, a turbidity removal efficiency of 50% could be found from Figure 24 for that specific suspension used in this study.

d. When the polymer flocculation process is applied to sediment slurries or suspensions, a removal efficiency higher than 90% could be achieved even at a high overflow rate of 1000 gal/day/ft^2.

225. The polymer flocculation process will increase the particle size and consequently increase the terminal settling velocity of the particles released in the containment area.

226. For small, limited disposal areas, the use of polymers for the treatment of both dredged slurries and their suspensions could prove to be a useful alternative for meeting water quality standards set by applicable regulatory agencies.

227. Provided an adequately large disposal area, sedimentation without polymer pretreatment may be a valid solid-liquid separation technique for the clarification of disposal area supernatants.

Short-Term Column Studies

228. Two types of short-term experimental tests were conducted at room temperature (25 $\pm 2^{\circ}$C): (1) treatment of dredged slurries; and (2) treatment of supernatants from resuspensions of dredged material.

Treatment of dredged slurries

229. Preliminary tests indicated that WT-3000 polymer was one of the most effective polymers in the treatment of slurries. Optimal dosages of 10 ppm and 3 ppm of WT-3000 were applied, respectively, to the columns with sediment/seawater ratios of 1:4 and 1:10 for sediment #6.

230. Laboratory observations during these column studies

showed that proper mixing is very important in obtaining optimal flocculation. Gentle agitation causes larger flocs to form, composed of only part of the suspended solids. Even though rapid settling occurs, the supernatant liquid is left somewhat turbid. For violent or prolonged agitation, flocs were found to be broken prior to settling. This leaves a turbid supernatant liquid with many small, light flocs in suspension. An optimum mixing time of 2 minutes at a pressure of 2 psig from a purified-air cylinder was applied to the column to aid flocculation.

231. When the sediment-water mixtures are poured into the water columns, the levels of dissolved oxygen immediately drop to almost zero in most cases, due to the high IDOD of most sediments. Bubbling of compressed air to the polymer-treated column for coagulation helped to recover dissolved oxygen concentration in the polymer-treated water column up around 1.0 ppm temporarily. Upon the termination of bubbling, D.O. dropped to zero ppm again within a short time for both ratios of 1:4 and 1:10.

232. pH values during the experiment were observed in the range of 7.5 to 7.7. Variations in pH were insignificant in all cases. No detectable sulfide was released into the water column when compressed air was bubbling.

233. By using polymer labeled with radioactive carbon, Black et al. (1965) determined that 85% of the polymer adsorption and 100% of zeta potential neutralization occurred within 30 seconds after adding the polymer, but that an additional 10% adsorption was obtained by extending the agitation period up to 30 to 40 minutes. It was also observed in this study that the rate of polymer flocculation (reaction) appears to be extremely rapid.

234. Immediately following the flocculation process, a mass of aggregates was observed to settle as a blanket with a distinct interface between the settling slurry and the clarified supernatant. The height of the interface level vs.

time for each column was plotted in Figure 25. Faster zone settling velocities and clearer supernatants were observed for the polymer-treated slurries; there was no significant difference in the release of organic nitrogen.

235. General water quality parameters such as total suspended solids, total phosphorus, and total nitrogen at different depths of the water columns with and without polymer treatment were determined. Results are shown in Figures 26 to 28.

236. As shown in Figures 26 to 28, it is clear that the removal patterns of total phosphorus and total nitrogen are quite similar to that of the suspended solids. Soluble nutrients in the water column are presented as follows:

Sediment/ Seawater (by volume)	Time Elapsed (hr.)	Nutrients (ppm)			
		T-P		TKN	
		A*	B	A	B
1/4	0	--	0.18	--	0.35
	0.5	0.10	0.10	0.25	0.27
	2.0	0.10	0.15	0.20	0.30
1/10	0	--	0.10	--	0.25
	0.5	0.07	0.07	0.20	0.20
	2.0	0.05	0.07	0.10	0.13
Background Seawater		0.03		0.10	

* A: Treated with Calgon WT-3000
B: No treatment
-- Not determined

237. The negligible amount of total phosphorus and total Kjeldahl nitrogen in the solution phase also confirmed that these nutrients are mainly associated with particulate fraction.

238. As shown in Figures 27 and 28, rapid removal of T-P and TKN was observed. Big flocs and fast zone settling

velocity were recorded with a somewhat turbid supernatant with residual T-P of 0.1 to 0.6 ppm and TKN of 1 to 35 ppm in the polymer-treated columns with sediment/seawater ratios of 1:4 and 1:10.

239. The concentrations of trace metals in the soluble phase at different time intervals are presented in Table 32. There is no indication that any soluble phase of trace metals was removed by polymer Calgon WT-3000. A slightly higher soluble concentration of trace metals was found in the polymer-treated column on several occasions. This might be attributed to contamination or experimental error.

240. Windom (1972 and 1973) suggested that heavy metal scavenging by freshly precipitated ferric oxyhydroxides may be contributing to the observed reduction in soluble trace metals when dredged materials are disposed of in water columns. In this study, dispersion of sediment in water (1:4 and 1:10) was not followed by metal release of any significant quantity except Zn and Fe, which were still in the ppb range.

241. In comparison with those of background water, a higher concentration of soluble trace metals was found in the water columns in most cases (except for Cd and Ni). The release of trace metals in this short-term study is most likely due to the dilution of interstitial waters, dissolution of the solid phase through complex formation, and release from the exchangeable phase. Higher soluble concentrations of trace metals were found in the water column with a 1:4 sediment/water ratio than those in a 1:10 sediment/water ratio.

242. The levels of trace metals with and without polymer treatment are presented in Figures 29 to 37. Obviously most of the trace metals removal is associated with the removal of suspended solids from water columns.

243. Zone settling of sediment/water mixtures (1:4) with optimum flocculation conditions (optimum mixing rate and

dosage) for sediment #7 was also conducted with Betz 1120 and Calgon WT-3000 polymers at different salinities. Higher zone settling velocities were observed with increasing salinities. The results are presented in Figures 38 and 39.

244. In general, Calgon WT-3000 and Betz 1120 polymers were found to be equally effective in producing clear supernatants, reducing sediment volumes (densification), and increasing zone settling velocities.

Treatment of resuspensions from contaminated sediments

245. Typical water quality resulting from the resuspension of contaminated sediments after two hours of sedimentation (without any pretreatment) is shown in the following table.

Total Suspended Solids (%)	Total P (ppm)	Total N (ppm)	Total Trace Metals (ppm)								
			Ag	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
0.1 - 8	2 - 10	5 - 80	0.03-0.05	0.02-0.4	0.5-8.0	0.5-6.0	280-4700	3.0-99	2.0-68	0.07-2.8	2.0-17.0

246. It is obvious that in most cases, concentrations of trace metals and biostimulants are all in the ppm range. Most of these parameters exceed the allowable discharged requirement imposed by regulatory agencies.

247. Betz 1160 polymer was found to be one of the most effective polymers in the treatment of sediment #6 resuspensions in the preliminary study. It was further evaluated in the column study. Optimum dosages of 2 and 5 ppm of Betz 1160 were applied to the suspensions with initial turbidity levels of 1100, 570, 270, and 150 NTU.

248. The results are presented in Figures 40 to 50. Rapid removal of contaminants was observed immediately after flocculation. When a detention time of a few minutes is provided, the concentration of contaminants in the treated effluent can be drastically reduced to the ppb range.

Release of Chemical Constituents After Resedimentation

249. The release of chemical constituents from resettled sediments was evaluated in three columns under different environmental conditions: (1) anaerobic control column, without polymer treatment; (2) anaerobic column, polymer treatment; (3) aerobic column, polymer treatment.

250. The D.O., pH, and $S(-II)_T$ were measured at different time periods up to 70 days. The dissolved oxygen level in the aerobic column was maintained at 2.5 ppm to 3.5 ppm (Figure 51). The pH was not controlled during the 70-day test period. The pH level in the three columns increased slowly with time; the anaerobic column without polymer treatment showed the largest variation, from 7.1 to 7.6 (Figure 52).

251. The aerobic, polymer-treated column showed the lowest pH value among the three columns. The production of hydrogen ions by oxidation reactions such as oxidation of ferrous iron and manganous manganese could account for this behavior.

252. No detectable sulfide was found in the aerobic, polymer-treated column. The oxidation of reduced sulfur species to sulfate would lower the pH of the slurry in the column.

253. Figure 53 shows the total dissolved sulfide in the two anaerobic columns which increased slowly with time; the total dissolved sulfide concentration in the untreated column was approximately 60% greater than that of the polymer-treated column.

254. The relative release of nitrogen compounds (NH_3-N and organic-N) is presented in Figure 54. The concentrations of both NH_3-N and organic-N increased during the first 20 days, followed by a gradual decrease during the rest of the test period. The anaerobic column, without polymer treatment, showed the largest release of NH_3-N. After

seventy days of contact, the NH_3-N in the aerobic column decreased to zero due to oxidation to nitrate nitrogen. After thirty days of contact, no significant difference in the release of organic-N was observed for the three test columns. The release of orthophosphate and total phosphorus is shown in Figure 55. The anaerobic column, without polymer treatment, showed the largest release of orthophosphate; the anaerobic and aerobic colums, with polymer treatment, showed similar lower release levels. The release of total phosphorus increased during the first fifteen days, then gradually decreased to minimum levels during the 70-day contact period. The minimum concentration levels were reached after sixty days and are comparable for the three test columns.

255. The availability of phosphorus compounds released from the sediment into the overlying water is complex in nature. Serruya (1972) suggested that in sediments, phosphorus may exist as calcium phosphate, organic phosphorus, orthophosphate dissolved in the interstitial water, aluminum and iron phosphate compounds, and phosphates adsorbed on silicates. Therefore, the availability of phosphorus compounds in the overlying water may be dependent upon complex chemical, biological, and physical reactions. The exact retention mechanism of phosphorus by polymer-flocculated sediments is not known; however, it is believed that the oxygen concentration in the overlying water may play a major role. The existence of oxygen in the overlying water will result in an aerobic sediment layer. Even though this aerobic layer, reported by Fillos and Molof (1972), may not be more than a few millimeters deep, it may possess a certain capacity of adsorption by which phosphorus will be retained by the sediments.

256. An assessment of mobilization of trace metals in nontreated and polymer-treated particulates was conducted to gain additional insight concerning the possibility of

release of trace metals to overlying waters. The results are presented in Figures 56 to 58.

257. Figure 56 shows that Cd can be significantly released under these experimental conditions. In the long-term leaching study, the Cd concentrations in the interfacial water were increased about 80 times, from the original background level of about 0.05 ppb to about 6.5 ppb, after two months of contact for the polymer-treated column with a dissolved oxygen concentration of 2.5 to 3.5 ppm. Under an anaerobic condition, the Cd concentration was found to increase up to 8 ppb at the end of the contact period.

258. No significant difference in the release of Cd from the settled sediments to interfacial waters was noted between the aerobic and anaerobic sediments of the polymer-treated columns. The trend of releasing patterns tends to be the same with the exception of a lower releasing rate at the beginning of the contact period for the aerobic, polymer-treated column.

259. In general, chromium concentrations were found to be below that of the background level. No significant change was observed (Figure 56). After two months incubation period, the Cr concentration in these three different columns seemed to reach a steady concentration of 0.2 ppb. The Cr concentration in the interfacial water of the nonpolymer-treated column showed a slightly higher amount compared with that of the polymer-treated columns during the incubation period. The original background Cr concentration was about 0.55 ppb, which was decreased to about 0.2 ppb after five days of contact, indicating a relatively quick precipitation of $Cr(OH)_3$ under all conditions.

260. When background water and sediment from Mobile Bay were contacted, scavenging effects were observed in the anaerobic, polymer-treated column (Figure 56). However, after a 30-day incubation period, the Cu concentration in the interfacial water was increased to above the background

concentration of 0.5 ppb. A concentration of 1.4 ppb was observed at the end of the 70-day contact period.

261. Among the three experimental conditions, Cu was found to have the highest release in the aerobic polymer-treated column with a concentration of 2.6 ppb after 70 days of contact. The concentration is about five times higher than the original background level.

262. In the anaerobic, nonpolymer-treated column, Cu was increased to a high level in about 8 days, followed by a very fast rate of removal to below the background level. After 20 days of contact, the Cu concentration was then increased above the original background level.

263. Iron was found to be released in high concentrations (up to 0.9 ppm) from the sediment into the interfacial water during the first fifteen days of contact in the three test colums followed by a decreasing trend (Figure 58). After 70 days of contact, the concentration of iron in the interfacial waters of these three columns decreased to 15 ppb. A very high concentration (37 ppb) of iron was also detected in the background Mobile Bay water. The aerobic polymer-treated column showed the lowest release. The control column, which was anaerobic without polymer treatment, showed the highest release.

264. A comparison of Hg concentrations in the interfacial water under all three different columns is shown in Figure 56. Like Cr, the Hg concentration in the interfacial water of these three different columns decreased to a level below that of the original background water after a 5-day contact period.

265. Concentrations of Hg in the interfacial waters were found to be relatively constant for these three columns, with only slight variations. Concentrations between 0.2 and 0.5 ppb seem to indicate that mercuric sulfide is the main controlled solid.

266. Soluble manganese of up to 2-3 ppm was found to be released into the interfacial water (Figure 57). The release phenomena of Mn were found to be similar to those of Fe, but at a somewhat slower rate. For a silty-clay sediment, the release follows the order of:

anaerobic nonpolymer treated > anaerobic polymer-treated > aerobic polymer-treated.

267. Under aerobic conditions, the release of Mn was quite insignificant. The final concentration of Mn in the anaerobic nonpolymer treated column was about 72 times the original background (55 ppb). For the anaerobic polymer-treated column, the concentration in the interfacial water was about 55 times that of the original (55 ppb).

268. For the aerobic, polymer-treated column, the concentration of Mn in the interfacial water reached the level of two ppm for the polymer-treated columns after 70 days of contact.

269. Concentrations of Ni in the interfacial waters of all three columns were found to be 3 to 5 times that of the original background water, and approaching the value of five ppb in all cases after 70 days of contact.

270. Similar to the release of Cu in the anaerobic column without polymer treatment, Ni showed a high releasing rate during the first two days of contact time. The concentration of Ni in the interfacial water decreased again during the 2-5 day contact period. As time proceeded, the releasing pattern was observed to be similar for both anaerobic columns.

271. A similar Pb releasing pattern was observed for all three columns. Only a slight increase in the Pb concentration was observed after a 2-day contact period. A relatively constant concentration of Pb was found in the interfacial water during the 70-day contact period. Among these three columns, the concentration of Pb in the interfacial waters was maintained within a range of 2.5 to 3.5 ppb, even after 70 days of contact.

272. The transport phenomenon of Zn also followed the same trend as Pb, showing higher concentrations in the interfacial water of the aerobic polymer-treated column (Figure 57). Under an anaerobic environment, the final Zn concentration was about 12 ppb for both the nonpolymer and polymer-treated columns. The releasing pattern for Zn in the interfacial water follows the order:

aerobic polymer-treated > anaerobic nonpolymer treated > anaerobic polymer-treated.

273. Other findings in this trace metals leaching study are summarized as follows:

a. Manganese (Mn) showed the highest release up to several ppm.

b. Ni, Pb, Zn, Cd, and Cu were released in the ppb range under the studied conditions.

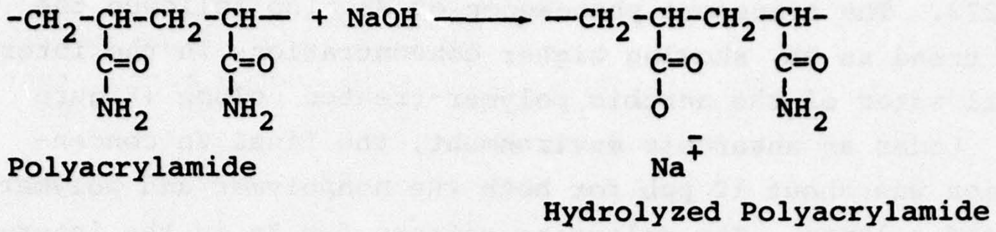
c. Mercury and chromium concentrations in the interfacial water were found to be less than that of the original background water after 5 days of contact time. However, the concentration was maintained in the sub-ppb range during the rest of the experimental period.

d. For the polymer-treated sediment in both the aerobic and anaerobic columns, smaller amounts of Mn and Cd were released compared with that of the control column.

e. Smaller amounts of Mn, Zn, Pb, and Cu were released in the anaerobic, polymer-treated column compared with the aerobic polymer-treated column.

Proposed Mechanisms of Polymer Flocculation

274. Calgon WT-3000 polymer is a hydrolyzed product of polyacrylamide with the following chemical reaction:



$$-CH_2-\underset{\underset{NH_2}{|}}{\underset{C=O}{|}}{CH}-CH_2-\underset{\underset{NH_2}{|}}{\underset{C=O}{|}}{CH}- + NaOH \longrightarrow -CH_2-\underset{\underset{\underset{Na^+}{O^-}}{|}}{\underset{C=O}{|}}{CH}-CH_2-\underset{\underset{NH_2}{|}}{\underset{C=O}{|}}{CH}-$$

Polyacrylamide

Hydrolyzed Polyacrylamide

Possible reactions involved between the polymer and suspended particulates are: bridging, adsorption, binding, entrapping, and electrolytic action.

275. Calgon WT-3000, an anionic polymer, is not involved with the neutralization of negatively charged particles, and functions as a flocculant almost exclusively through the bridging action.

276. Most polymers are macromolecules with very high molecular weights. When a polymer is dispersed in resuspension, the long, linear, ionized chain is spread out by repulsion of a like charge distributed along its colloidal chain. Such a large molecule makes an excellent "trap" for suspended impurities. They also can be thought of as making a "long bridge" for coagulated particulates (bridging action) to adsorb on, and thus causing larger and heavier, faster settling "flocs."

277. Many aspects of coagulation remain elusive and are not clearly understood. A bridging model is conceptualized as follows (Weber, 1972):

a. The individual adsorption at the optimum polymer dosage takes place when a polymer molecule comes into contact with colloidal particles (resuspensions). Some of the active substituent groups adsorb on the particle surface leaving others extended out into the solution.

b. When a second particle with available adsorption sites contacts the extended portion of the polymer chain, floc formation flocculation takes place and a bridge is formed.

c. If the extended portion in the initial adsorption at the optimum polymer dosage fails to contact a second particle with vacant adsorption sites within a specified time period, the extended portion may adsorb on the other sites of the original particle in such a manner that the particle is no longer capable of forming a bridge and the particle is restabilized.

d. If the initial adsorption exceeds the polymer dosage, the colloidal particles can be restabilized. This is due to the unavailability of sites for forming interparticle bridgings.

e. Restabilization of a floc may also occur as a result of excessive mixing. Particle-polymer bonds are broken and the particles become restabilized by interparticle adsorption of the extended segment.

278. Divalent ions such as calcium present in the resuspensions may also improve the polymer-resuspension system in the following ways: (1) by compressing the thickness of the double layer of the clay particles, thereby reducing interparticle repulsive forces; (2) by reducing the repulsive forces between the anionic polymer and clay particle; and (3) by reducing interactions between polymer molecules adsorbed on clay particle surfaces.

279. The ionized polyelectrolytes can form reasonably stable complexes with divalent metal ions. This has been reported by Sommerauer et al. (1968). A fraction of the functional group ($-COO^-$) of the polymer Calgon WT-3000 used in this study may be associated with metal ions to have complex forms such as $R\text{-}COO\text{-}Me^+$, $R\text{-}COO\text{-}M\text{-}OOC\text{-}R$. In this manner the soluble phase of trace metals could not be expected to be removed from the bulk of the solution.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

280. This study shows, conclusively, that flocculation and sedimentation can remove a major fraction of contaminants resulting from the confined disposal of dredged materials. In some cases, where sand is the major component of sediments, if adequate retention time (>4 hours) is provided, sedimentation alone can produce an acceptable effluent for discharge.

281. The major findings of this study are summarized as follows:

a. Comparison of settling rates in the standard jar test showed that organic polymers were more effective than conventional inorganic flocculants (alum and ferric sulfate) in achieving rapid sedimentation and clarification of supernatants. It was found that massive doses of Fe(III) and Al(III) salts were required to obtain clear supernatants.

b. Alum and ferric sulfate flocculants are not acceptable for the treatment of dredged material, not only because of the high dosages required, but also because these inorganic flocculants result in carry-over of trace metals in the effluent. Furthermore, polymers affect pH to a minor extent, thereby eliminating the need for pH adjustment of the treated effluent.

c. Many of the synthetic flocculants studied provide good settling rates and clarification. The anionic flocculants, i.e., Calgon WT-3000 and Betz 1120, were found to be the most effective polymers for the treatment of sediment slurries. The cationic flocculants, i.e., Betz 1160, Betz 1150 and Hercofloc 849, etc., were found to be most effective in clarifying supernatants with turbidities up to 1000 NTU for the materials studied. These results are not meant to imply that the cited flocculants are the most effective for all sediments. Flocculant selection must be on a site-specific basis.

d. It was found that a supernatant having a high level of turbidity (1000 NTU) is easier to clarify than supernatant with a much lower level of turbidity (100 or 250 NTU). Obviously, it is necessary to have impingement or collision of particles for agglomeration and sedimentation. When the concentration of particles is low, the frequency of collisions is also low, which results in slow floc formation.

e. Preliminary jar tests will be necessary under all circumstances to determine the optimum dosage of flocculant. The validity of the standard jar test was confirmed by the batch scale column studies.

f. Characterization of resettled sediments shows no significant differences in the soil properties such as plastic limit, liquid limit, and plasticity index with and without polymer treatment. However, significant improvement in the coefficient of permeability was observed for polymer-treated sediments.

g. A preliminary polymer screening experiment is necessary in the selection of the most effective polymer for a specific sediment slurry to be treated. The optimum dosage range was found to be dependent on the sediment characteristics. Among the general sediment characteristics, COD and particle size distribution could be used as guidelines in the selection of optimum polymer dosage range.

h. Direct relationships between polymer dosage requirements and the initial turbidity of the supernatants have been demonstrated. Larger polymer dosages are needed for supernatants with higher initial turbidity levels.

i. The optimum dosage of a polymer is closely related to the level of salinity and initial turbidity of suspensions. A suspension with high salinity and low initial turbidity usually demands less polymer.

j. The polymer-treated particulates do not show, in most cases, a significant difference in the release of contaminants and biostimulants from that of the untreated sample.

Recommendations

282. Optimum turbidity removal was achieved when the coagulant was dispersed very rapidly and uniformly throughout the entire body

of water to be treated. There were indications that a diluted solution of polymer may offer some mixing advantages that promote rapid and uniform dispersion. Dilution of the polymer mixture down to a 0.1 percent solution seems to be quite effective judging from the results obtained.

283. The following recommendations are made:

a. Before any promising treatment process can be confirmed, selected synthetic polymers should be evaluated in field studies for the treatment of dredged material and supernatants. Only modest polymer dosages were required in the dredged material tested. Polymers can, therefore, be regarded as being relatively cheap even though the price per pound of these materials is much higher than the price per pound of inorganic coagulants, such as lime, ferric chloride, and alum. For example, dosage requirements of only 2 to 7 ppm are common for polymers, while dosages of 100 ppm are required for some inorganic coagulants. Moreover, costly pH adjustments are not required when polymers are used.

b. Considering the factors such as the volume of the dredged material to be treated, the dosage of some specific polymers, and the water quality of the treated slurry, the direct treatment of nonsettled dredged material would not be practical. However, a 60 to 120 minute settling time, followed by the treatment of supernatants with 2 to 7 ppm Betz 1160 polymer would yield an acceptable effluent. This suggests the use of a settling basin for in-situ operations. The settling basin would provide for the removal of readily settleable materials and allow for overflow into the flocculators. Flocculation of the remaining solids would be carried out in the flocculators before return of the clarified supernatant to the receiving waters. Retention times can be estimated for the settling basin and flocculators, depending on the characteristics of the dredged material. Retention times of 1-2 hours for the settling basin and 10 minutes for the flocculator will, in most cases, produce an effluent of acceptable quality.

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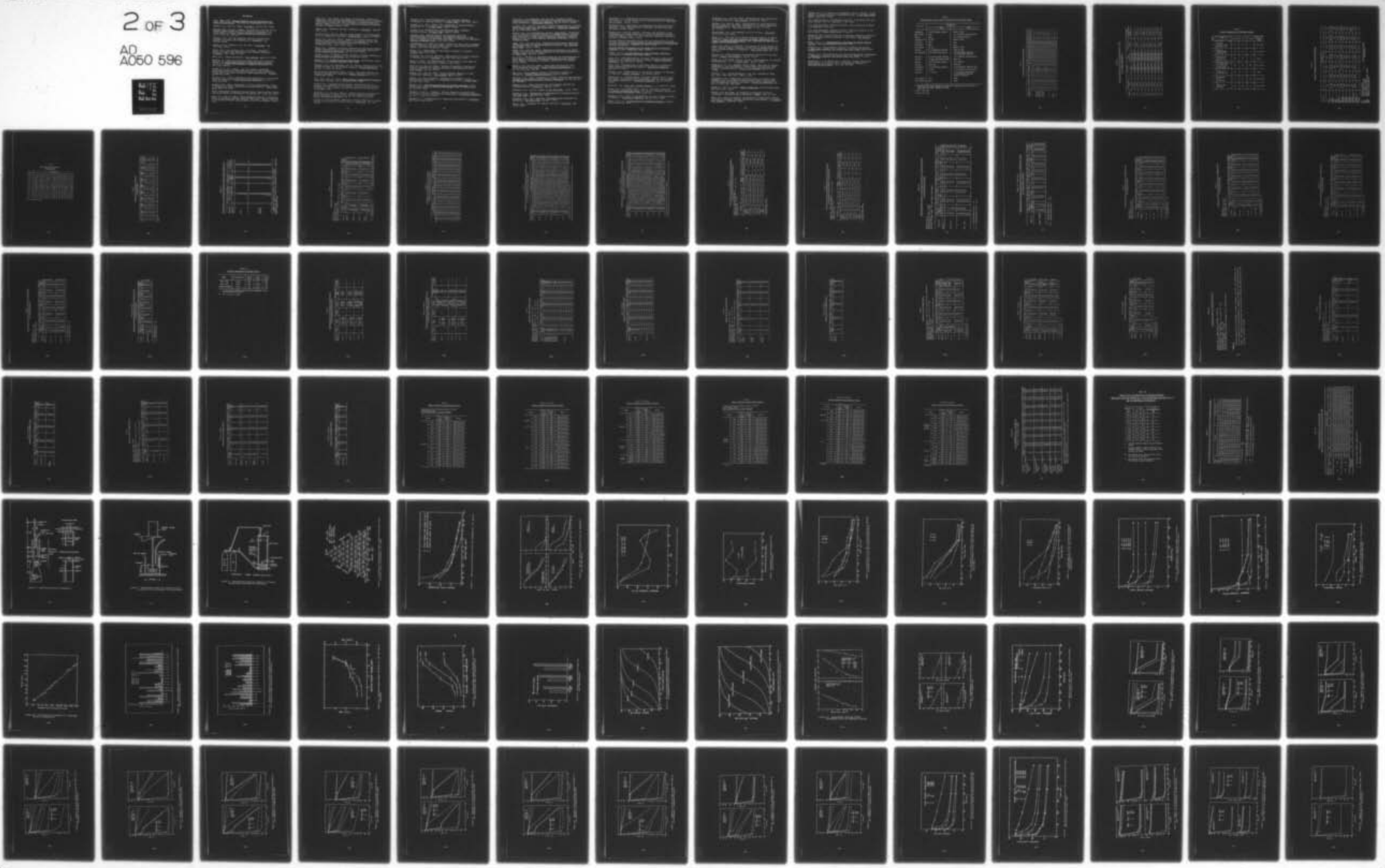

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Table 1

Recent Effluent Water Quality Standards From Disposal Areas

District	Standards*	
	1973	1975
Galveston	8 g/l(SS)above ambient	Same as 1973
New Orleans	None	1.5 x ambient concentration
Mobile	None	50 JTU above ambient
Jacksonville	50 JTU	Same as 1973
Savannah	None	None
Charleston	None	None
Wilmington	50 JTU	Same as 1973
Norfolk	13 g/l(SS)above ambient	Same as 1973
Philadelphia	8 g/l(SS)above ambient	8 g/l(SS)above ambient** 4 g/l(SS)above ambient†
New York	8 g/l(SS) above ambient	1.5 x ambient concentration
Buffalo	50 ppm settleable solids	None set
Detroit	8 g/l(SS)above ambient	No standards
Chicago	None set	None set
Sacramento	8 g/l(SS)above ambient	6 g/l(SS)above ambient conc.
Portland	5 JTU	1.5 x ambient concentration
Seattle	5 -10 JTU	5 JTU (State Requirement) 5 g/l(SS)above ambient (Corps Criterion)
Los Angeles	None	None
San Francisco	None	None

* Standards were State imposed or voluntarily imposed by the District in cases where no State standard existed

** Small size area

† Large size area

Table 2

Working Conditions for HGA Injection Method

Sample Background	Element	Wavelength (nm)	Slit No.	Background Corrector	Sample Size (µl)	Drying		Charring		Atomizing		Sensitivity
						Temp °C	Time sec	Temp °C	Time sec	Temp °C	Time sec	Pg/0.0044 A
APDC-MIBK Extraction 6N Ultrex HNO_3 back extraction (Aqueous)	Ag	328.1	4	Without	5 - 10	125	20	650	30	2450	7	---
	Cd	228.8	4	With	10 - 25	115	30	400	30	1500	8	1.5
	Cu	324.7	4	With or Without	10 - 25	115	30	1000	30	2500	8	30
	Fe	248.3	3	With	10 - 25	120	20	1000	20	2400	6	15
	Ni	232.0	3	With	10 - 25	115	30	1200	20	2500	7	100
	Pb	283.3	4	With or Without	10 - 25	115	30	500	40	2000	6	20
	Zn	231.9	4	With	10 - 25	125	30	650	30	2000	8	0.5
Saline Water	Cr	357.9	4	With	10 - 25	115	30	1250	25	2600	8	---
	Fe	248.3	3	With	10 - 25	120	20	1250	50	2400	7	---
	Mn	279.5	3	With	10 - 25	120	30	1150	40	2500	8	---

Table 3

Working Conditions for the Flame Atomizer of the A. A, Spectrophotometer

Element	Wavelength (nm)	Slit	Oxidant & Fuel	Flame *Condition*	Sensitivity (ppm)	Suitable Working Range (ppm)
Ag	328.1	4	Air-acetylene	oxidizing-lean blue	---	---
Cd	228.8	4	Air-acetylene	oxidizing-lean blue	0.025	0,025 - 2
Cr	357.9	4	Air-acetylene	*reducing*-rich yellow	0.1	0.1 - 5
Cu	324.7	4	Air-acetylene	oxidizing-lean blue	0.09	0.09 - 5
Fe	248.3	3	Air-acetylene	oxidizing-lean blue	0.12	0.12 - 5
Mn	279.5	3	Air-acetylene	oxidizing-lean blue	0.06	0.06 - 3
Ni	232.0	3	Air-acetylene	oxidizing-lean blue	0.15	0,15 - 5
Pb	283.3	4	Air-acetylene	oxidizing-lean blue	0.5	0.5 - 20
Zn	231.9	4	Air-acetylene	oxidizing-lean blue	0.018	0.018 - 1

Table 4

Textural Composition of Sediment Samples

Sed. No.	Composition / Location	% Sand	% Silt	% Clay	Class. of Sediment Type
1	Clinton Disposal Area Houston, TX	77	16	7	Silty Sand
2	Houston Ship Channel Houston, TX	78	15	7	Silty Sand
3	Rouge River at Detroit Detroit, MI	83	12	5	Sand
4	Anchorage Basin in Cape Fear River Mouth Wilmington, NC	16	46	38	Silty Clay
5	James River Richmond, VA	97	2	1	Sand
6	Calcasieu River Louisiana	21	43	36	Silty Clay
7	Mobile Bay Alabama	55	33	12	Silty Sand

Table 5

General Parameters of Sediment Samples

Parameter	Sediment No.						
	1	2	3	4	5	6	7
M.C.*	35	37	44	80	39	68	52
T.V.S. (ppm)	47,400	47,500	44,700	170,000	31,000	68,000	52,000
T.O.C. (%)	0.83	0.90	0.82	3.04	0.69	2.0	1.36
IDOD (mg/kg)	590	500	160	1540	140	440	1620
COD (mg/kg)	25,300	26,700	25,300	163,000	16,000	99,800	37,400
Total-N (mg/kg)	890	1000	900	3690	176	2820	1470
Total-P (mg/kg)	455	450	352	1670	420	831	636
Sulfide (mg/kg)	451	430	53	21	trace	55.2	689.0
Oil & Grease (mg/kg)	3800	3900	3010	6590	1570	2810	837
Salinity (o/oo)	--	--	--	2.0	0.5	18	15

MC: Moisture Content
TVS: Total Volatile Solids
TOC: Total Organic Carbon
IDOD: Immediate Dissolved Oxygen Demand
COD: Chemical Oxygen Demand

*M.C.: $\left(\frac{\text{Wet Weight - Dry Weight}}{\text{Wet Weight}}\right)$

Table 6

Concentration of Trace Metals in Sediment Samples

Element	Sediment No.						
	1	2	3	4	5	6	7
Ag	1.29	0.96	1.56	0.70	0.30	0.25	0.41
Cd	0.69	0.37	0.68	1.96	0.29	0.98	2.30
Cr	57.0	39.3	110	92	5.7	60	135
Cu	44.9	61.2	111	87.1	10.2	55.9	89.4
Fe	12,900	8800	15,200	44,000	1960	21,000	46,000
Mn	159	108	376	478	54	683	969
Ni	50.1	41.2	115	43.5	18.8	47.8	91.8
Pb	17.7	12.8	23.5	22.9	3.8	10.9	20.7
Zn	119	71.0	187	109	5.8	72.2	29.5

Units in mg/kg dry weight

Table 7

Concentrations of Chlorinated Hydrocarbons in Sediment Samples

Sediment No.	Moisture Content (%)	OP'DDE / t-DDT (%)	PP'DDE / t-DDT (%)	OP'DDD / t-DDT (%)	PP'DDD / t-DDT (%)	OP'DDT / t-DDT (%)	PP'DDT / t-DDT (%)	Total DDT (ppm)	Total Chlorinated Hydrocarbons (ppm)
4	78	29.1	42.7	--	--	28.9	--	0.11	0.11
5	29	41.2	59.8	--	--	--	--	0.04	0.04
6	66	28.0	36.9	--	--	--	32.4	0.13	0.13
7	65	15.3	23.0	15.0	17.5	15.4	13.8	0.28	0.28

PCB (Arochlor 1242, 1254 and 1260), heptachlor epoxide, chlordane, endrin, dieldrin are below detection limit.

Table 8

Determination of Minimum Dosage for Conventional Coagulants

Coagulant	Conc. of Coagulant (ppm) as Al (III) or Fe (III)	Residual* Turbidity (NTU)	% Removal in Turbidity
Control	0	370	--
Alum	5	92	76
	10	62	84
	20	50	87
	30	49	87
	40	65	83
	50	67	82
	250	90	76
Ferric Sulfate	10	60	84
	20	37	90
	30	31	92
	40	30	92
	50	25	94
	60	43	89
	70	46	88
	80	63	83
	90	70	81
	100	75	80
	150	98	74
	200	230	38
	250	250	23

* Dosage of 20 ppm was chosen as the minimum dosage

Seawater was used to prepare the background turbidity of 960 NTU

pH of seawater ≈ 8.02

Table 9

Determination of Optimum Dosage for Conventional Coagulants

Sediment No.: 7
Dates of Collection: 2-4-76
Classification: silty sand
Salinity of Sediment: 15 o/oo
Salinity of Water Used: 33 o/oo (Reference point sea water)

Coagulant	Conc. of Coagulant (ppm)		Floc Hgts at Beginning of slow mixing (cm)		Floc Hgts at end of slow mixing (cm)		Floc Hgts at end of settling (cm)		Residual Turbidity (NTU)	
	A*	B**	A	B	A	B	A	B	A†	B
Control	0	0	12.5	12.5	10.0	9.0	9.0	5.0	16,000	150
Alum (as Al(III))	50	50	12.5	12.5	10.0	9.0	9.0	5.0	12,800	80
	100	100	12.5	12.5	10.0	9.0	9.0	5.0	14,400	50
	200	200	12.5	12.5	10.0	8.5	8.5	5.0	14,400	30
	400	400	12.5	12.5	10.0	8.5	8.5	5.0	15,000	32
	800	800	12.5	12.5	10.0	8.5	8.0	5.0	16,200	35
	1000	1000	12.5	12.5	10.0	9.0	8.0	5.0	14,600	51
	1500		12.5		10.0		8.0		17,000	
Control	0	0	12.5	12.5	10.0	9.0	9.0	6.0	16,000	140
Ferric Sulfate (as Fe(III))	100	100	12.5	12.5	9.5	9.0	9.0	6.0	14,000	42
	200	200	12.5	12.5	9.5	8.5	9.0	6.0	14,000	35
	400	400	12.5	12.5	9.5	8.5	9.0	5.5	15,000	25
	800	800	12.5	12.5	9.5	8.5	8.0	5.5	16,000	20
	1000	1000	12.5	12.5	9.5	8.5	8.0	5.5	17,000	20
	1500	1500	12.5	12.5	9.5	9.0	8.0	5.5	20,000	39
	2000		12.5		10.0		9.0		18,000	

* A: Sediment/Water Ratio: 1:4
** B: Sediment/Water Ratio: 1:10

† A: Sample for turbidity was taken 2" below surface
B: Sample for turbidity was taken 0.5" below surface

Table 10

Percentage (%) of Trace Metals, TOC, T-P, and TKN in Different Size Fractions of Dredged Sediments

	Sediment #4			Sediment #5			Sediment #6			Sediment #7		
	< 5 µm	5 - 50 µm	>50 µm	< 5 µm	5 - 50 µm	>50 µm	< 5 µm	5 - 50 µm	>50 µm	< 5 µm	5 - 50 µm	>50 µm
Dry Weight	38	46	16	1	2	97	36	43	21	12	33	55
Ag	56	35	9	62	23	15	53	34	13	57	37	6
Cd	48	29	23	28	37	35	68	24	8	41	42	17
Cr	38	56	6	65	28	7	47	45	8	25	65	10
Cu	42	51	7	28	40	32	54	29	17	34	58	8
Fe	36	61	3	80	12	8	52	39	9	19	68	13
Mn	72	16	12	41	46	13	52	45	3	21	65	14
Ni	27	48	25	10	52	38	58	24	18	19	45	36
Pb	36	56	8	31	61	8	46	51	3	25	65	10
Zn	44	54	2	28	65	7	61	31	8	25	62	13
T.O.C.	29	58	13	31	46	23	32	59	9	21	42	37
T-P	34	54	12	10	16	74	31	20	49	15	35	50
TKN	30	55	15	24	26	50	29	26	45	21	47	32

Table 11.

Residual Turbidity of Supernatants With Different Initial Turbidity Levels After Treatment at Different Polymer Dosages

Salinity Level	Original Turbidity (NTU)	Polymer Dosages (ppm)													Control Blank (NTU)
		0.5	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	
33 o/oo	100	9.0	5.0	3.0	3.0	3.75	4.0	5.2	5.3	--	--	--	--	--	78
	250	--	4.4	1.9	1.8	1.8	1.8	2.2	2.8	2.8	2.9	--	--	--	186
	540	14	8.4	5.0	2.8	2.7	1.3	1.2	1.5	2.0	--	--	--	--	400
	1000	47	10	4.4	3.6	2.4	1.7	1.3	1.1	1.3	1.8	--	--	--	750
	2000	--	24	4.2	4.3	3.2	2.7	2.3	2.1	1.5	1.5	1.5	2.0	--	1800
	5000	--	120	--	63	30	--	13	--	7.0	--	--	--	3.0	4000
16 o/oo	100	10	5.0	3.2	3.0	3.0	4.0	5.2	5.3	--	--	--	--	--	85
	250	--	4.9	2.8	1.8	1.8	1.8	2.4	2.5	2.7	2.9	--	--	--	194
	540	15	8.6	4.6	3.0	2.4	1.3	1.3	1.3	1.5	--	--	--	--	420
	1000	50	11	4.5	3.7	2.5	1.7	1.3	1.1	1.4	2.0	--	--	--	750
	2000	--	24	6.1	4.5	34	2.8	2.5	2.1	2.1	2.1	2.5	--	--	1860
	5000	--	120	--	66	40	--	13	--	8.5	--	--	--	3.0	4000
8 o/oo	100	11	6.0	3.5	3.1	3.3	3.6	6.0	6.0	--	--	--	--	--	85
	250	--	6.0	3.8	3.2	2.0	2.0	2.2	2.7	3.0	--	--	--	--	200
	540	16	9.5	4.2	3.0	2.5	1.4	1.3	1.3	1.3	10	--	--	--	450
	1000	55	15	4.7	3.7	2.6	17	1.3	1.1	1.4	2.0	--	--	--	780
	2000	--	46	8.4	4.5	3.4	3.4	3.0	3.0	2.9	2.9	2.8	--	--	1880
	5000	--	140	--	69	45	--	25	--	10	--	--	--	3.5	4200

-- Experiment was not run or data could not be obtained

Both filtered background seawater and deionized-redistilled water have a zero turbidity.

Table 11 - Continued

Residual Turbidity of Supernatants With Different Initial Turbidity Levels

After Treatment at Different Polymer Dosages

Salinity Level	Original Turbidity (NTU)	Polymer Dosages (ppm)													Control Blank (NTU)
		0.5	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	
5.5 o/oo	100	13	7.0	3.7	3.5	3.5	4.8	4.8	5.6	--	--	--	--	--	85
	250	--	6.6	4.8	3.2	2.3	2.3	2.2	2.4	3.7	4.5	--	--	--	204
	540	23	10	6.5	5.3	3.3	1.7	1.5	1.4	1.4	1.7	--	--	--	450
	1000	68	21	5.0	4.4	3.7	2.0	1.6	1.4	1.5	2.0	--	--	--	780
	2000	--	52	13	5.5	4.5	4.1	3.8	3.8	3.6	3.5	3.5	--	--	1880
	5000	--	310	--	92	87	--	30	--	10	--	--	--	4.5	4500
2.5 o/oo	100	15	9.0	5.0	3.7	3.7	4.2	4.6	4.8	--	--	--	--	--	86
	250	--	14	6.4	3.6	3.1	2.5	2.4	2.9	4.2	--	--	--	--	200
	540	28	11	8.0	7.5	6.0	1.9	1.7	1.6	1.6	1.9	--	--	--	450
	1000	84	22	7.8	5.7	5.6	3.8	2.3	2.5	2.7	3.2	--	--	--	800
	2000	--	100	23	12	6.3	5.0	4.4	4.2	4.0	4.0	--	4.0	--	1920
	5000	--	400	--	200	110	--	55	--	40	--	--	--	15	4700
0.0 o/oo	100	75	35	12	7.0	4.2	3.7	4.0	5.0	--	--	--	--	--	89
	250	--	110	65	40	28	17	11	8.0	5.7	--	7.2	--	--	210
	540	250	200	105	70	43	24	19	15	--	--	15	--	--	480
	1000	900	860	560	290	165	115	90	--	50	--	47	50	--	850
	2000	--	1800	1600	1400	1200	1000	800	800	--	--	--	--	--	2000
	5000	--	5000	--	4800	3750	--	3750	--	3000	--	--	--	1750	4900

-- Experiment was not run or data could not be obtained

Both filtered background seawater and deionized-redistilled water have a zero turbidity.

Table 12

Salinity Effect on the Optimum Dosage Ranges and Their Residual Turbidity of the Three Most Effective Polymers in Standard Jar Test

Sediment: No. 7 (Mobile Bay, Alabama)
Sediment Type: Silty Sand (sand: 55%; silt: 33%; clay: 12%)
Salinity of Sediment: 15 o/oo
Sediment/Water = 1:4

Polymer / Salinity	Betz 1120		Betz 1160		Calgon WT-3000		Turbidity of Background W.	Turbidity of Control Sample	Data Shown in Tables
	A*	B**	A	B	A	B			
0 o/oo Mobile Bay Water	10-15	230-250	>50	520	10-15	220-270	50	9000-9500	14
2.5 o/oo 10 D^2 W: 1SW	15-20	130-180	35-40	250-350	15-20	120~150	1	9000-9400	15
8 o/oo 3 D^2 W: 1SW	10-15	100~150	20~35	75-78	10-15	100~140	1.0	9500-9800	16
16 o/oo 1 D^2 W: 1SW	10-15	34~40	25-30	30-40	10-15	30~34	1.0	9400-9500	17
33 o/oo Ref. Seawater	6-7	30-35	25-30	35-37	6-7	35-38	1.0	7000-7200	18

* Optimum dosage in ppm
** Residual turbidity in NTU

Table 13

Salinity Effect on the Optimum Dosage Ranges and Their Residual Turbidity of the Three Most Effective Polymers in Standard Jar Test

Sediment: No. 7 (Mobile Bay, Alabama)
Sediment Type: Silty Sand (sand: 55%; silt: 33%; clay: 12%)
Salinity of Sediment: 15 o/oo
Sediment/Water = 1:10

Polymer / Salinity	Betz 1120		Betz 1160		Calgon WT-3000		Turbidity of Background W.	Turbidity of Control Sample	Data Shown in Tables
	A*	B**	A	B	A	B			
0 o/oo Mobile Bay Water	5-7	240-310	25-30	100-130	5-7	200-210	47	720-820	14
2.5 o/oo 10 D W: 1SW	5-7	40-48	25-30	23-27	5-7	25-30	1.0	200-280	15
8 o/oo 3 D W: 1SW	5-7	25-35	20-25	13-14	5-7	20-25	1.0	100-120	16
16 o/oo 1 D W: 1SW	5-7	22-28	5-10	19-21	5-7	20-25	1.0	100-110	17
33 o/oo Ref. Seawater	2-5	20-22	5-10	19-36	2-5	20-22	1.0	100-130	18

* Optimum dosage in ppm
** Residual turbidity in NTU

Table 14

Optimum Polymer Dosages and Residual Turbidity in Standard Jar Test at a Fixed Salinity Level

Sediment No.: 7
Dates of Collection: 2-4-76
Classification: silty sand
Salinity of Water Used: ~0 o/oo (Mobile Bay Water)

Coagulant	Conc. of Coagulant (ppm)		Floc Hgts at beginning of slow mixing (cm)		Floc Hgts at end of slow mixing (cm)		Floc Hgts at end of settling (cm)		Residual Turbidity (NTU)	
	A*	B**	A	B	A	B	A	B	A	B
Control	0	0	12.25	12.25	10.5	10.0	9.0	4.5	19,600	880
Betz 1120	5	2	12.0	12.0	8.5	3.0	6.0	2.5	400	230
	10	5	11.5	8.0	4.5	2.0	4.5	2.0	220	200
	15	7	11.0	6.0	4.5	2.0	4.5	2.0	250	210
	20	10	11.0	6.0	4.5	2.0	4.5	2.0	250	210
	25	15	10.0	4.0	4.5	2.0	4.5	2.0	300	220
		20		4.0		2.0		2.0		220
Betz 1160	10	10	12.5	12.5	9.0	9.0	8.0	3.0	1140	150
	15	20	12.5	12.5	8.5	3.0	7.0	3.0	2080	140
	20	25	12.5	12.5	8.5	3.0	7.0	3.0	960	130
	25	30	12.5	12.5	8.0	3.0	7.0	3.0	940	100
	30	35	12.5	12.5	8.0	3.0	7.0	3.0	940	140
	40		12.5		7.5		6.0		800	
	50		12.5		9.0		6.5		520	

* A: Sediment/Water Ratio: 1:4

** B: Sediment/Water Ratio: 1:10

Table 14 - Continued

Optimum Polymer Dosages and Residual Turbidity in Standard Jar Test at a Fixed Salinity Level

Coagulant	Conc. of Coagulant (ppm)		Floc Hgts at beginning of slow mixing (cm)		Floc Hgts at end of slow mixing (cm)		Floc Hgts at end of settling (cm)		Residual Turbidity (NTU)	
	A*	B**	A	B	A	B	A	B	A	B
Calgon WT-3000	5	2	12.5	12.0	10.0	3.0	6.0	4.0	540	220
	10	5	11.5	8.0	5.0	2.5	5.0	2.5	220	200
	15	7	9.0	6.0	4.0	2.5	4.0	2.5	270	210
	20	10	8.5	6.0	4.0	2.5	4.0	2.5	260	270
	25	15	8.0	4.0	4.0	2.5	4.0	2.5	270	270
	30	20	7.5	4.0	4.0	2.5	4.0	2.5	310	280

* A: Sediment/Water Ratio: 1:4

** B: Sediment/Water Ratio: 1:10

Table 15

Optimum Polymer Dosages and Residual Turbidity in Standard Jar Test at a Fixed Salinity Level

Sediment No.: 7
Dates of Collection: 2-4-76
Classification: silty sand
Salinity of Water Used: 2.5 o/oo

Coagulant	Conc. of Coagulant (ppm)		Floc Hgts at beginning of slow mixing (cm)		Floc Hgts at end of slow mixing (cm)		Floc Hgts at end of settling (cm)		Residual Turbidity (NTU)	
	A*	B**	A	B	A	B	A	B	A	B
Control	0	0	12.5	12.5	10.5	9.0	9.0	5.0	9500	270
Betz 1120	5	2	12.5	12.0	9.0	3.0	6.5	3.0	210	70
	10	5	12.0	8.0	5.0	2.5	5.0	2.5	200	48
	15	7	10.0	6.0	4.5	2.0	4.5	2.0	130	55
	20	10	9.0	4.0	4.0	2.0	4.0	2.0	180	100
	25	15	9.0	4.0	4.0	2.0	4.0	2.0	180	98
Betz 1160	20	5	12.5	12.5	9.0	11.0	7.0	4.0	420	48
	30	10	12.5	12.0	8.5	7.0	7.0	3.5	370	36
	35	20	12.5	11.0	7.5	3.0	7.0	3.0	350	37
	40	25	12.5	9.0	7.5	3.0	6.0	3.0	240	23
	50	30	12.5	9.0	7.5	3.0	3.0	3.0	240	18
Calgon WT-3000	5	2	12.5	12.0	8.0	3.5	6.0	3.0	300	77
	10	5	12.0	8.0	4.5	3.0	4.0	2.5	120	53
	15	7	10.0	6.0	4.0	2.5	4.0	2.0	150	57
	20	10	7.0	4.0	4.0	2.0	3.5	2.0	170	82
	25	15	7.0	4.0	4.0	2.0	3.5	2.0	170	95

* A: Sediment/Water Ratio: 1:4
** B: Sediment/Water Ratio: 1:10

Table 16

Optimum Polymer Dosages and Residual Turbidity in Standard Jar Test at a Fixed Salinity Level

Sediment No.: 7
Dates of Collection: 2-4-76
Classification: silty sand
Salinity of Water Used: 8 o/oo

Coagulant	Conc. of Coagulant (ppm)		Floc Hgts at beginning of slow mixing (cm)		Floc Hgts at end of slow mixing (cm)		Floc Hgts at end of settling (cm)		Residual Turbidity (NTU)	
	A*	B**	A	B	A	B	A	B	A	B
Control	0	0	12.5	12.5	10.5	9.5	9.0	6.5	9600	105
Betz 1120	5	2	12.5	12.0	9.5	4.0	7.5	3.0	210	45
	10	5	12.5	6.0	6.0	2.5	5.0	2.5	150	35
	15	7	12.5	4.0	7.0	2.5	5.0	2.5	150	45
	20	10	11.0	4.0	4.5	2.5	4.5	2.5	150	60
	25	15	10.5	4.0	4.0	2.5	4.0	2.5	150	65
	30		10.0		4.0		4.0		150	
Betz 1160	20	5	12.5	12.5	10.0	11.0	7.0	4.0	85	22
	25	10	12.5	12.0	10.0	3.0	6.0	3.0	80	27
	30	20	12.5	6.0	10.0	2.5	6.0	2.5	78	14
	35	25	12.5	4.0	10.0	2.5	5.0	2.5	75	13
	40	30	12.5	4.0	10.0	2.5	6.5	2.5	82	15
Calgon WT-3000	5	2	12.5	12.0	8.5	4.0	6.5	3.0	170	43
	10	5	12.5	8.0	5.0	2.5	5.0	2.5	140	27
	15	7	11.0	6.0	4.0	2.5	4.0	2.5	100	34
	20	10	11.0	4.0	5.0	2.5	4.5	2.5	100	47
	25	15	10.5	4.0	4.5	2.5	4.0	2.5	100	57

* A: Sediment/Water Ratio: 1:4
** B: Sediment/Water Ratio: 1:10

Table 17

Optimum Polymer Dosages and Residual Turbidity in Standard Jar Test at a Fixed Salinity Level

Sediment No.: 7
Dates of Collection: 2-4-76
Classification: silty sand
Salinity of Water Used: 16 o/oo

Coagulant	Conc. of Coagulant (ppm)		Floc Hgts at beginning of slow mixing (cm)		Floc Hgts at end of slow mixing (cm)		Floc Hgts at end of settling (cm)		Residual Turbidity (NTU)	
	A*	B**	A	B	A	B	A	B	A	B
Control	0	0	12.5	12.5	10.5	9.0	9.0	4.5	9500	105
Betz 1120	5	2	12.5	12.5	10.5	10.0	5.5	3.5	45	29
	10	5	11.0	10.0	4.5	3.0	5.0	2.5	34	22
	15	7	9.0	6.0	4.0	2.5	4.0	2.5	40	28
	20	10	8.0	4.0	4.0	3.0	4.0	2.5	50	37
	25	15	8.0	4.0	4.0	3.0	4.0	2.5	50	46
	30		8.0		4.0		4.0		55	
Betz 1160	15	5	12.5	12.5	10.0	10.0	5.5	4.0	46	19
	20	10	12.0	12.0	10.0	4.0	5.5	3.0	42	21
	25	20	11.5	6.0	5.5	3.0	4.5	3.0	38	13
	30	25	11.0	4.0	4.5	3.0	4.5	3.0	30	18
	35	30	11.0	4.0	4.0	3.0	4.0	3.0	30	18
Calgon WT-3000	5	2	12.5	12.5	10.0	9.0	5.5	3.5	45	40
	10	5	11.0	10.0	4.5	2.5	4.0	2.5	30	25
	15	7	11.0	6.0	4.5	2.5	4.0	2.5	34	36
	20	10	10.5	4.0	4.0	2.5	4.0	2.5	45	45
	25	15	10.0	4.0	4.0	2.5	4.0	2.5	45	47

* A: Sediment/Water Ratio: 1:4
** B: Sediment/Water Ratio: 1:10

Table 18

Optimum Polymer Dosages and Residual Turbidity in Standard Jar Test at a Fixed Salinity Level

Sediment No.: 7
Dates of Collection: 2-4-76
Classification: silty sand
Salinity of Water Used: 33 o/oo

Coagulant	Conc. of Coagulant (ppm)		Floc Hgts at beginning of slow mixing (cm)		Floc Hgts at end of slow mixing (cm)		Floc Hgts at end of settling (cm)		Residual Turbidity (NTU)	
	A*	B**	A	B	A	B	A	B	A	B
Control	0	0	12.5	12.5	10.0	9.0	9.0	4.5	14,000	130
Betz 1120	5	1	12.5	12.5	10.0	10.0	7.5	4.0	72	35
	6	2	11.0	12.0	4.5	2.5	5.5	2.5	40	18
	7	8	9.0	4.0	4.0	2.0	4.0	2.0	35	22
	8	7	9.0	4.0	4.0	2.0	4.0	2.0	35	33
	10	10	9.0	4.0	4.0	2.5	4.0	2.5	35	40
	15		9.0		4.0		4.0		34	
	20		8.5		4.0		4.0		35	
Betz 1160	15	2	12.0	12.5	10.5	10.0	6.0	5.0	63	36
	20	5	12.0	12.5	10.5	10.0	6.0	4.0	58	19
	25	10	12.0	12.0	10.5	3.5	5.5	3.0	37	18
	30	15	12.0	11.0	10.0	3.0	5.5	3.0	35	16
	35	20	12.0	6.0	10.0	3.0	5.5	3.0	60	13
	40	25	12.0	4.0	10.0	3.0	5.0	3.0	73	17
	45	30	12.0	4.0	4.5	3.0	4.5	3.0	41	18

* A: Sediment/Water Ratio: 1:4

** B: Sediment/Water Ratio: 1:10

Table 18 - Continued

Optimum Polymer Dosages and Residual Turbidity in Standard Jar Test

at a Fixed Salinity Level

Coagulant	Conc. of Coagulant (ppm)		Floc Hgts at beginning of slow mixing (cm)		Floc Hgts at end of slow mixing (cm)		Floc Hgts at end of settling (cm)		Residual Turbidity (NTU)	
	A*	B**	A	B	A	B	A	B	A	B
Calgon WT-3000	5	1	12.5	12.5	9.0	10.0	6.5	3.0	68	21
	6	2	10.0	12.5	5.0	2.5	6.5	2.5	42	19
	7	5	10.0	7.0	5.0	2.0	4.5	2.0	40	25
	8	7	10.0	4.0	5.0	2.0	4.5	2.0	40	36
	10	10	10.0	4.0	5.0	2.0	4.5	2.5	40	43
	15		10.0		4.0		4.0		38	

* A: Sediment/Water Ratio: 1:4

** B: Sediment/Water Ratio: 1:10

Table 19

General Information on Polymer Purity*

Name	Trace Metals	T.O.C. (ppm)	I.O.C. (ppm)	T.C.** (ppm)
Betz 1120	trace	352	10	362
Betz 1160	trace	430	trace	430
Calgon WT-3000	trace	325	trace	325

* 0.1 percent of polymer stock solution prepared in deionized-redistilled water

** T.C. = T.O.C. + I.O.C.

Table 20

Optimum Dosage Ranges of the Polymers in Standard Jar Test for the Treatment of Sediment Slurries

Date of Collection	Sediment No.	Sediment Type	Sediment/ Water	Effective Polymer	Optimum Dosage Range (ppm)	Data Shown in Tables
11-9-75	2	Silty-Sand (sand: 78%) (silt: 15%) (clay: 7%)	1:4	WT-3000 Betz 1120 WT-2690	3.5-4.5 4.0-5.0 15-20	21
2-6-76	3	Sand (sand: 83%) (silt: 12%) (clay: 5%)	1:4	WT-3000 Betz 1120 WT-2690 CAT-Floc T	2.0-3.0 2.0-3.0 7.0-10.0 15-20	22
2-6-76	4	Silty-Clay (sand: 16%) (silt: 46%) (clay: 38%)	1:4	Betz 1100 Betz 1120 Betz 1140 Betz 1150 WT-3000 WT-2690	15.0-20.0 9.0-10.0 25-30 25-30 9.0-10.0 50-70	23

Table 20 - Continued

<u>Optimum Dosage Ranges of the Polymers in Standard Jar Test</u>

<u>for the Treatment of Sediment Slurries</u>

Date of Collection	Sediment No.	Sediment Type	Sediment/ Water	Effective Polymer	Optimum Dosage Range (ppm)	Data Shown in Tables
2-6-76	4	Silty-Clay (sand: 16%) (silt: 46%) (clay: 38%)	1:10	Nalco 72C-25 Nalco 72D-13 WT-3000 WT-2690 CAT-Floc T Betz 1100 Betz 1120 Betz 1140 Betz 1150	250-300 15-20 2-3 6-7 40-50 2-5 2-3 4-8 2-5	23
2-4-76	6	Silty-Clay (sand: 21%) (silt: 43%) (clay: 36%)	1:4	WT-3000 WT-2690 Betz 1120 Polyox WSR-301 Polyox Coag.	8-9 50-60 8-9 25-30 25-30	25
2-4-76	7	Silty-Sand (sand: 55%) (silt: 33%) (clay: 12%)	1:4	Betz 1160 Betz 1120 Betz 1140 Betz 1100 WT-2690 WT-3000 Polyox Coag.	20-30 5-6 20-30 10-15 20-30 5-6 40-50	26

Table 21

Standard Jar Test for Sediment Slurries

Sediment No.: 2 (Houston Ship Channel, Houston, Texas)
Dates of Collection: 11-9-75
Classification: sandy sediment (sand: 78%; silt: 15%; clay: 7%)
Sediment/Water Ratio: 1:4
Salinity of Water Used: 33 o/oo (seawater from a reference point)

Coagulant	Conc. of Coagulant (ppm)	Floc Hgts at beginning of slow mixing (cm)	Floc Hgts at end of slow mixing (cm)	Floc Hgts at end of settling (cm)	Residual Turbidity (NTU)
Control	0	12.5	10.0	8.0	8700
WT-2600	1000	12.5	10.0	8.0	8700
WT-2640	1000	12.5	10.0	8.0	8700
CAT-Floc T	1000	12.5	7.0	5.5	17
72-C-25	1000	11.5	4.0	3.5	78
81-C-09	150	12.5	11.5	9.5	8500
72-D-13	150	4.0	3.5	3.5	17
WT-3000	1	12.5	8.5	6.0	82
	2	12.5	8.5	6.0	75
	3.5	12.5	5.0	4.5	20
	4.5	12.5	5.0	4.5	20
	5.0	12.5	5.0	4.5	20
	7.5	12.5	5.0	4.5	20
	10.0	12.5	4.5	4.0	25
	15.0	9.0	4.5	4.0	25

Table 21 - Continued

Standard Jar Test for Sediment Slurries

Coagulant	Conc. of Coagulant (ppm)	Floc Hgts at beginning of slow mixing (cm)	Floc Hgts at end of slow mixing (cm)	Floc Hgts at end of settling (cm)	Residual Turbidity (NTU)
WT-2690	10	12.5	3.5	3.5	16
	20	12.0	3.5	3.5	16
	30	4.0	3.5	3.0	16
	40	3.5	3.0	3.0	15
	50	3.5	3.0	3.0	15
Betz 1120	1	12.5	8.0	6.0	80
	2	12.0	8.0	5.0	77
	3	12.0	5.0	4.5	21
	4	9.5	4.5	4.5	20
	5	9.5	4.5	4.5	20
	6	9.5	4.5	4.0	20
	7	9.5	4.0	4.0	22

Table 22

Standard Jar Test for Sediment Slurries

Sediment No.: 3 (Rouge River at Detroit, Michigan)
Dates of Collection: 2-6-76
Classification: sandy (sand: 83%; silt: 12%; clay: 5%)
Sediment/Water Ratio: 1:4
Salinity of Water Used: 33 o/oo (seawater from a reference point)

Coagulant	Conc. of Coagulant (ppm)	Floc Hgts at beginning of slow mixing (cm)	Floc Hgts at end of slow mixing (cm)	Floc Hgts at end of settling (cm)	Residual Turbidity (NTU)
Control	0	9.0	8.0	6.0	195
WT-3000	1	8.5	7.5	6.0	95
	2	5.5	5.0	4.0	70
	3	4.0	4.0	4.0	70
	4	5.5	5.5	5.0	70
	5	5.5	5.5	5.0	70
Control	0	11	9.0	5.0	210
WT-2690	1	10	8.0	4.5	110
	3	9	4.5	4.0	67
	5	8	4.0	4.0	60
	7	5	3.5	3.5	65
	10	5	3.5	3.5	62
	15	5	3.5	3.5	62
Control	0	13	9.0	6.0	175
CAT-Floc T	2	13	9.0	6.0	150
	6	13	9.0	6.0	105
	10	13	9.0	6.0	75
	14	13	9.0	6.0	50
	20	13	9.0	6.0	43

Table 22 - Continued

Standard Jar Test for Sediment Slurries

Coagulant	Conc. of Coagulant (ppm)	Floc Hgts at beginning of slow mixing (cm)	Floc Hgts at end of slow mixing (cm)	Floc Hgts at end of settling (cm)	Residual Turbidity (NTU)
Control	0	9.0	8.0	6.0	180
Betz 1120	1	8.5	7.0	6.0	80
	2	5.0	4.5	4.0	65
	3	4.0	4.0	4.0	65
	4	5.5	5.5	5.5	65
	5	5.5	5.5	5.5	65

Table 23

Standard Jar Test for Sediment Slurries

Sediment No.: 4 (Anchorage Basin in Cape Fear River Mouth, Wilmington, North Carolina)
Dates of Collection: 2-6-76
Classification: silty clay (sand: 16%; silt: 46%; clay: 38%)
Sediment/Water Ratio: 1:4 & 1:10
Salinity of Sediment: 2.0 o/oo
Salinity of Water Used: 33 o/oo (seawater from a reference point)

Coagulant	Conc. of Coagulant (ppm)		Floc Hgts at beginning of slow mixing (cm)		Floc Hgts at end of slow mixing (cm)		Floc Hgts at end of settling (cm)		Residual Turbidity (NTU)	
	A*	B**	A	B	A	B	A	B	A	B
Control	0	0	12.5	12.5	11.0	9.0	9.5	4.5	15,000	80
CAT-Floc T	50	50	12.5	12.5	10.5	7.5	9.5	3.5	15,000	3
	500	100	12.0	12.5	9.0	7.5	8.5	4.5	15,000	5
	1500	250	12.0	12.5	9.0	7.5	8.0	4.5	15,000	5
72-C-25	50	100	12.5	12.5	9.5	5.0	9.0	3.0	15,000	15
	1000	200	12.0	12.5	9.0	4.0	8.5	3.0	15,000	9
		300		12.5		4.0		3.0		10
		400		11.5		3.0		3.0		20
Betz 1100	5.0	1	12.5	12.0	9.0	8.0	6.0	2.5	150	17
	7.5	2	12.5	12.0	8.0	3.0	5.0	2.5	120	18
	10.0	3	12.5	12.0	7.5	3.0	5.0	2.5	105	21
	12.5	4	11.0	12.0	4.5	2.5	4.0	2.5	46	25
	15.0	5	10.0	11.0	4.0	2.5	4.0		45	28
	20.0		10.5		4.0		4.0		45	

* A: Sediment/Water Ratio: 1:4

** B: Sediment/Water Ratio: 1:10

Table 23 - Continued

Standard Jar Test for Sediment Slurries

Coagulant	Conc. of Coagulant (ppm)		Floc Hgts at beginning of slow mixing (cm)		Floc Hgts at end of slow mixing (cm)		Floc Hgts at end of settling (cm)		Residual Turbidity (NTU)	
	A*	B**	A	B	A	B	A	B	A	B
Control	2.5	0.5	12.5	12.0	9.0	9.0	4.0	3.5	130	55
Betz 1120	5.0	1	12.5	12.0	4.5	3.0	4.0	2.5	130	52
	7.5	2	12.0	12.0	4.0	3.0	4.0	2.5	125	49
	9.0	3	11.0	11.0	4.0	2.5	4.0	2.5	125	53
	10.0	4	11.0	9.0	4.0	2.5	4.0	2.5	125	53
	15.0		9.0		4.0		4.0		125	
Control	0	0	12.5	12.5	11.0	9.0	9.5	4.5	15,000	80
Betz 1140	5.0	1	12.5	12.0	8.5	10.0	5.5	3.5	12,000	32
	10.0	2	12.5	12.0	8.0	10.0	5.5	3.5	9000	21
	15.0	4	12.5	12.0	7.5	3.0	5.0	2.5	6400	16
	20.0	6	12.5	12.0	7.0	2.5	4.5	2.5	68	20
	25.0	8	12.5	11.0	4.5	2.5	4.0	2.5	47	25
	30.0		12.0		4.5		4.0		47	
Betz 1150	5.0	1	12.5	12.0	8.5	9.0	5.5	3.0	12,000	32
	10.0	2	12.5	12.0	8.5	3.0	5.5	2.5	12,000	20
	15.0	3	12.5	12.0	5.5	3.0	4.5	2.5	90	18
	20.0	4	12.5	12.0	5.0	2.5	4.5	2.0	70	16
	25.0	5	11.0	11.0	4.5	2.5	4.0	2.0	32	15
	30.0		10.0		4.0		4.0		30	

* A: Sediment/Water Ratio: 1:4

** B: Sediment/Water Ratio: 1:10

Table 23 - Continued

Standard Jar Test for Sediment Slurries

Coagulant	Conc. of Coagulant (ppm)		Floc Hgts at Beginning of slow mixing (cm)		Floc Hgts at end of slow mixing (cm)		Floc Hgts at end of settling (cm)		Residual Turbidity (NTU)	
	A*	B**	A	B	A	B	A	B	A	B
Control	2	1	12.0	12.5	9.0	3.5	4.0	3.0	12,500	20
WT-3000	5	2	9.0	12.0	4.0	3.5	4.0	3.0	200	30
	7	4	9.0	12.0	4.0	3.5	4.0	3.0	200	38
	8	8	6.5	11.0	4.0	3.0	4.0	3.0	200	31
	9		6.5		4.0		4.0		200	
	10		6.5		4.0		4.0		200	
	15		5.5		4.0		4.0		200	
WT-2690	25	2.5	12.5	12.5	7.0	3.0	5.0	3.5	55	12
	50	5.0	9.0	12.5	5.5	3.0	5.0	3.0	52	14
	75	7.5	7.0	12.0	5.5	3.0	5.0	3.0	66	19
	100	10.0	7.0	11.0	4.5	3.0	4.5	3.0	70	22
	150		7.0		4.5		4.5		70	

* A: Sediment/Water Ratio: 1:4

** B: Sediment/Water Ratio: 1:10

Table 24

Standard Jar Test for Sediment Slurries

Sediment No.: 5 (James River, Richmond, Virginia)
Dates of Collection: 1-27-76
Classification: sand (sand: 97%; silt: 2.0%; clay: 1.0%)
Sediment/Water Ratio: 1:4 & 1:10
Salinity of Sediment: 0.5 o/oo
Salinity of Water Used: 33 o/oo (seawater from a reference point)

Comments:

Textural composition of this sediment is shown to contain 1.0% clay. The standard jar test for this sediment with different polymers as coagulants showed no significant clarification effect. This sediment (more than 95% sand) settles easily without any polymer addition with a residual turbidity of 15 NTU.

Table 25

Standard Jar Test for Sediment Slurries

Sediment No.: 6 (Calcasieu River, Louisiana)
Dates of Collection: 2-4-76
Classification: silty clay (sand: 21%; silt: 43%; clay: 36%)
Sediment/Water Ratio: 1:4
Salinity of Sediment: 18 o/oo
Salinity of Water Used: 33 o/oo (seawater from a reference point)

Coagulant	Conc. of Coagulant (ppm)	Floc Hgts at beginning of slow mixing (cm)	Floc Hgts at end of slow mixing (cm)	Floc Hgts at end of settling (cm)	Residual Turbidity (NTU)
Control	0	12.5	11.5	10.5	21,000
WT-3000	2	12.5	9.5	7.0	21,000
	4	12.5	9.0	6.5	21,000
	6	12.0	8.0	5.5	175
	8	11.5	6.0	5.0	83
	9	11.0	5.0	4.0	40
	10	11.0	4.0	4.0	37
	11	11.0	4.0	4.0	40
Betz 1120	2	12.5	9.0	8.5	21,000
	4	12.5	6.5	5.5	21,000
	6	12.0	6.0	5.5	175
	8	11.5	5.0	5.0	90
	9	11.0	5.0	4.0	50
	10	10.0	4.0	4.0	53
	11	10.0	4.0	4.0	50

Table 25 - Continued

Standard Jar Test for Sediment Slurries

Coagulant	Conc. of Coagulant (ppm)	Floc Hgts at beginning of slow mixing (cm)	Floc Hgts at end of slow mixing (cm)	Floc Hgts at end of settling (cm)	Residual Turbidity (NTU)
Polyox WSR-301	10	12.5	10.0	8.5	22,000
	15	12.5	9.5	6.5	52
	20	12.5	8.5	6.5	65
	25	12.5	8.5	6.5	65
	30	12.5	8.5	6.0	70
Polyox Coagulant	15	12.5	9.0	7.5	22,000
	20	12.5	8.5	6.5	120
	25	12.5	8.5	6.0	89
	30	12.5	8.5	6.0	65
	35	12.5	8.5	6.0	62
	40	12.5	8.5	6.0	57

Table 26

Standard Jar Test for Sediment Slurries

Sediment No.: 7 (Mobile Bay, Alabama)
Dates of Collection: 2-4-76
Classification: silty-sand (sand: 55%, silt: 33%, clay: 12%)
Sediment/Water Ratio: 1:4
Salinity of Sediment: 15 o/oo
Salinity of Water Used: 33 o/oo (seawater from a reference point)

Coagulant	Conc. of Coagulant (ppm)	Floc Hgts at beginning of slow mixing (cm)	Floc Hgts at end of slow mixing (cm)	Floc Hgts at end of settling (cm)	Residual Turbidity (NTU)
Control	0	12.5	9.5	9.0	7000
Betz 1160	1	12.5	9.0	7.0	200
	5	12.5	8.5	6.0	62
	10	12.5	5.5	5.0	50
	15	12.5	4.5	4.5	33
	20	12.5	4.0	4.0	25
	30	5.0	3.5	3.5	18
	40	5.0	4.0	4.0	22
	50	5.0	4.5	4.5	18
Betz 1120	1	12.5	9.0	6.0	73
	5	12.5	5.5	5.5	55
	6	12.0	4.0	4.0	53
	7	12.0	4.0	4.0	53
	10	5.0	3.5	3.5	49
	20	4.0	3.0	3.0	60

Table 26 - Continued

Standard Jar Test for Sediment Slurries

Coagulant	Conc. of Coagulant (ppm)	Floc Hgts at beginning of slow mixing (cm)	Floc Hgts at end of slow mixing (cm)	Floc Hgts at end of settling (cm)	Residual Turbidity (NTU)
Betz 1140	1	12.5	9.5	8.0	7000
	5	12.5	8.0	6.0	70
	10	12.5	6.5	5.5	48
	20	12.0	4.5	4.5	31
	30	11.0	4.5	4.5	35
	40	6.0	4.5	4.5	42
Control	0	12.5	9.5	9.0	7000
WT-2690	5	12.5	9.0	7.5	200
	10	12.5	8.5	7.0	200
	20	12.0	4.5	4.5	42
	30	11.5	4.5	4.5	40
	40	11.0	4.5	4.5	40
Polyox Coagulant	10	12.5	5.5	5.5	78
	20	12.0	5.0	5.0	74
	30	11.5	5.0	5.0	62
	40	11.0	5.5	5.5	53
	50	10.0	5.5	5.5	61
WT-3000	1	12.5	7.5	6.5	160
	5	12.0	7.0	6.0	130
	6	11.0	6.0	5.0	100
	7	11.0	6.0	5.0	105
	8	11.0	6.0	5.0	105
	10	11.0	6.0	5.0	105
	20	9.0	4.5	4.5	105

Table 26 - Continued

Standard Jar Test forSediment Slurries

Coagulant	Conc. of Coagulant (ppm)	Floc Hgts at beginning of slow mixing (cm)	Floc Hgts at end of slow mixing (cm)	Floc Hgts at end of settling (cm)	Residual Turbidity (NTU)
Betz 1100	5	12.5	8.0	7.0	200
	10	11.5	5.0	4.5	45
	15	11.0	4.0	4.0	42
	20	7.0	4.0	4.0	51
	40	6.0	4.0	4.0	53

Table 27

Summary of Laboratory Screening Tests on Polymers

Turbidity of original simulated supernatants: 200 NTU
Polymer dosage: 4 ppm
Salinity of supernatant: 2.5 o/oo and 8.0 o/oo
Residual turbidity of control blank: 170 NTU

Polymer		Salinity of Solution (o/oo)	Residual Turbidity (NTU)	Remarks
Hercofloc	#860	2.5	40	loose flocs, slow settling velocity
		8.0	33	
	#863	2.5	36	loose flocs, slow settling velocity
		8.0	35	
	#864	2.5	47	loose flocs, slow settling velocity
		8.0	42	
	#848	2.5	38	loose flocs, slow settling velocity
		8.0	32	
	#834.5	2.5	85	loose flocs, slow settling velocity
		8.0	80	
	#815.3	2.5	17	dense flocs, fast settling velocity
		8.0	10	
	#821.2	2.5	30	loose flocs, slow settling velocity
		8.0	26	
	#849	2.5	18	dense flocs, fast settling velocity
		8.0	8	
	#847	2.5	22	loose flocs, medium settling velocity
		8.0	14	
	#853	2.5	22	loose flocs, medium settling velocity
		8.0	18	
	#852	2.5	37	loose flocs, slow settling velocity
		8.0	30	
	#1036	2.5	42	loose flocs, slow settling velocity
		8.0	38	

Table 27 - Continued

Summary of Laboratory Screening Tests on Polymers

Polymer		Salinity of Solution (o/oo)	Residual Turbidity (NTU)	Remarks
Hercofloc	#834.1	2.5	27	loose flocs, slow settling velocity
		8.0	20	
	#871	2.5	26	loose flocs, slow settling velocity
		8.0	19	
	#821.2	2.5	27	loose flocs, slow settling velocity
		8.0	18	
Betz	#1190	2.5	100	loose flocs, slow settling velocity
		8.0	95	
	#1185	2.5	32	loose flocs, slow settling velocity
		8.0	30	
	#1180	2.5	28	loose flocs, slow settling velocity
		8.0	25	
	#1175	2.5	40	loose flocs, slow settling velocity
		8.0	30	
	#1160	2.5	3	big, dense flocs, fast settling velocity
		8.0	3	
	#1150	2.5	6	dense flocs, fast settling velocity
		8.0	5	
	#1140	2.5	7	dense flocs, medium fast settling velocity
		8.0	6	
	#1130	2.5	23	loose flocs, slow settling velocity
		8.0	20	
	#1120	2.5	40	loose flocs, slow settling velocity
		8.0	35	
	#1110	2.5	40	loose flocs, slow settling velocity
		8.0	34	
	#1100	2.5	7	loose flocs, slow settling velocity
		8.0	6	

Table 27 - Continued

Summary of Laboratory Screening Tests on Polymers

Polymer		Salinity of Solution (o/oo)	Residual Turbidity (NTU)	Remarks
Magnifloc	#587 C	2.5	25	loose flocs, slow settling velocity
		8.0	20	
	#591 C	2.5	25	loose flocs, slow settling velocity
		8.0	30	
	#905 N	2.5	3	dense flocs, fast settling velocity
		8.0	2	
	#835 N	2.5	19	loose flocs, slow settling velocity
		8.0	13	
	#834 A	2.5	22	loose flocs, slow settling velocity
		8.0	16	
	#573 C	2.5	17	loose flocs, medium fast settling velocity
		8.0	12	
	#581 C	2.5	18	loose flocs, slow settling velocity
		8.0	14	
Calgon Co. nonionic	Cat-Floc T	2.5	27	loose flocs, slow settling velocity
		8.0	22	
	WT-2690	2.5	5	dense flocs, fast settling velocity
		8.0	3	
	WT-2870	2.5	27	loose flocs, slow settling velocity
		8.0	18	
	WT-3000	2.5	80	loose flocs, slow settling velocity
		8.0	60	
Union Carbide	Polyox WSR-301	2.5	29	loose flocs, slow settling velocity
		8.0	25	
	Polyox Coagulant	2.5	25	loose flocs, slow settling velocity
		8.0	20	

Table 28

Summary of Laboratory Screening Tests on Polymers

Turbidity of original simulated supernatants: 1000 NTU
Polymer dosage: 8.5 ppm
Salinity of supernatant: 2.5 o/oo and 8.0 o/oo
Residual turbidity of control blank: 780 NTU

Polymer		Salinity of Solution (o/oo)	Residual Turbidity (NTU)	Remarks
(Hercules, Inc.) Hercofloc	#860	2.5	60	loose flocs, slow settling velocity
		8.0	52	
	#863	2.5	22	loose flocs, slow settling velocity
		8.0	16	
	#864	2.5	35	loose flocs, slow settling velocity
		8.0	33	
	#848	2.5	20	loose flocs, slow settling velocity
		8.0	14	
	#834.5	2.5	170	loose flocs, slow settling velocity
		8.0	150	
	#815.3*	2.5	10	dense flocs, fast settling velocity
		8.0	6	
	#821.2	2.5	21	loose flocs, slow settling velocity
		8.0	17	
	#849*	2.5	8	dense flocs, fast settling velocity
		8.0	5	
	#847	2.5	70	dense flocs, medium fast settling velocity
		8.0	14	
	#853	2.5	17	dense flocs, medium fast settling velocity
		8.0	12	
	#852	2.5	27	loose flocs, slow settling velocity
		8.0	24	
	#1036	2.5	23	loose flocs, slow settling velocity
		8.0	19	

* Cationic

Table 28 - Continued

Summary of Laboratory Screening Tests on Polymers

Polymer		Salinity of Solution (o/oo)	Residual Turbidity (NTU)	Remarks
Hercofloc	#834.1	2.5	22	loose flocs, slow settling velocity
		8.0	15	
	#871	2.5	20	loose flocs, slow settling velocity
		8.0	13	
	#821.2	2.5	22	loose flocs, slow settling velocity
		8.0	16	
Betz	#1190	2.5	25	loose flocs, slow settling velocity
		8.0	20	
	#1185	2.5	22	loose flocs, slow settling velocity
		8.0	18	
	#1180	2.5	13	loose flocs, slow settling velocity
		8.0	9	
	#1175	2.5	25	loose flocs, slow settling velocity
		8.0	20	
	#1160*	2.5	2	big, dense flocs, fast settling velocity
		8.0	2	
	#1150	2.5	4	dense flocs, fast settling velocity
		8.0	3	
	#1140	2.5	5	dense flocs, medium fast settling velocity
		8.0	4	
	#1130	2.5	10	loose flocs, slow settling velocity
		8.0	8	
	#1120	2.5	15	loose flocs, slow settling velocity
		8.0	12	
	#1110	2.5	6	loose flocs, medium fast settling velocity
		8.0	4	
	#1100	2.5	12	loose flocs, slow settling velocity
		8.0	9	

* Cationic

Table 28 - Continued

Summary of Laboratory Screening Tests on Polymers

Polymer		Salinity of Solution (o/oo)	Residual Turbidity (NTU)	Remarks
(American Cyanamid Co.) Magnifloc	#587 C	2.5	15	loose flocs, slow settling velocity
		8.0	12	
	#591 C	2.5	10	loose flocs, slow settling velocity
		8.0	7	
	#905 N†	2.5	3	big, dense flocs, fast settling velocity
		8.0	2	
	#835 N	2.5	10	loose flocs, medium fast settling velocity
		8.0	7	
	#834 A	2.5	10	loose flocs, slow settling velocity
		8.0	6	
	#573 C	2.5	12	loose flocs, slow settling velocity
		8.0	9	
	#581 C	2.5	10	loose flocs, slow settling velocity
		8.0	6	
Calgon Co.	Cat-Floc T	2.5	17	loose flocs, slow settling velocity
		8.0	10	
	WT-2690†	2.5	5	dense flocs, fast settling velocity
		8.0	3	
	Wt-2870	2.5	9	loose flocs, slow settling velocity
		8.0	7	
	WT-3000	2.5	22	loose flocs, slow settling velocity
		8.0	18	
Union Carbide	Polyox WSR-301	2.5	41	loose flocs, slow settling velocity
		8.0	34	
	Polyox Coagulant	2.5	40	loose flocs, slow settling velocity
		8.0	34	

† Nonionic

Table 29

SOIL CHARACTERISTICS: SEDIMENT #7

Control - no polymer added

Test Type		Time (sec) of shaking	% Moisture	Void Ratio	Porosity	Specific Gravity	Density (wet)	Liquid Limit	Plastic Limit	Plasticity Index
	Control	0	274.87	2.57	0.720	1.20	1.26	90.6	40.10	50.50
1:4 sedi/seawater	A	7	277.45	2.76	0.734	1.21	1.22	107.0	40.13	66.87
Betz 1120	B	15	278.39	2.76	0.734	1.22	1.23	100.5	36.25	64.25
10 ppm	C	30	278.61	2.79	0.736	1.20	1.20	99.4	44.56	54.84
	D	60	282.25	2.91	0.744	1.20	1.18	96.2	36.46	59.74
	E	120	280.18	2.79	0.736	1.18	1.18	102.5	40.63	61.87
	F	5	268.47	2.70	0.730	1.22	1.21	92.1	45.56	46.54
	Control	0	251.89	3.00	0.750	1.27	1.12	85.0	37.68	47.32
1:10 sedi/seawater	A	12	243.94	2.57	0.720	1.27	1.22	80.5	41.92	38.58
Betz 1120	B	15	248.22	2.47	0.712	1.23	1.23	86.1	32.63	53.47
3 ppm	C	30	248.20	2.68	0.728	1.27	1.20	83.9	38.97	44.93
	D	60	247.93	2.33	0.700	1.18	1.23	86.75	43.39	43.36
	E	120	257.87	2.60	0.722	1.25	1.24	82.5	38.72	43.78
	Control	0	372.55	3.70	0.786	1.08	1.09	136.0	40.00	96.00
1:4 sedi/water	A	5	368.80	3.60	0.782	1.14	1.16	111.9	44.99	66.91
Mobile Bay water	B	15	380.96	3.70	0.786	1.14	1.17	96.9	41.09	55.81
Betz 1120	C	30	398.77	3.70	0.788	1.06	1.12	117.5	38.08	79.42
10 ppm	D	60	365.72	3.70	0.776	1.11	1.15	112.8	40.66	72.14
	E	120	465.98	4.60	0.820	1.10	1.12			
1:4 sed/water	Control	0	139.14	1.05	0.512	1.34	1.56	46.4	20.93	25.47
8% salinity	A	5	145.17	1.10	0.524	1.28	1.50	62.75	25.18	37.57
Betz 1120	B	10	152.04	1.30	0.560	1.24	1.38	60.8	21.33	39.47
10 ppm	C	30	142.30	1.20	0.548	1.26	1.38	55.6	22.92	32.68
	Control	0	253.36	1.87	0.652	1.14	1.41	85.2	35.4	49.8
1:4 sedi/water	A	60	246.12	1.98	0.664	1.11	1.30	82.5	38.15	44.35
2.5% salinity	B	30	242.17	1.84	0.648	1.12	1.35	84.4	34.86	49.55
Betz 1120	C	15	246.06	2.25	0.692	1.09	1.16	93.8	33.38	60.42
17.5 ppm	D	5	219.91	1.48	0.596	1.13	1.47	69.9	31.05	38.85

void ratio = the quotient of the volume of voids divided by the volume of solids in a soil mass
porosity = the ratio of the volume of voids to the total volume
density = weight per unit volume
specific gravity = ratio of the dry weight of a given volume divided by the weight of an equal volume of water

Table 30

PARTICLE SIZE DISTRIBUTION OF THE RESETTLED SEDIMENT UNDER BATCH STUDY FOR SEDIMENT NO. 7 WITH SEDIMENT/BAY WATER RATIO OF 1:4 AND ITS PERCENTAGE OF FLOCCULATION

Particle Size (µm)	% Finer		% of Flocculation
	(a)	(b)	$\frac{U-T^*}{U}$
< 62.5	82.9	73.0	12
< 31.3	57.9	54.9	5
< 15.6	32.1	24.0	25
< 7.8	24.7	18.1	27
< 3.9	22.0	16.6	25
< 1.95	19.3	13.8	28
< 0.97	15.9	10.4	35
< 0.48	12.9	10.1	22

a: settled sediment sample from controlled column

b: settled sediment sample from best flocculated column in which 10 ppm Betz 1120 polymer was added

*U: the percent finer than particle size D for untreated sediments

T: the percent finer than particle size D for polymer-treated sediments

Table 31

Salinity Effect Upon Particle Size Distribution of the Resettled Sediments

Particle Size (μm)	% Finer					% Flocculation*					
	A**	B	C	D	E	F	a†	b	c	d	e
< 62.5	38.0	35.7	34.8	33.9	31.4	35.2	--	--	1	4	11
< 31.3	30.5	24.8	24.3	19.9	9.7	26.2	--	5	7	24	63
< 15.6	22.4	15.0	15.0	10.9	7.5	15.0	--	--	--	27	50
< 7.8	14.3	9.5	9.5	7.1	6.2	10.5	--	10	10	32	41
< 3.9	9.0	6.6	6.6	5.3	5.1	7.7	--	14	14	31	34
< 1.95	6.6	4.9	4.9	4.1	4.2	5.8	--	16	16	29	28
< 0.97	4.5	3.8	3.1	2.9	2.5	4.2	--	10	26	31	40
< 0.48	2.3	1.9	1.4	1.8	2.0	3.2	28	41	56	44	38

* % Flocculation $= \frac{U-T}{U}$

** A-E: Settled sediment with Mobile Bay water, 2.5, 8, 16, 33 o/oo salinity solution in which 10 ppm of Betz 1120 was used.

† a-e: % of flocculation corresponding to Columns A-E.

F: settled sediment from control column.

Table 32.

Soluble Trace Metals in the Water Column

After Treatment of Sediment Slurries (Sediment #6)

Sediment/ Seawater (by vol.)	Sampling Point	Time Elapsed (hrs)	Trace Metals (ppb)																	
			Ag		Cd		Cr		Cu		Fe		Mn		Ni		Pb		Zn	
			A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1/4	#2	0	0.03	0.03	0.2	0.3	0.5	0.5	0.5	0.5	8.5	7.0	2.5	2.5	0.5	0.5	0.4	0.3	0.5	0.5
		0.5	0.03	0.03	0.2	0.2	0.6	0.6	0.3	0.4	8.0	7.0	3.0	3.0	0.7	0.7	0.4	0.4	4.0	4.2
		2.0	0.03	0.03	0.1	0.1	0.6	0.6	0.3	0.4	9.0	8.0	3.5	3.5	0.7	0.6	0.3	0.4	3.0	3.2
1/10	#2	0	0.03	0.03	0.2	0.2	0.5	0.5	0.5	0.5	7.0	7.0	1.4	1.0	0.2	0.2	0.4	0.4	0.4	0.4
		0.5	0.03	0.03	0.1	0.2	0.5	0.4	0.2	0.3	7.3	6.0	2.5	2.5	0.7	0.6	0.2	0.2	2.0	1.5
		2.0	0.03	0.03	0.1	0.1	0.5	0.5	0.2	0.2	10.1	8.0	4.0	4.0	0.3	0.3	0.2	0.2	1.8	1.0
	Background Seawater		0.02		0.24		0.50		0.23		2.97		1.03		0.75		0.17		0.27	

A: Polymer calgon WT-3000 treated column

B: Nonpolymer treated column

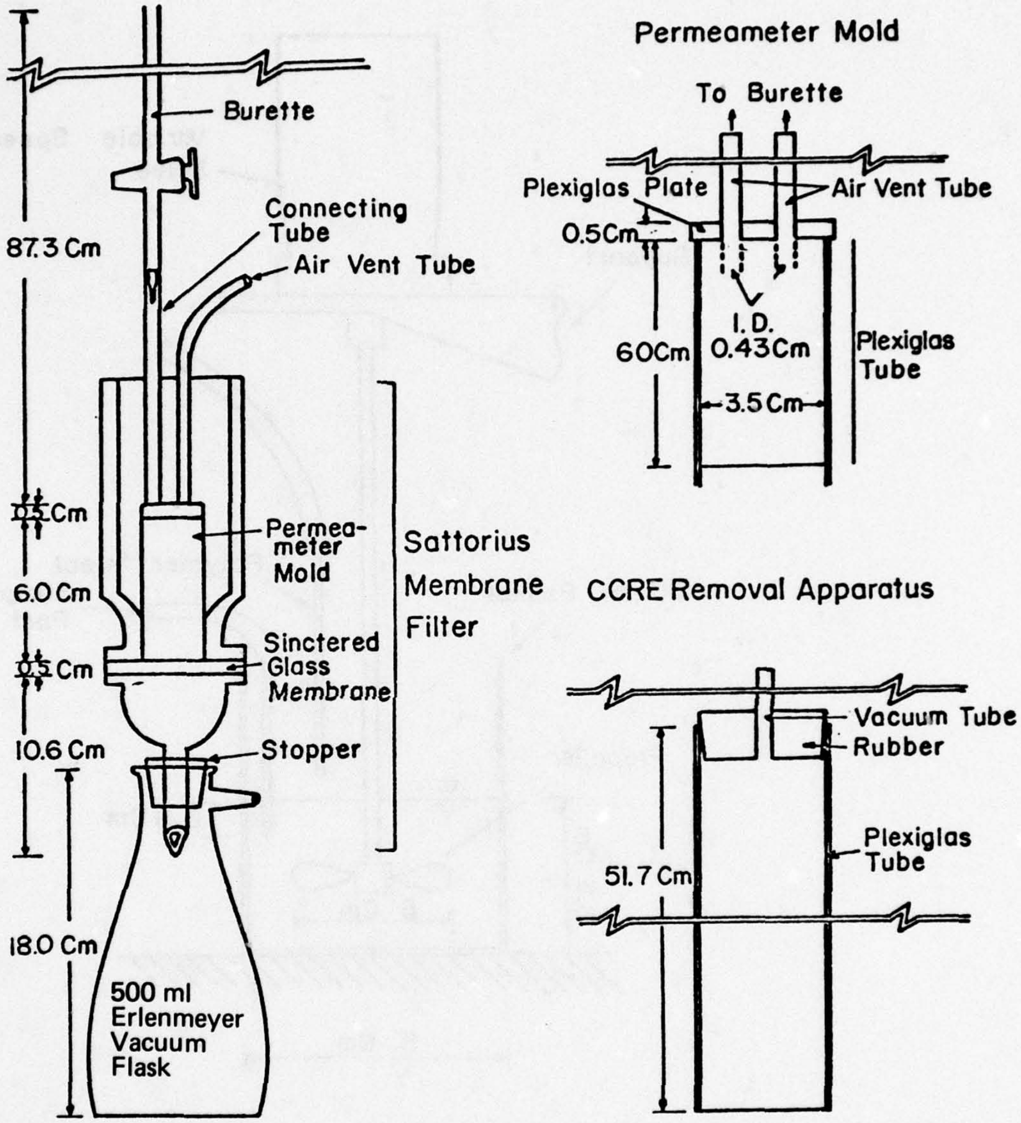

Figure 1. Modified Laboratory Permeameter.

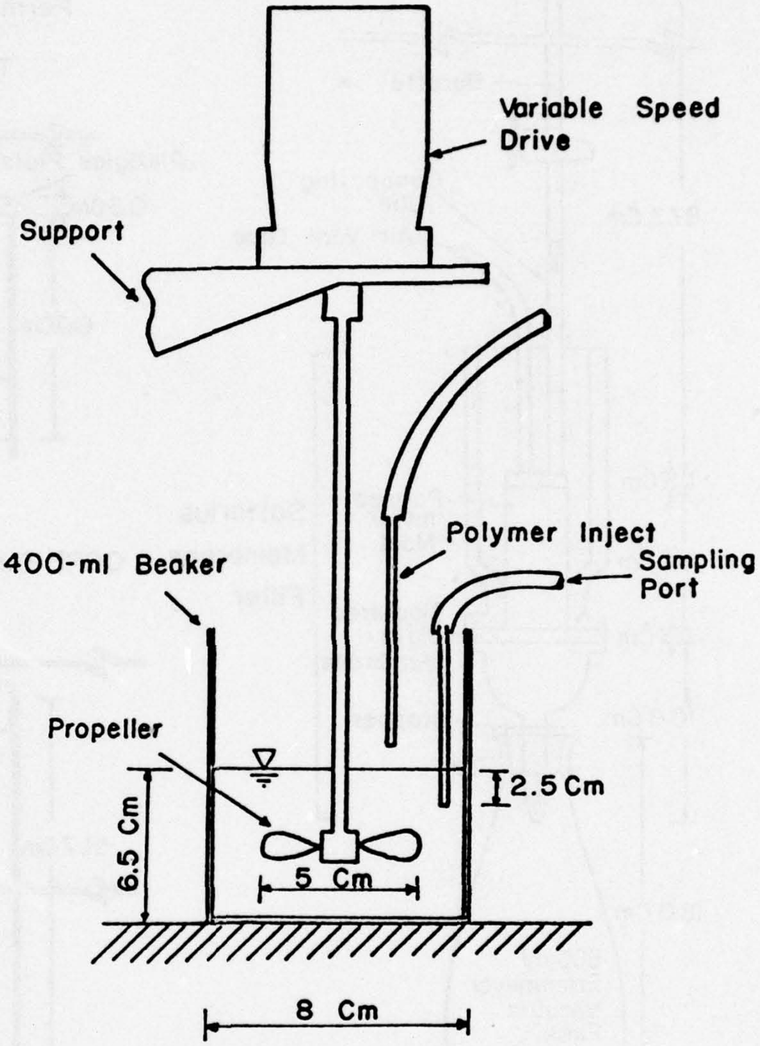

Figure 2. Experimental Setup for Studying Effects of Salinity on the Treatment of Supernatants.

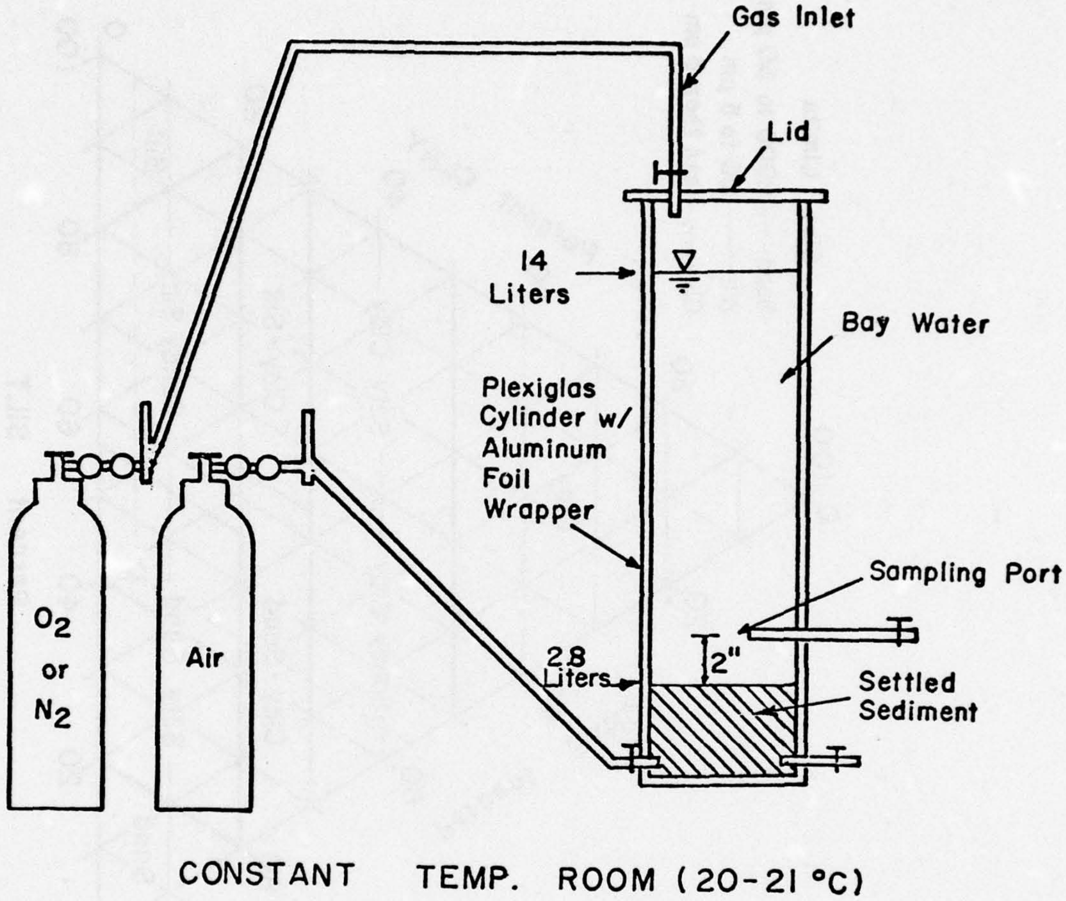

Figure 3. Experimental Setup for Release of Chemical Constituents from Resettled Sediments.

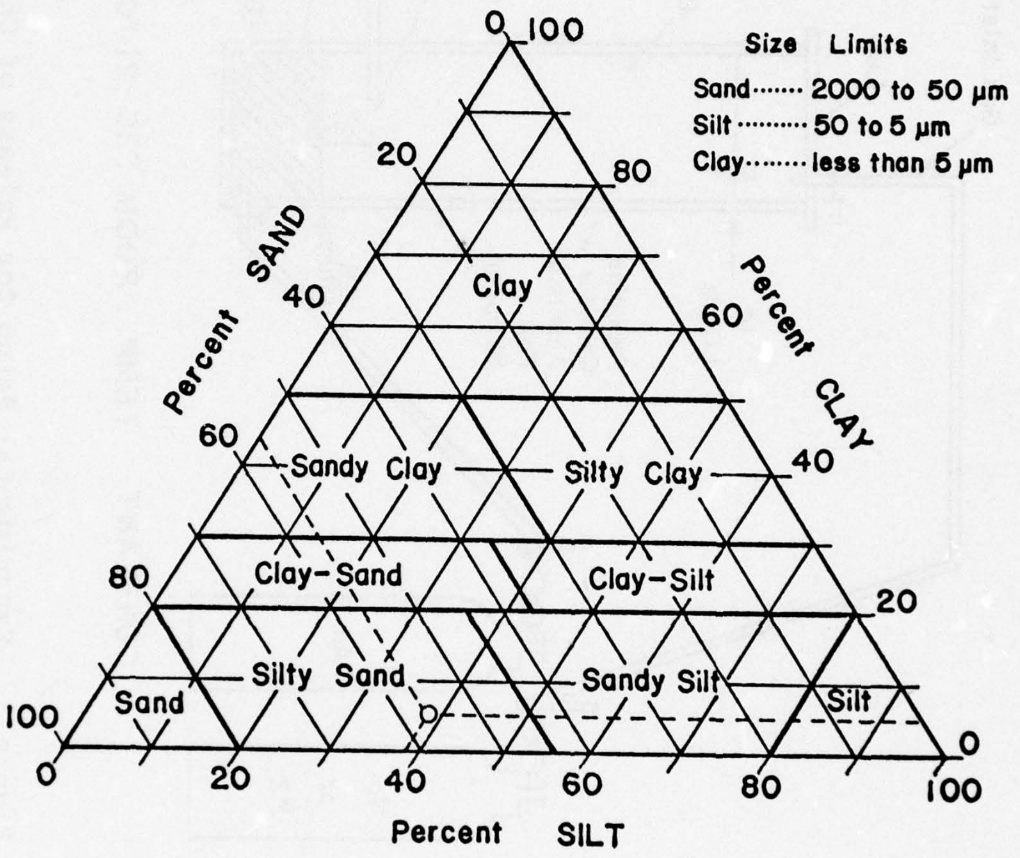

Figure 4. Triangular Classification Chart (Lower Mississippi Valley Division, Corps of Engineers, U.S. Army).

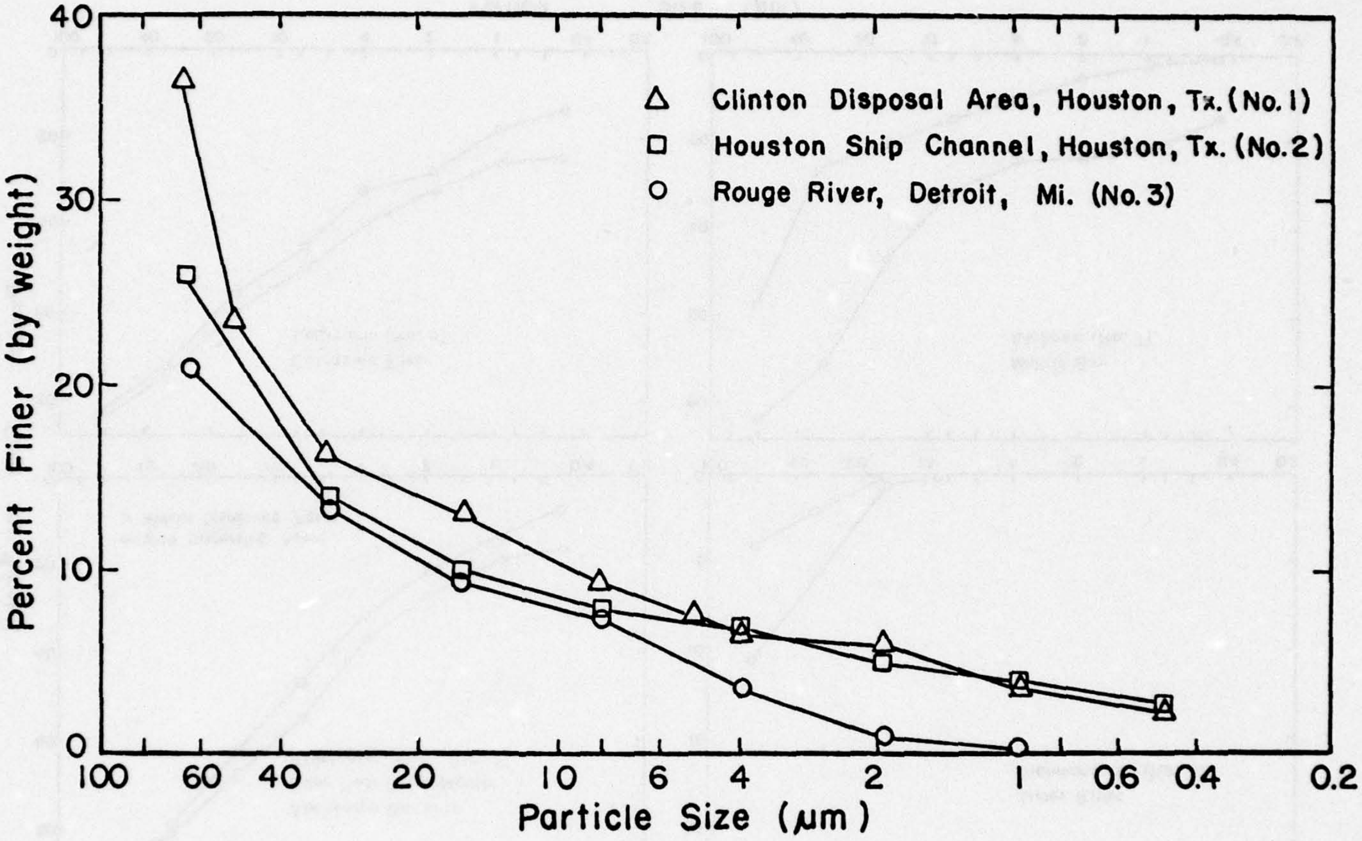

Figure 5. Particle Size Distribution Curve for Sediments #1, #2, and #3.

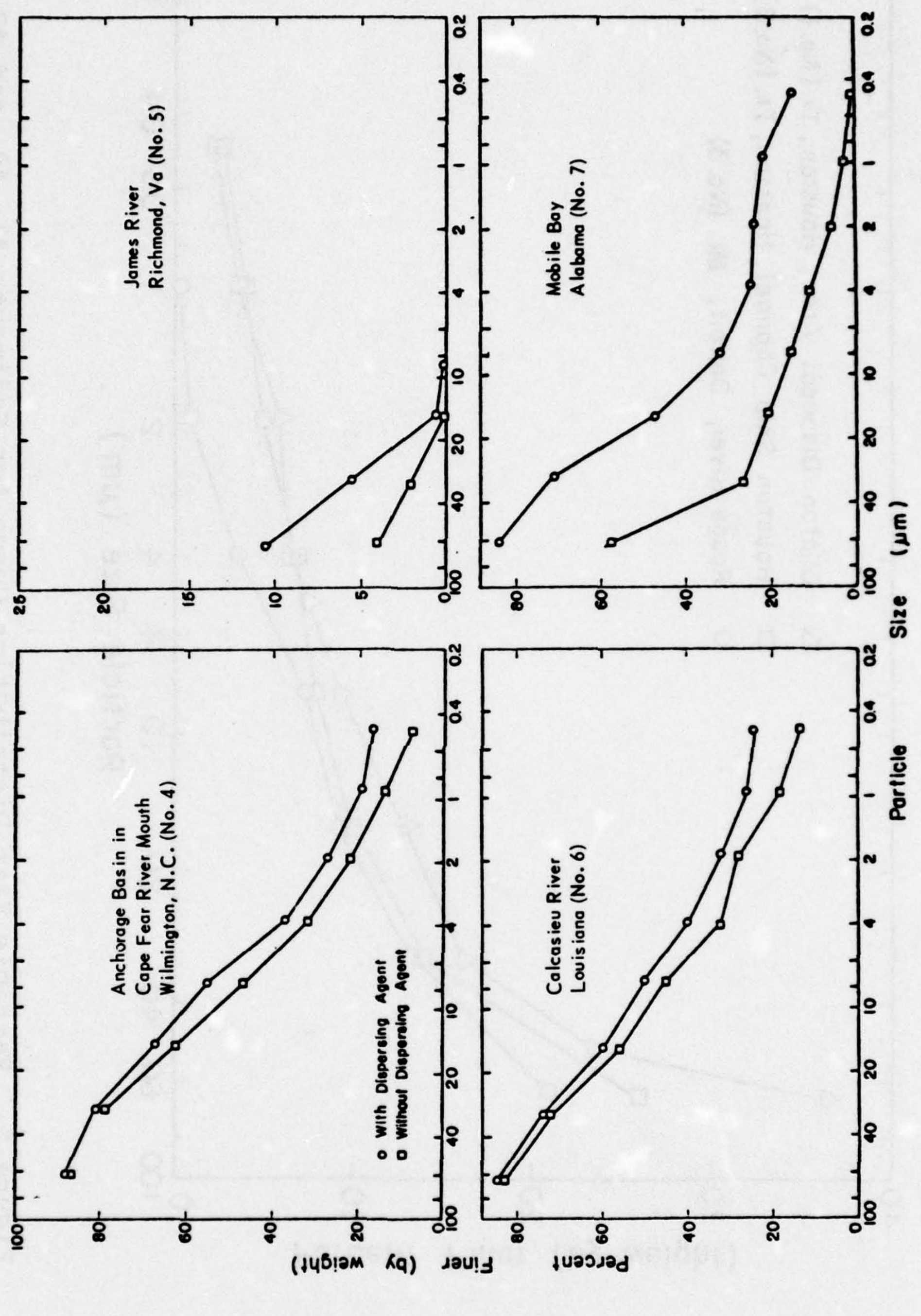

Figure 6. Particle Size Distribution Curve for Sediments #4, #5, #6, and #7.

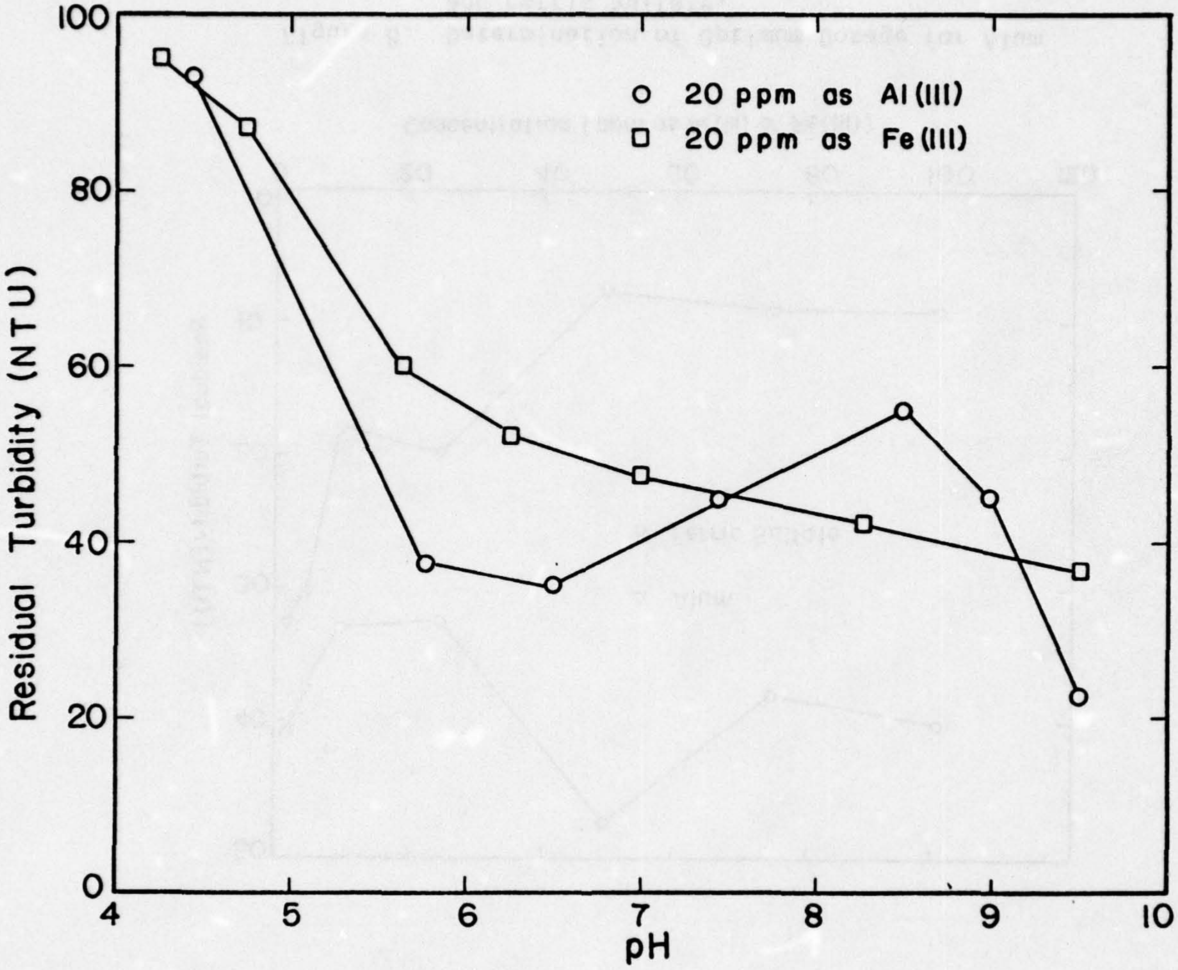

Figure 7. Determination of Optimum pH for Alum and Ferric Sulfate

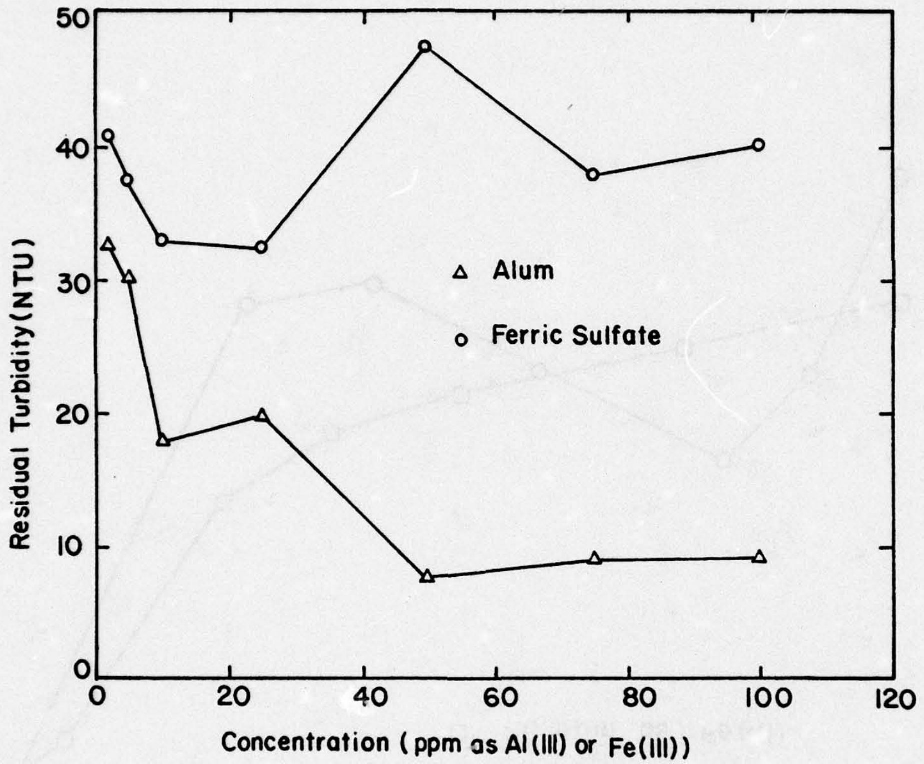

Figure 8. Determination of Optimum Dosage for Alum and Ferric Sulfate.

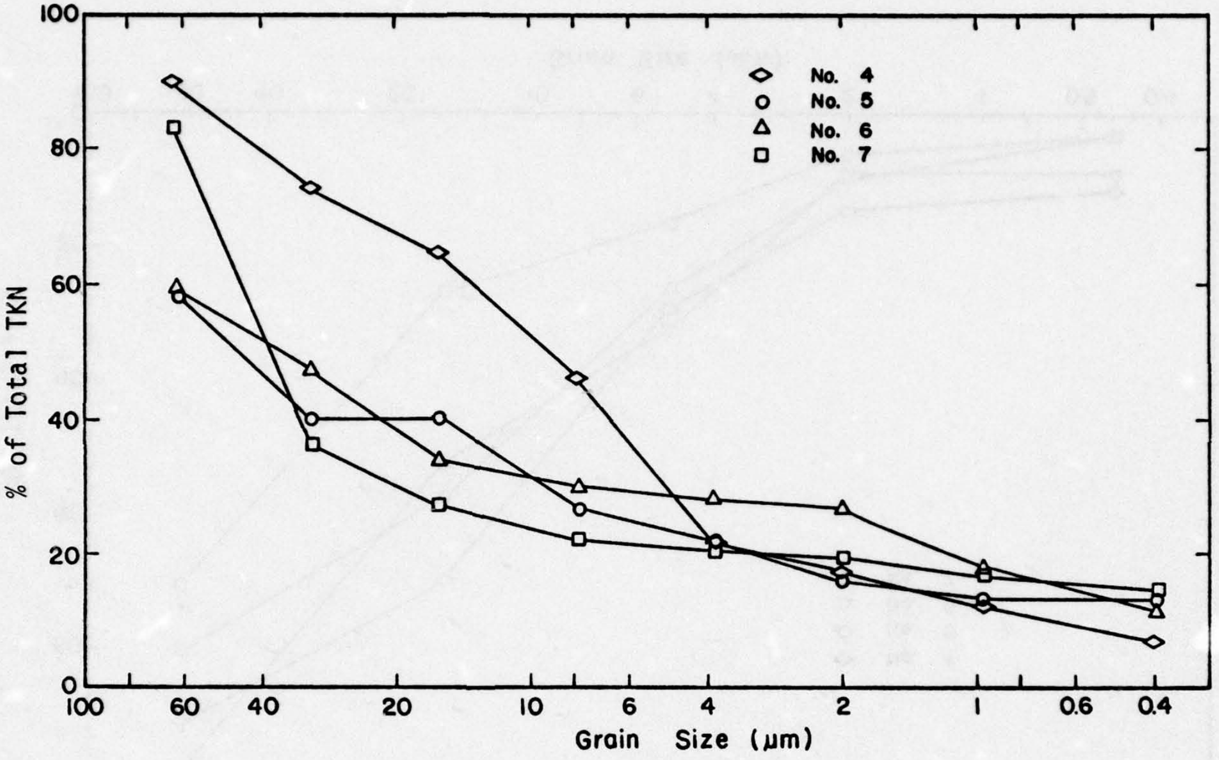

Figure 9. Percentage (%) of TKN in Size Fractions of Dredged Sediments Finer than the Indicated Grain Size.

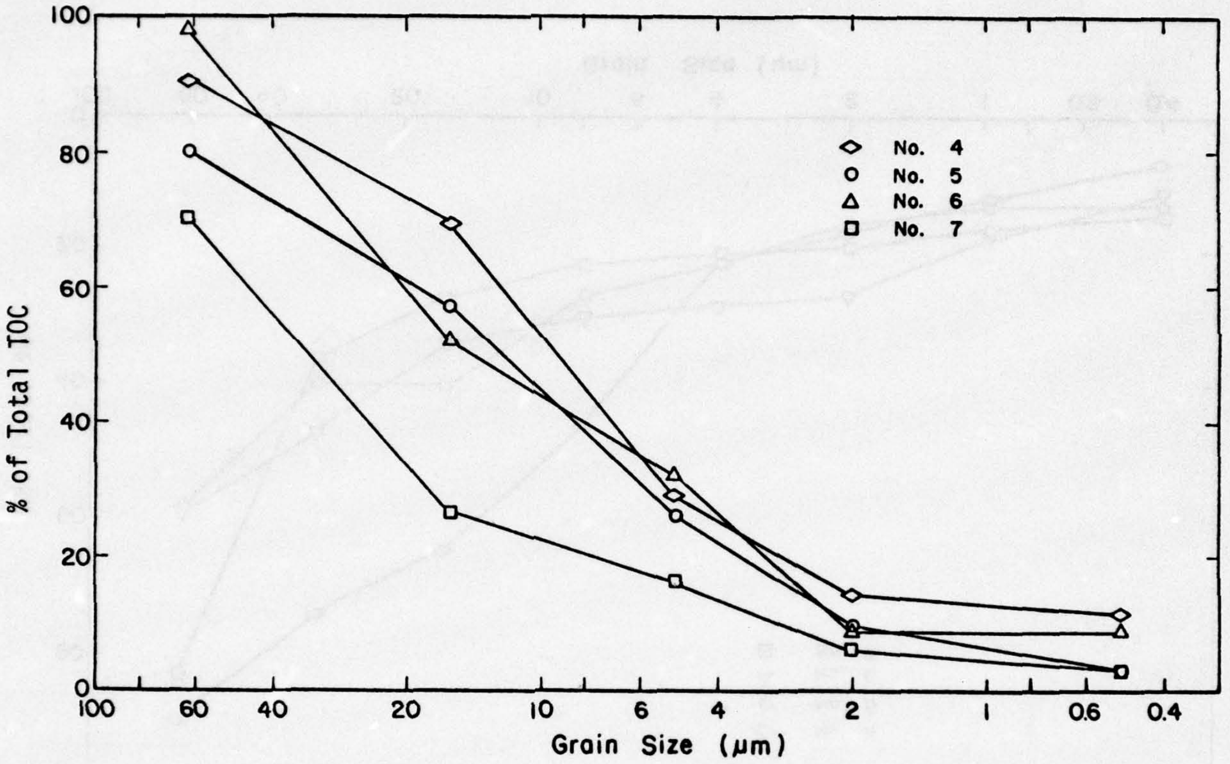

Figure 10. Percentage (%) of TOC in Size Fractions of of Dredged Sediments Finer than the Indicated Grain Size.

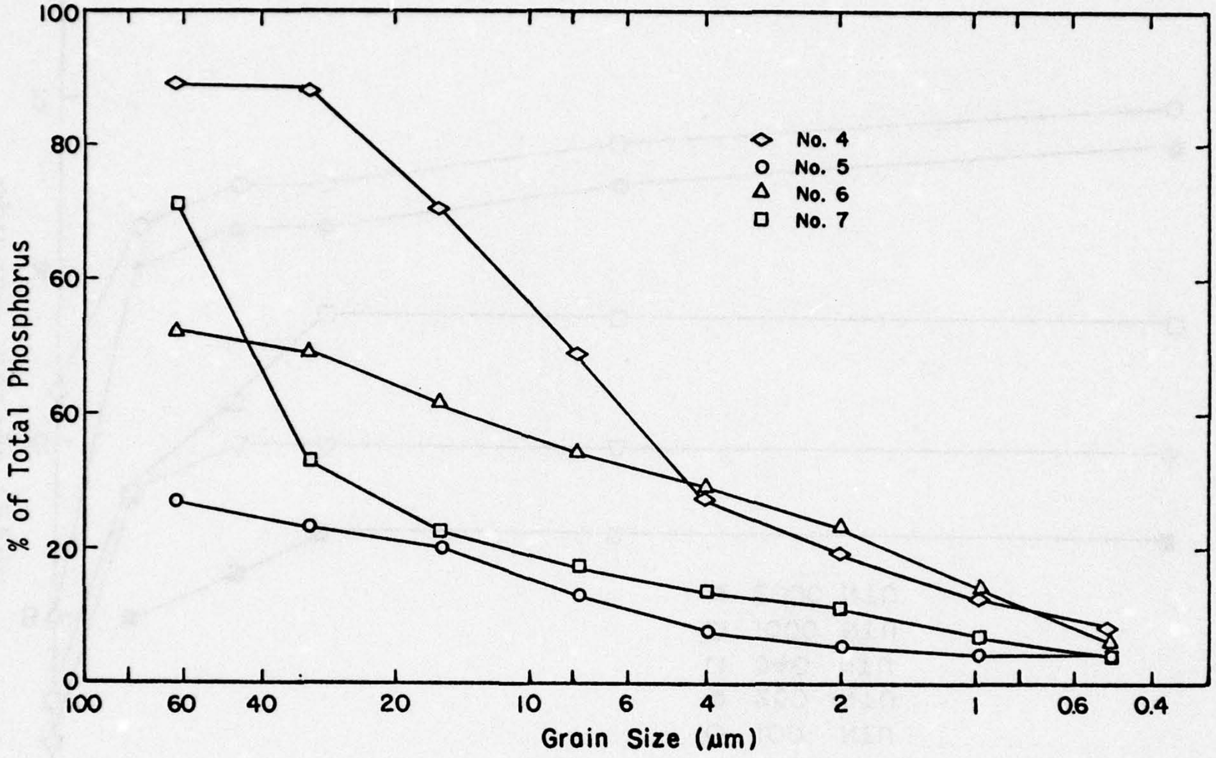

Figure 11. Percentage (%) of T-P in Size Fractions of Dredged Sediments Finer than the Indicated Grain Size.

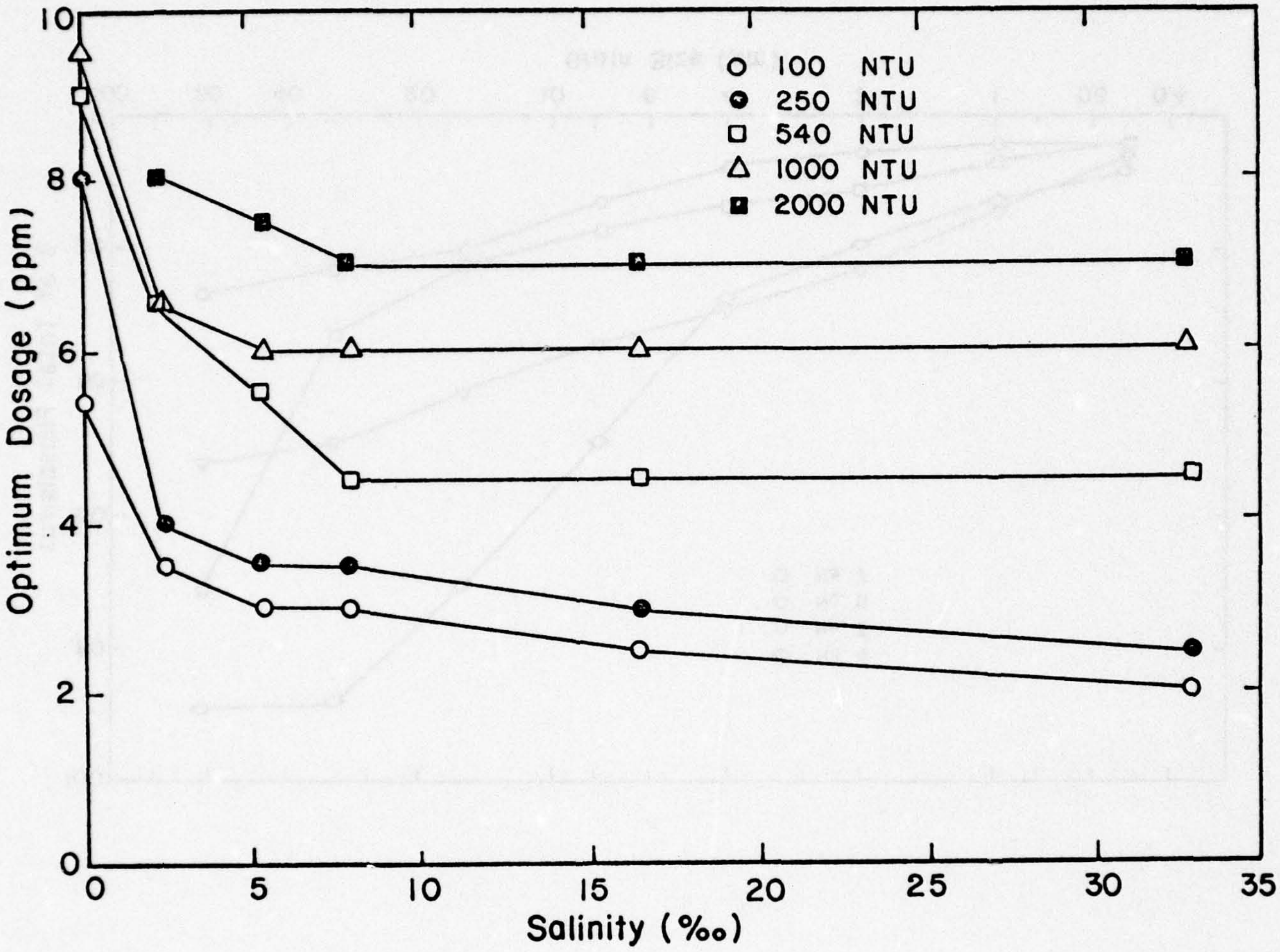

Figure 12. Relationship of Optimum Dosage vs. Initial Turbidity Levels at Different Salinities.

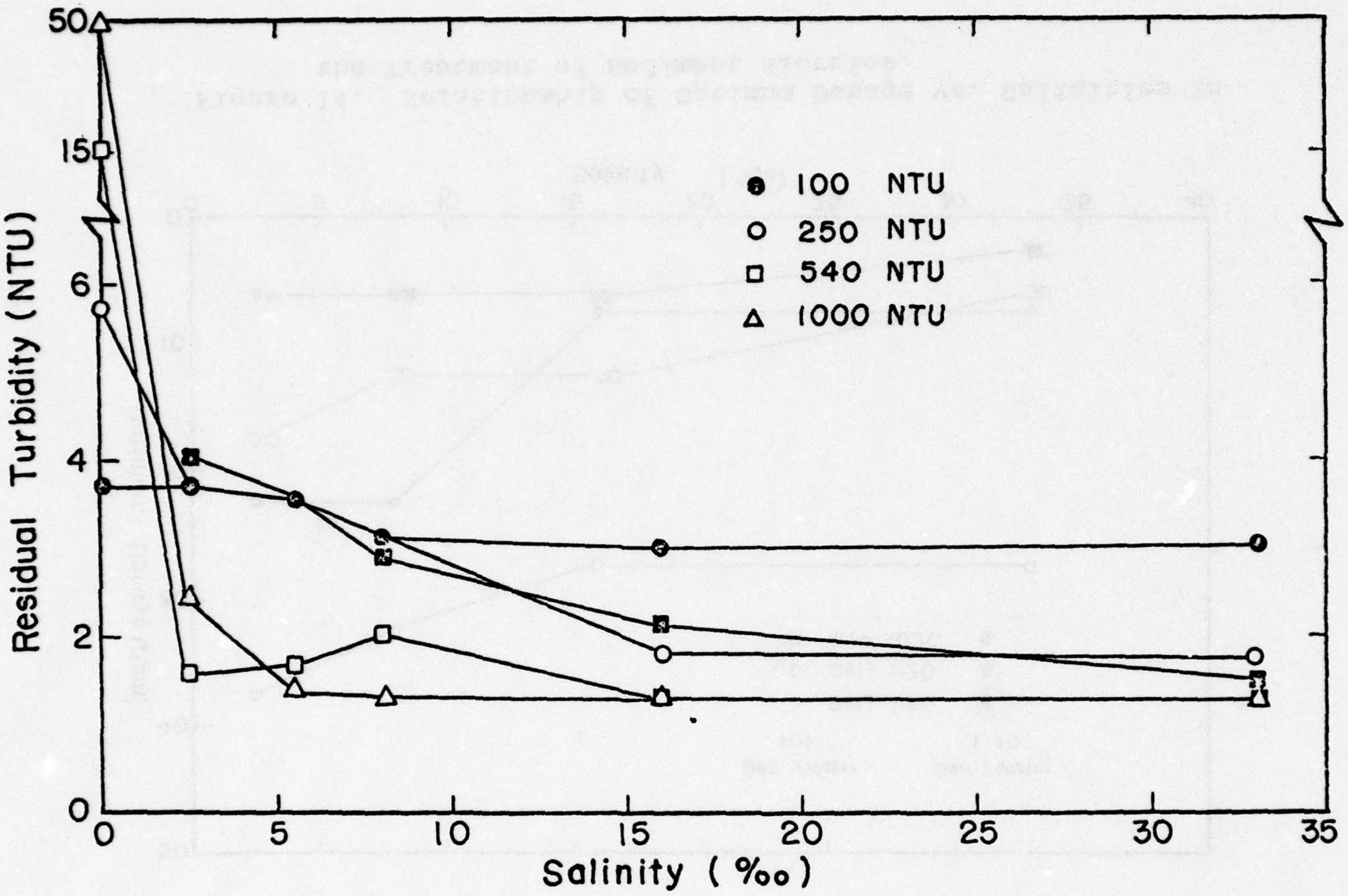

Figure 13. Relationship Between Residual Turbidity and Salinity at Different Initial Turbidity Levels (Optimum Dosages).

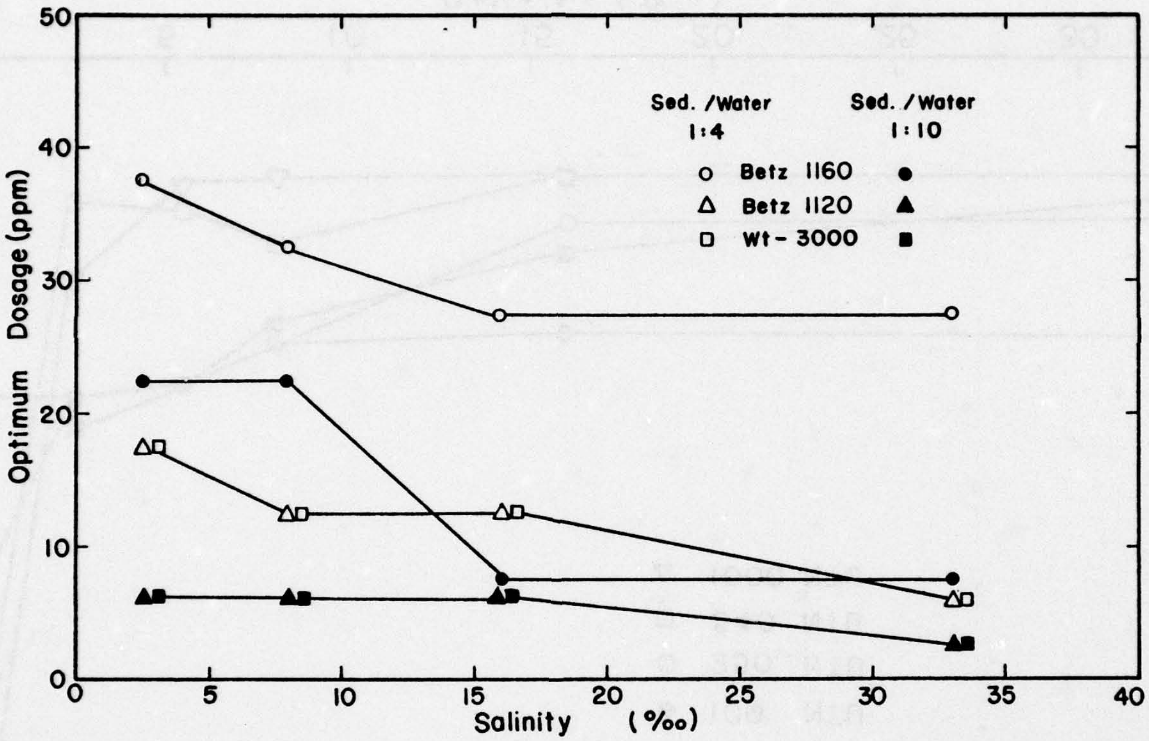

Figure 14. Relationship of Optimum Dosage vs. Salinities in the Treatment of Sediment Slurries.

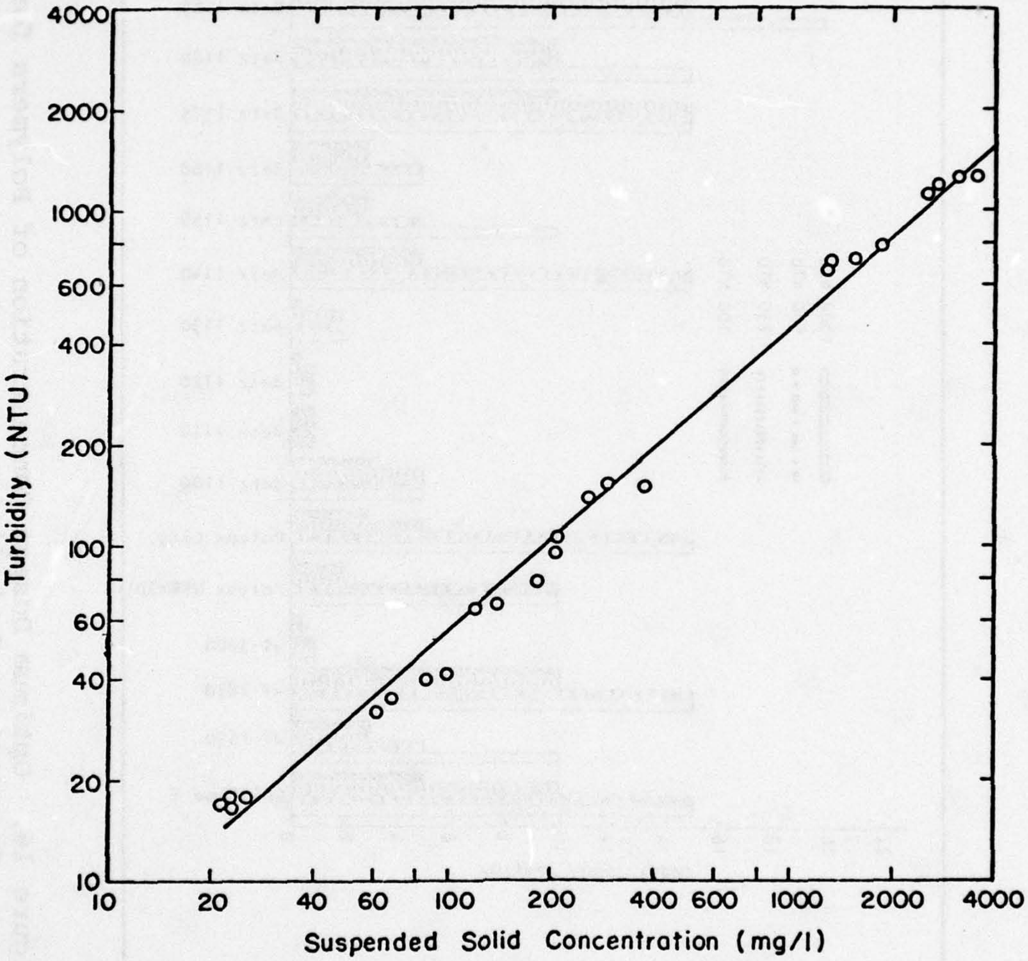

Figure 15. Correlation of Turbidity vs. Suspended Solids in Suspensions.

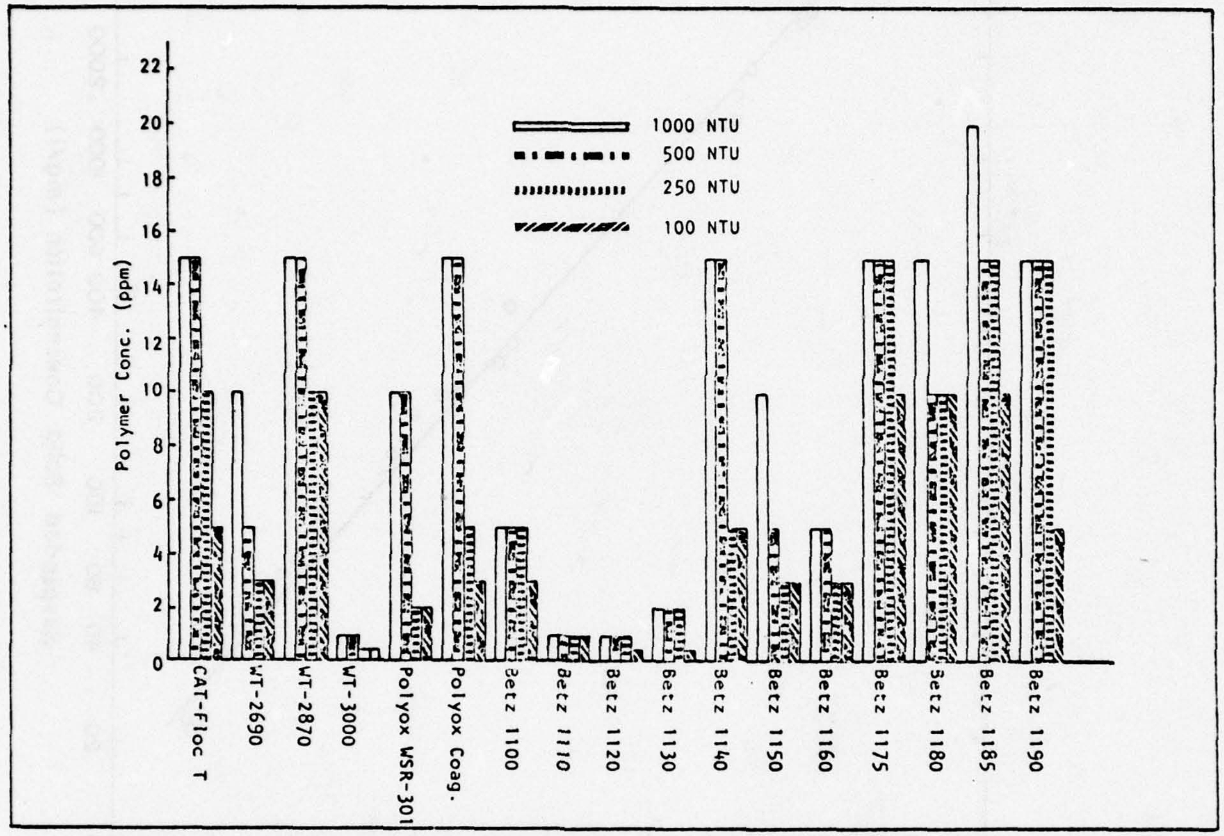

Figure 16. Optimum Dosage Concentration of Polymers for Various Supernatant Turbidities.

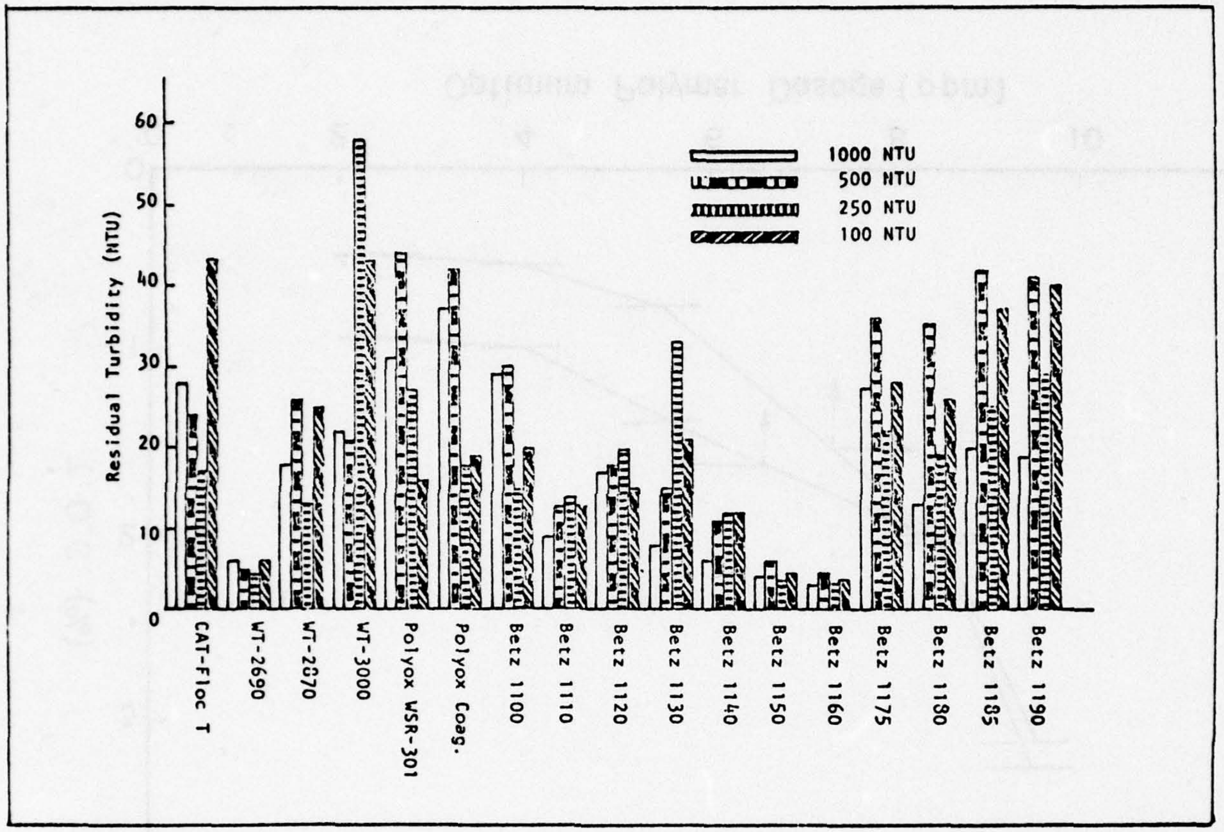

Figure 17. Residual Turbidity Following Optimum Polymer Treatment for Various Original Supernatant Turbidities.

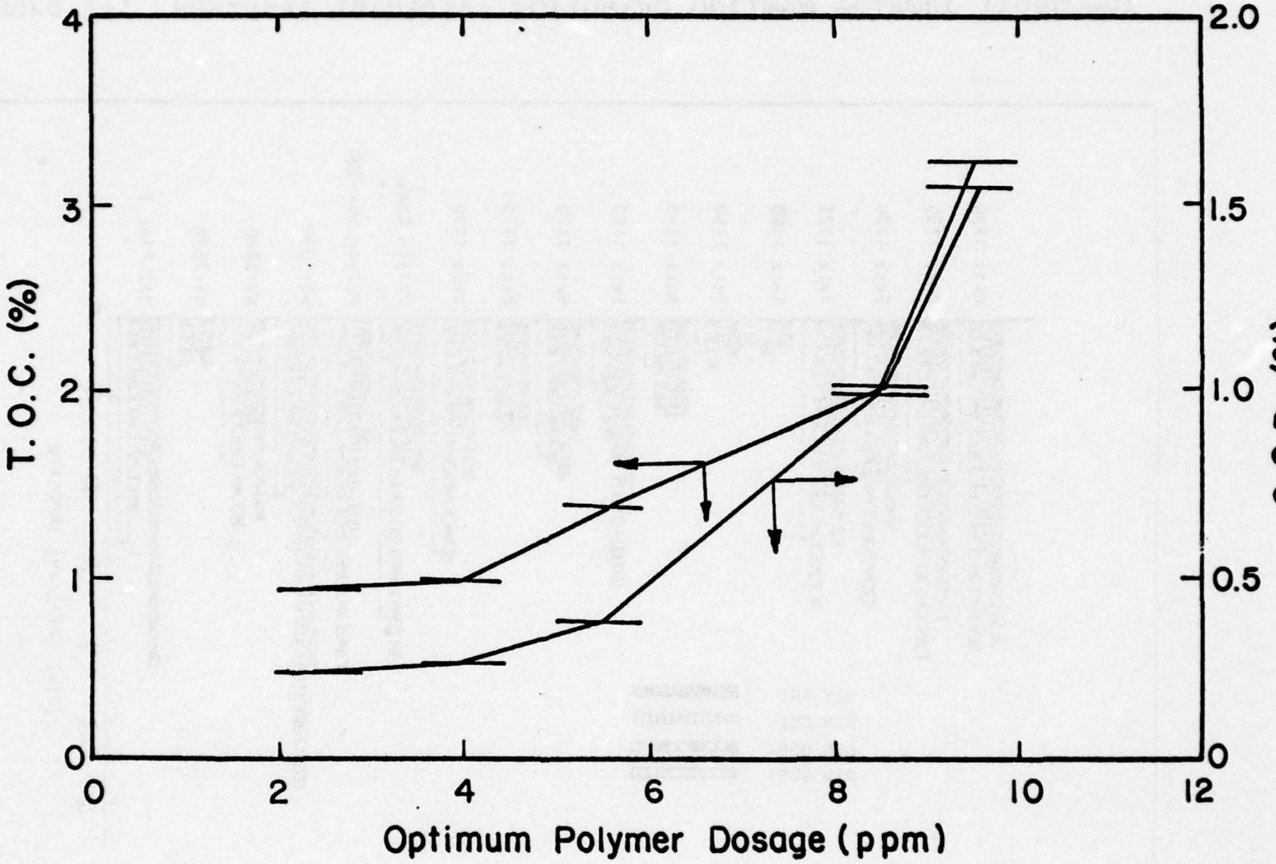

Figure 18. Optimum Polymer Dosage (WT-3000) vs. TOC AND COD of Sediments.

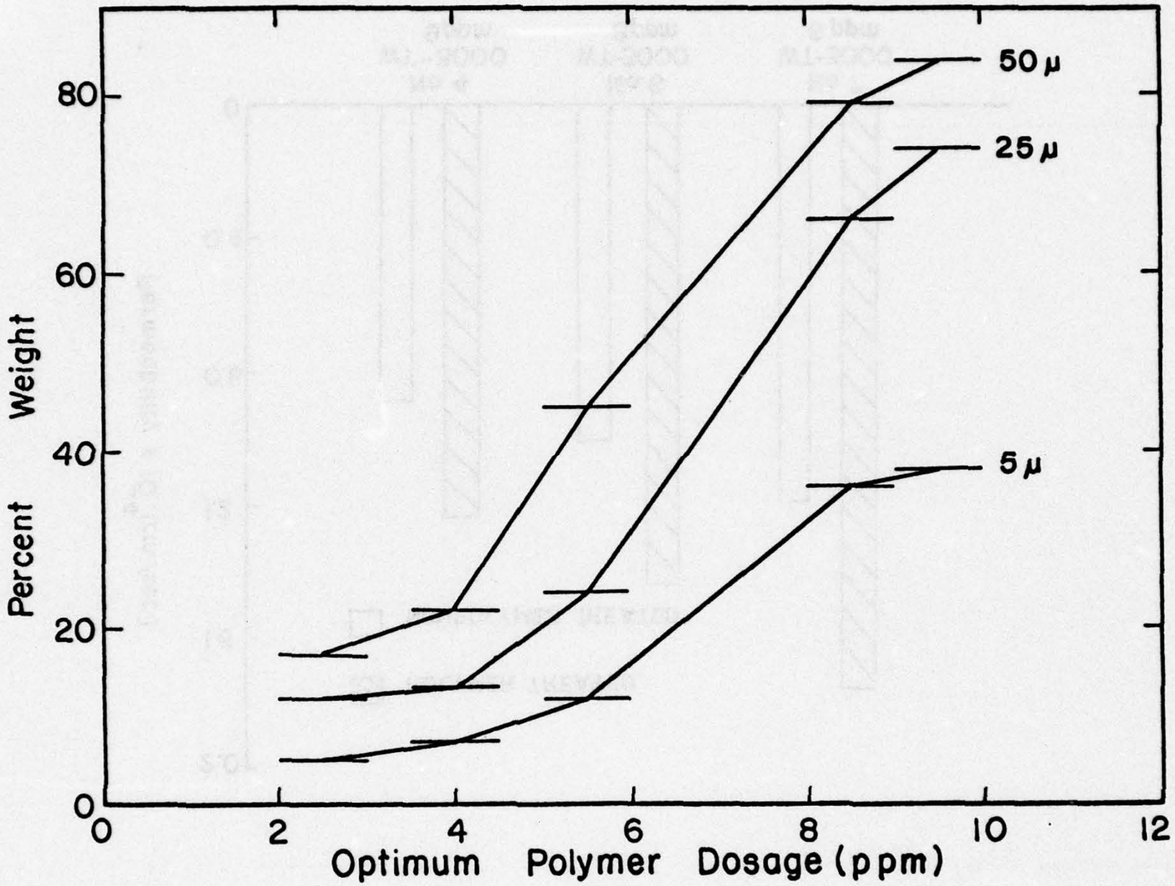

Figure 19. Optimum Polymer Dosage (WT-3000) vs. Sediment Particles Finer than the Indicated Size.

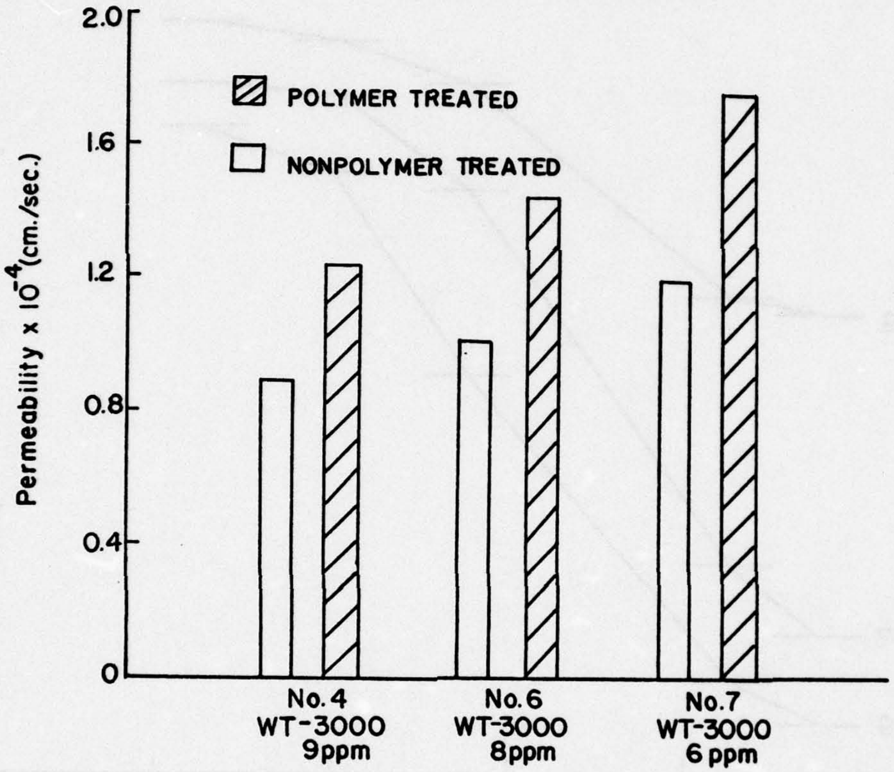

Figure 20. Permeabilities of Polymer-Treated and Non-treated Sediments.

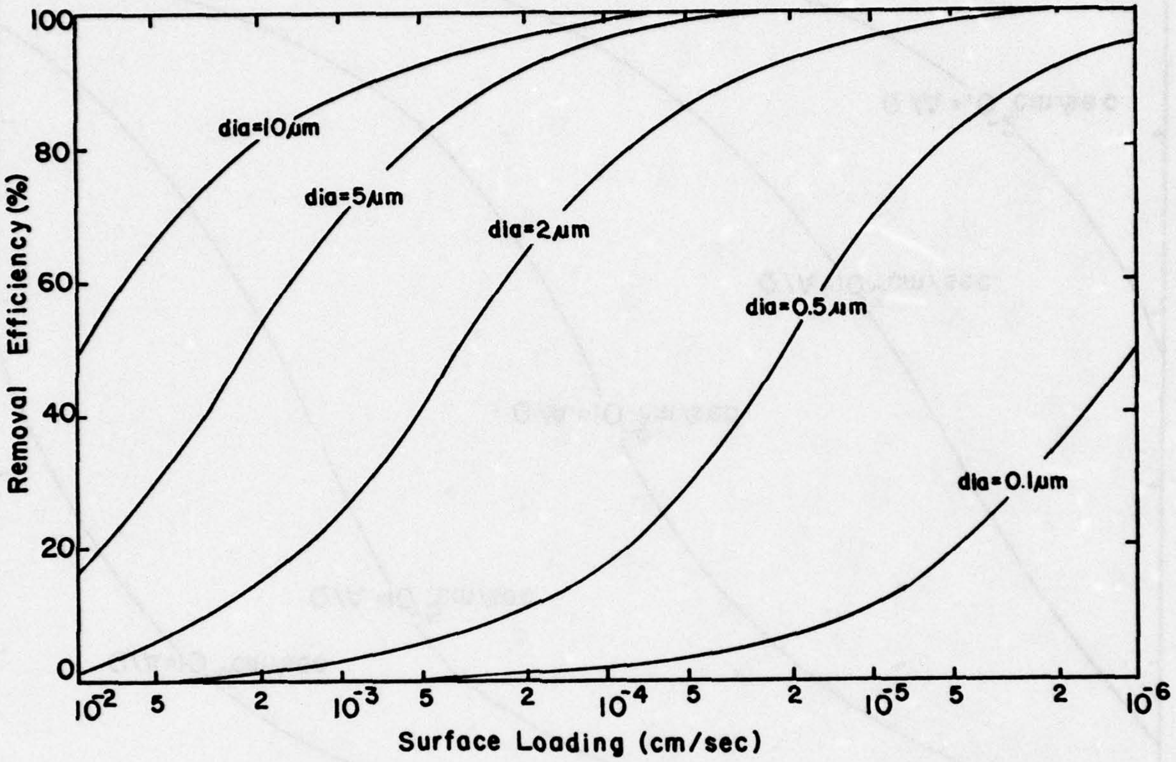

Figure 21. Relationship Between Removal Efficiency and Surface Loading for Suspended Particles of Different Grain Sizes.

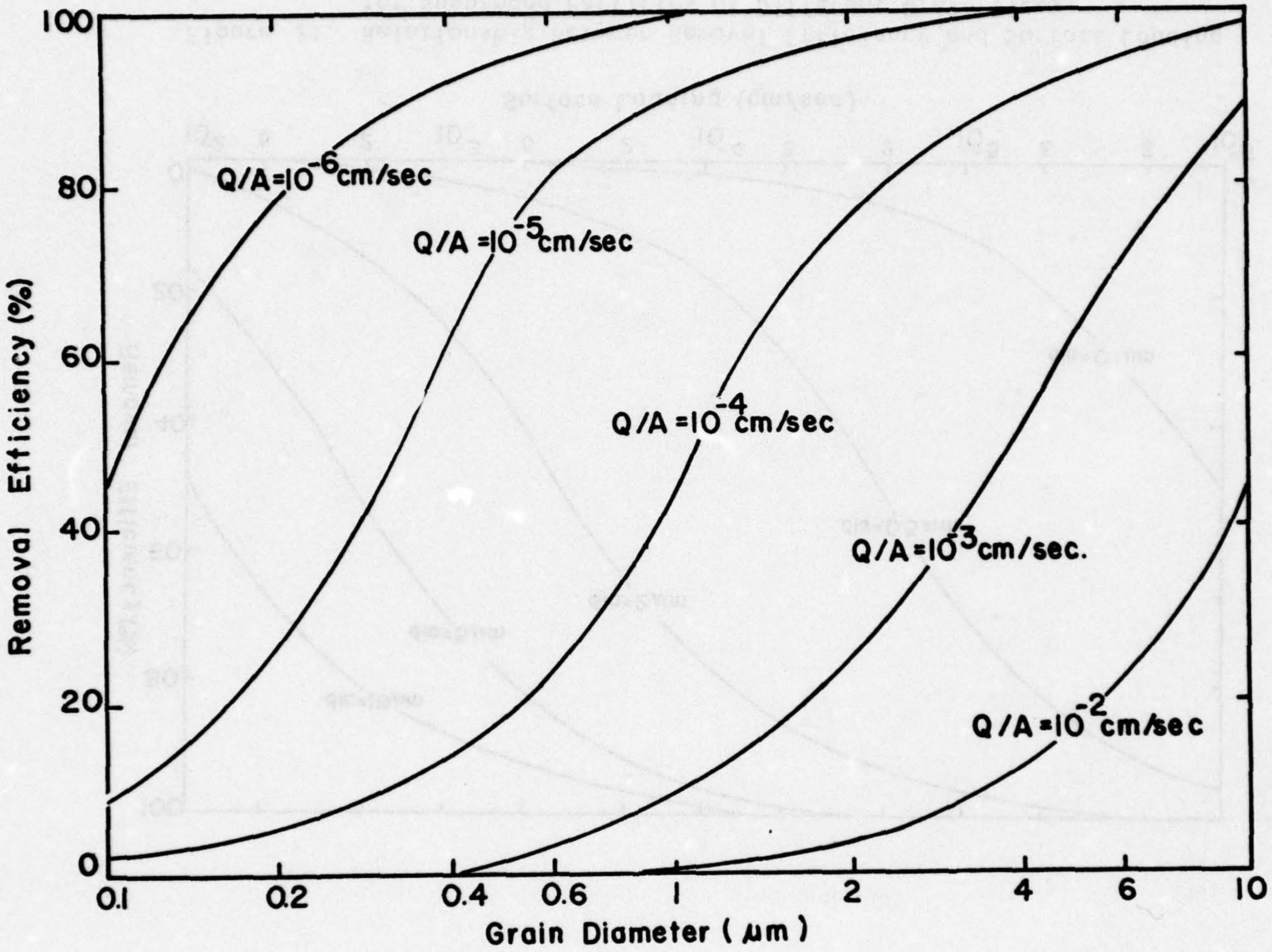

Figure 22. Relationship Between Removal Efficiency and Suspended Solids Diameter Under Different Surface Loading Rates.

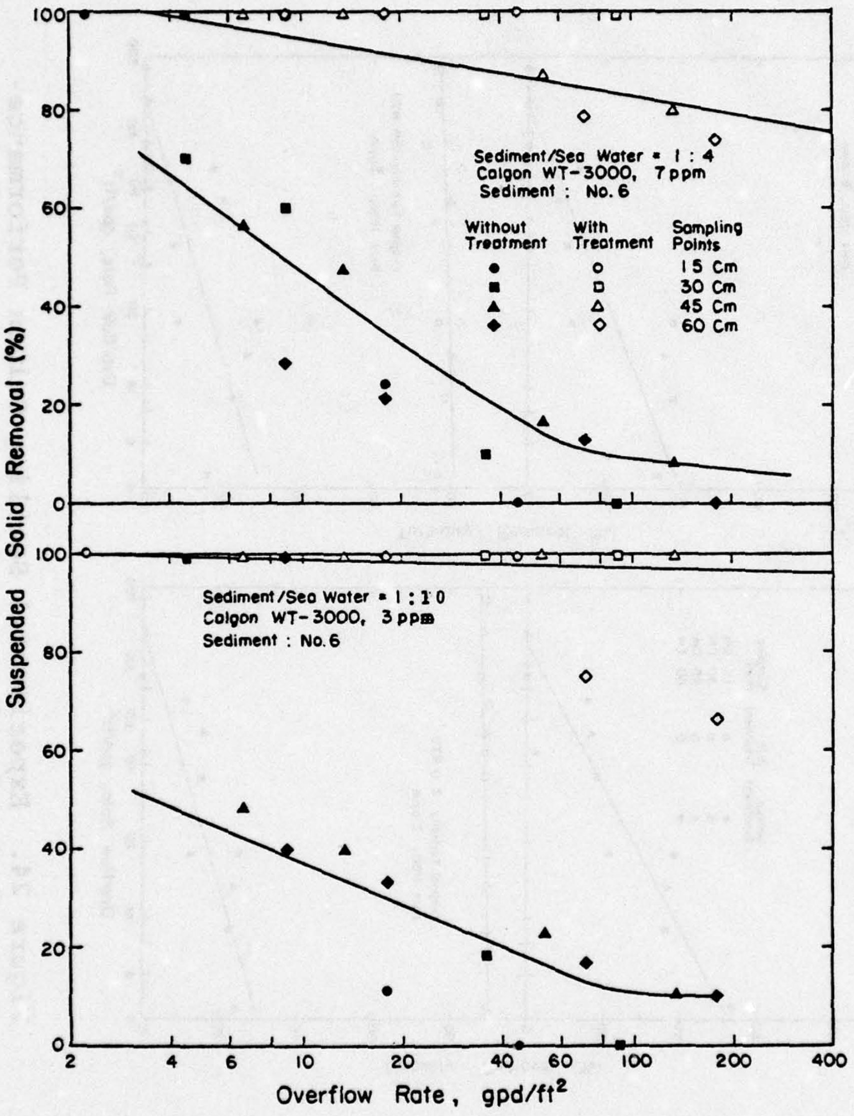

Figure 23. Experimental Settling Column Performance Curve for Sediment Slurries.

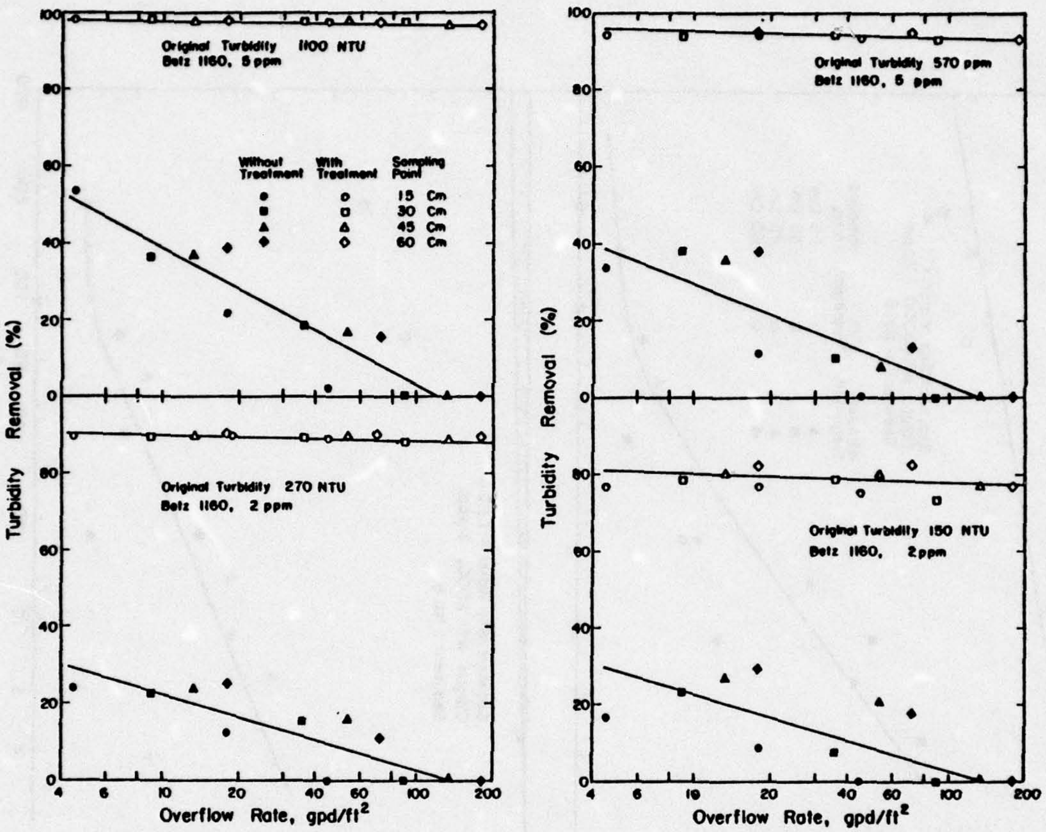

Figure 24. Experimental Settling Column Performance Curve for Suspensions.

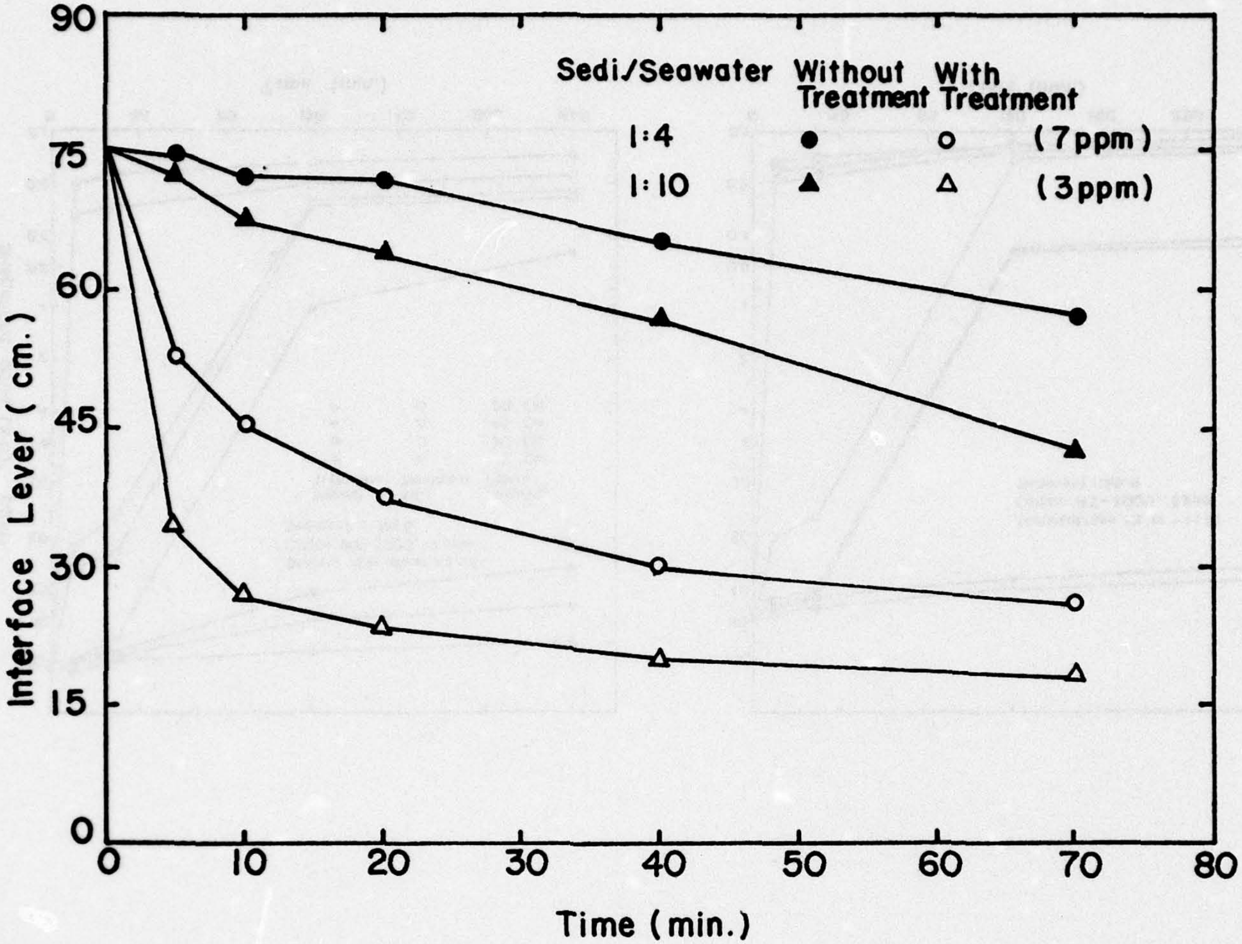

Figure 25. Decline in Slurry Level with Respect to Time Using Polymer Calgon WT-3000 in Column Study.

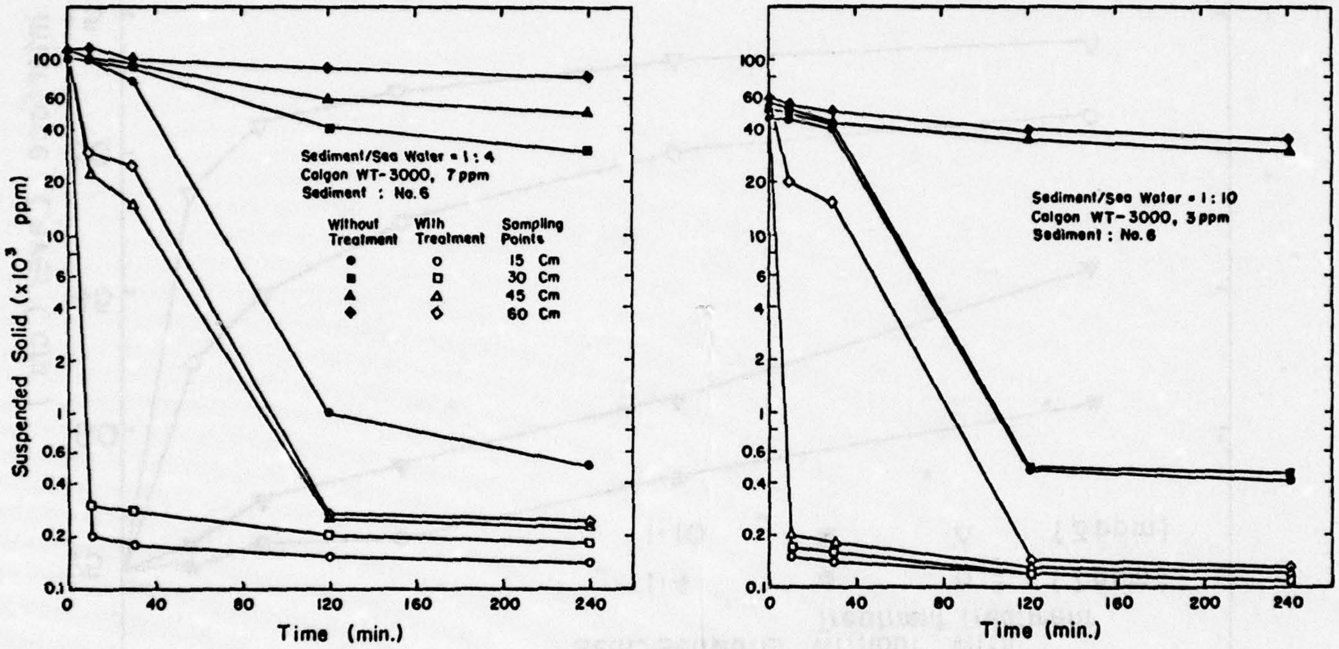

Figure 26. Removal of Suspended Solids by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

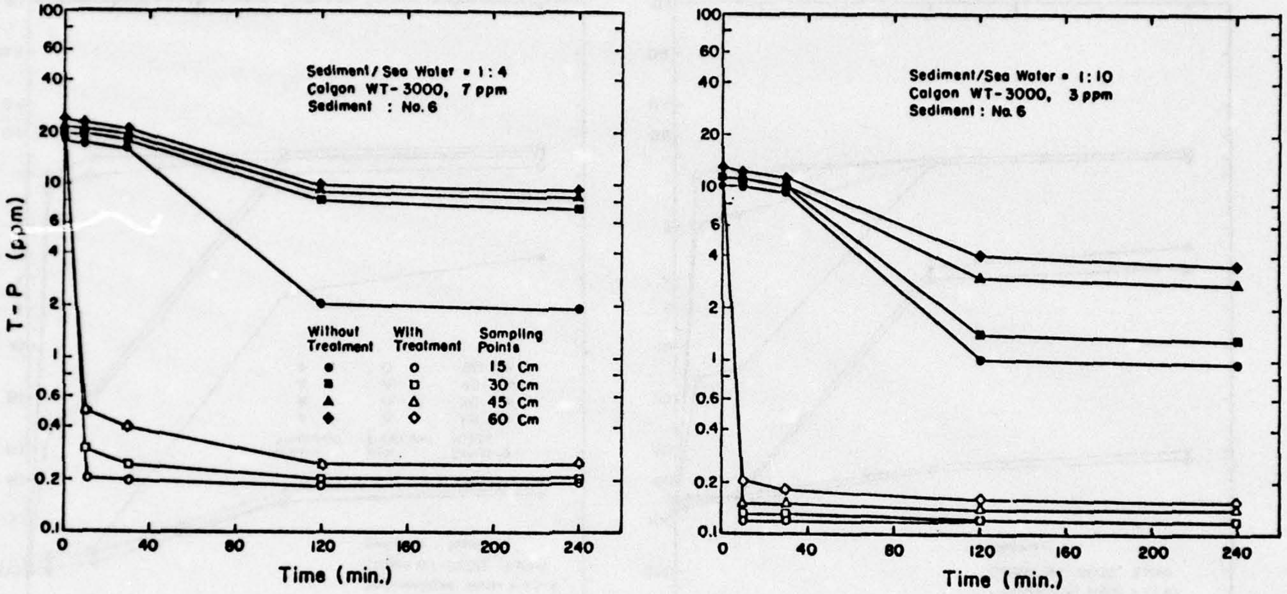

Figure 27. Removal of T-P by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

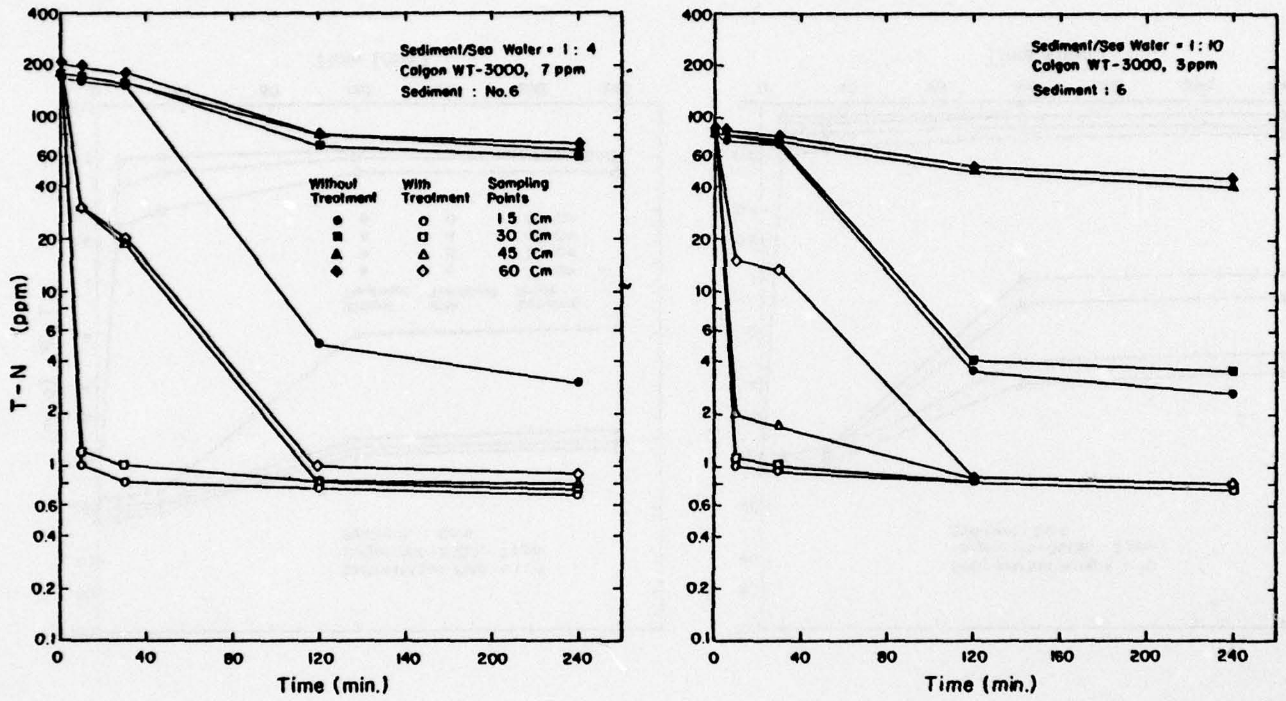

Figure 28. Removal of T-N by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

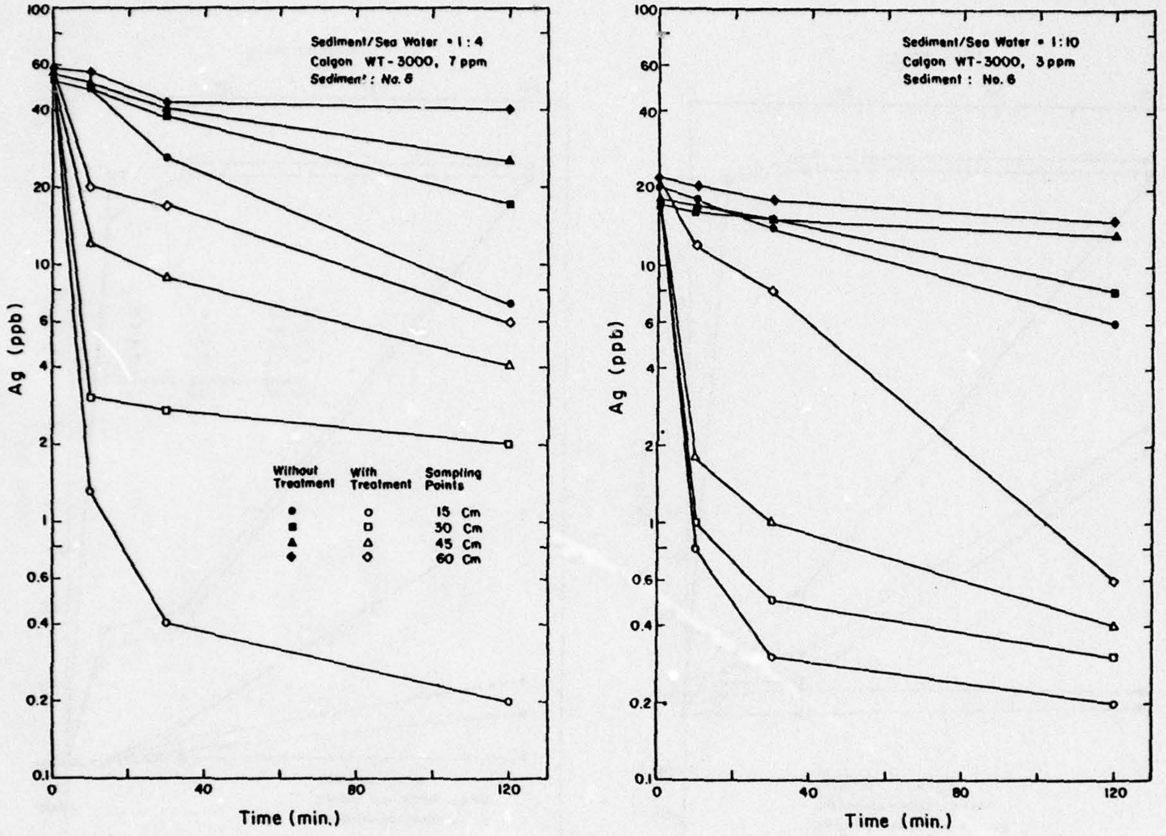

Figure 29. Removal of Ag by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

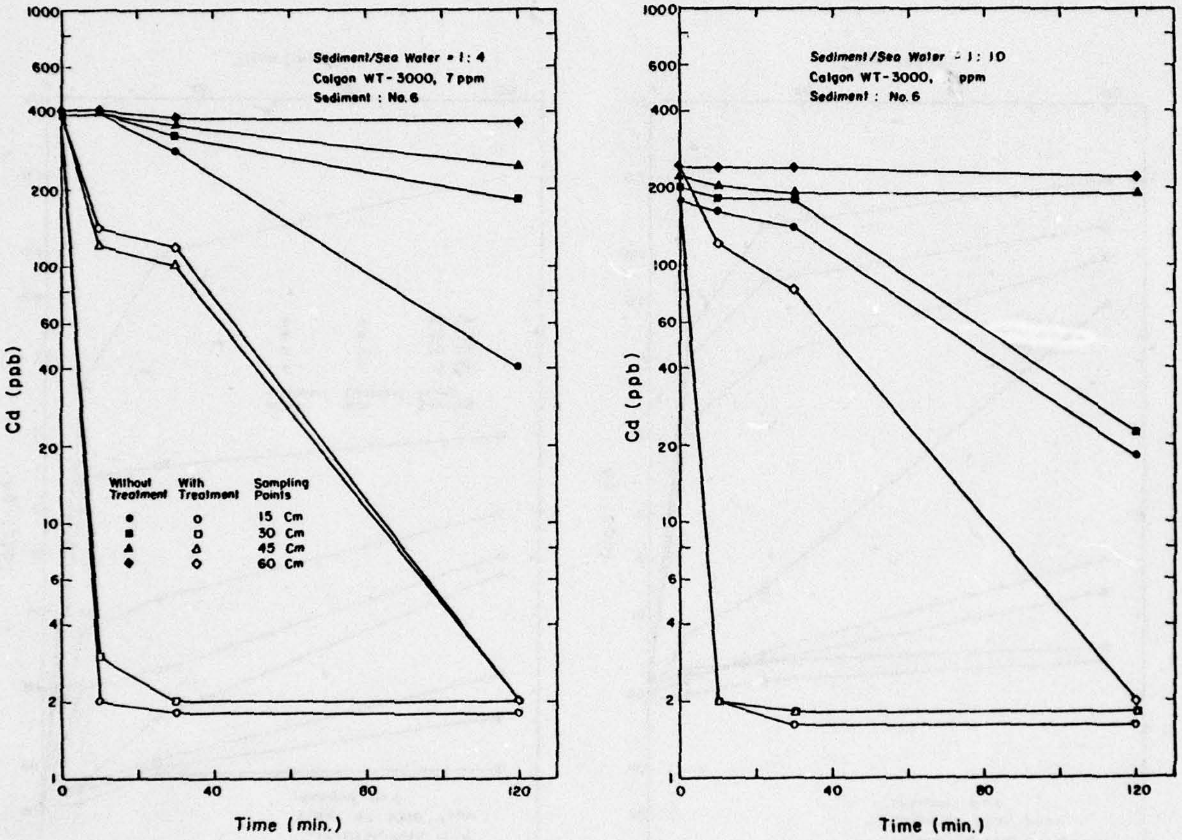

Figure 30. Removal of Cd by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

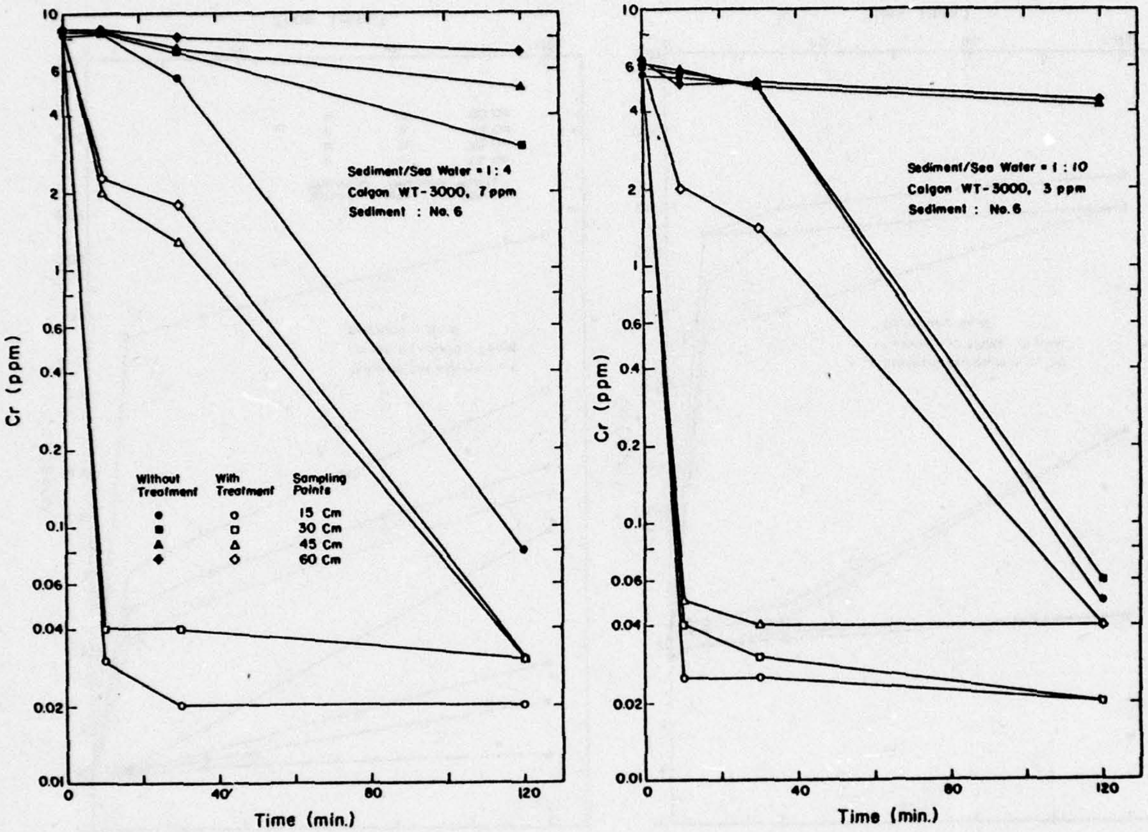

Figure 31. Removal of Cr by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

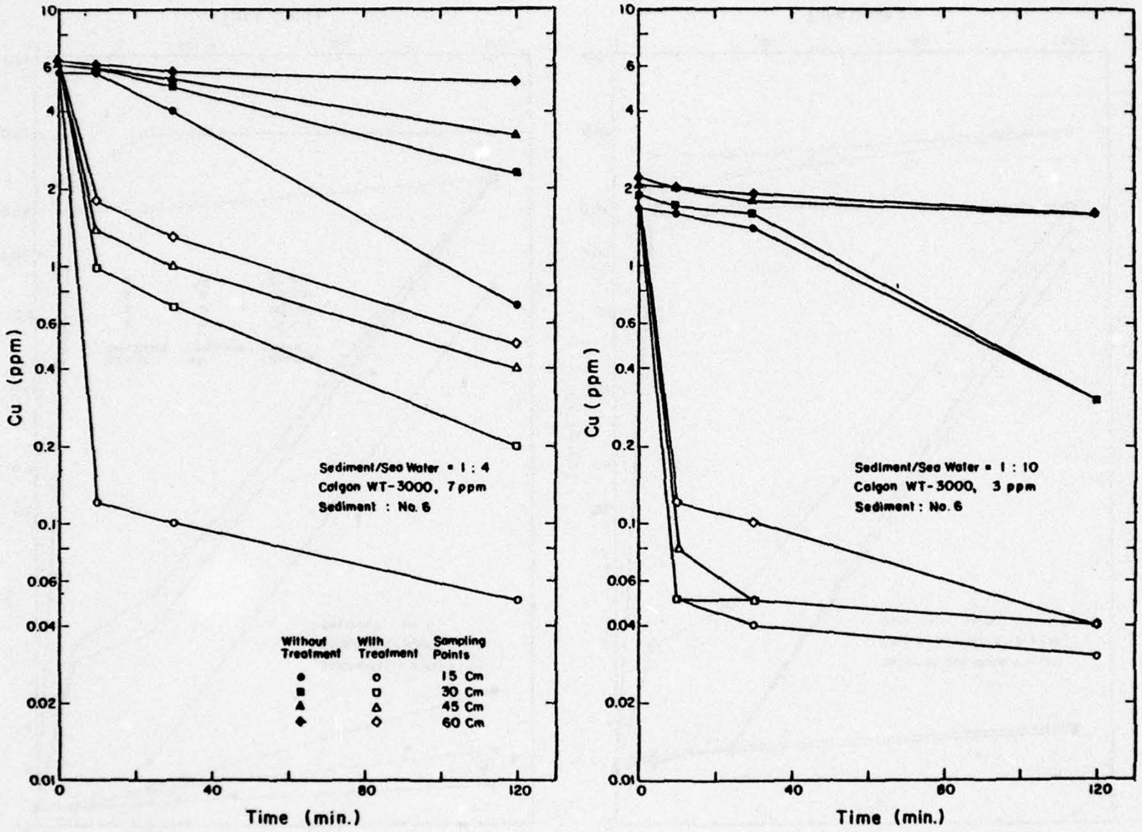

Figure 32. Removal of Cu by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

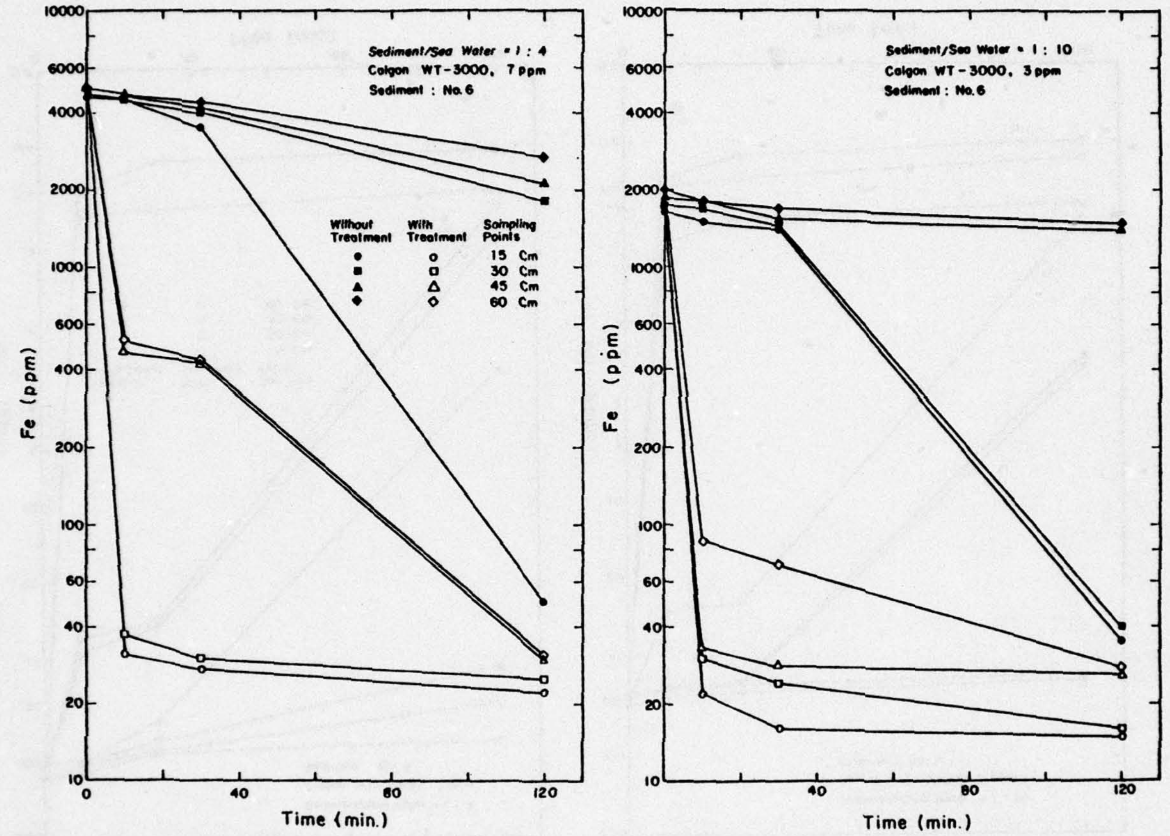

Figure 33. Removal of Fe by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

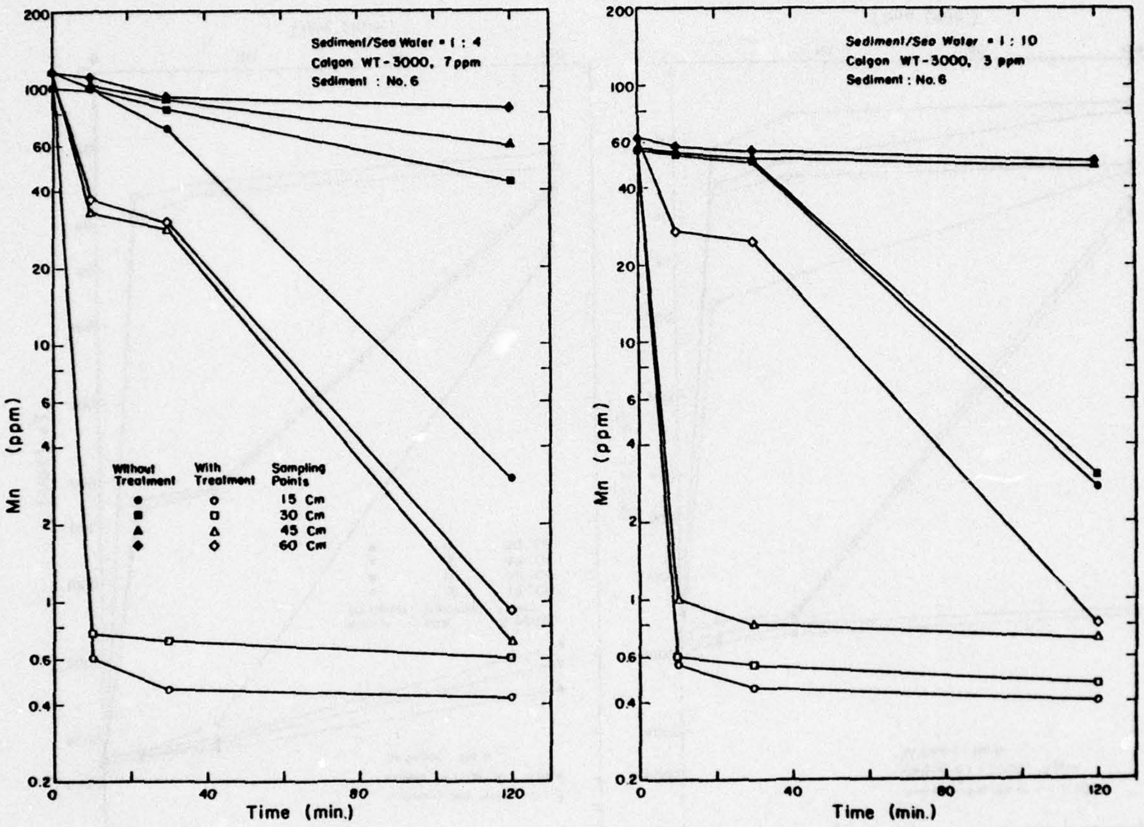

Figure 34. Removal of Mn by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

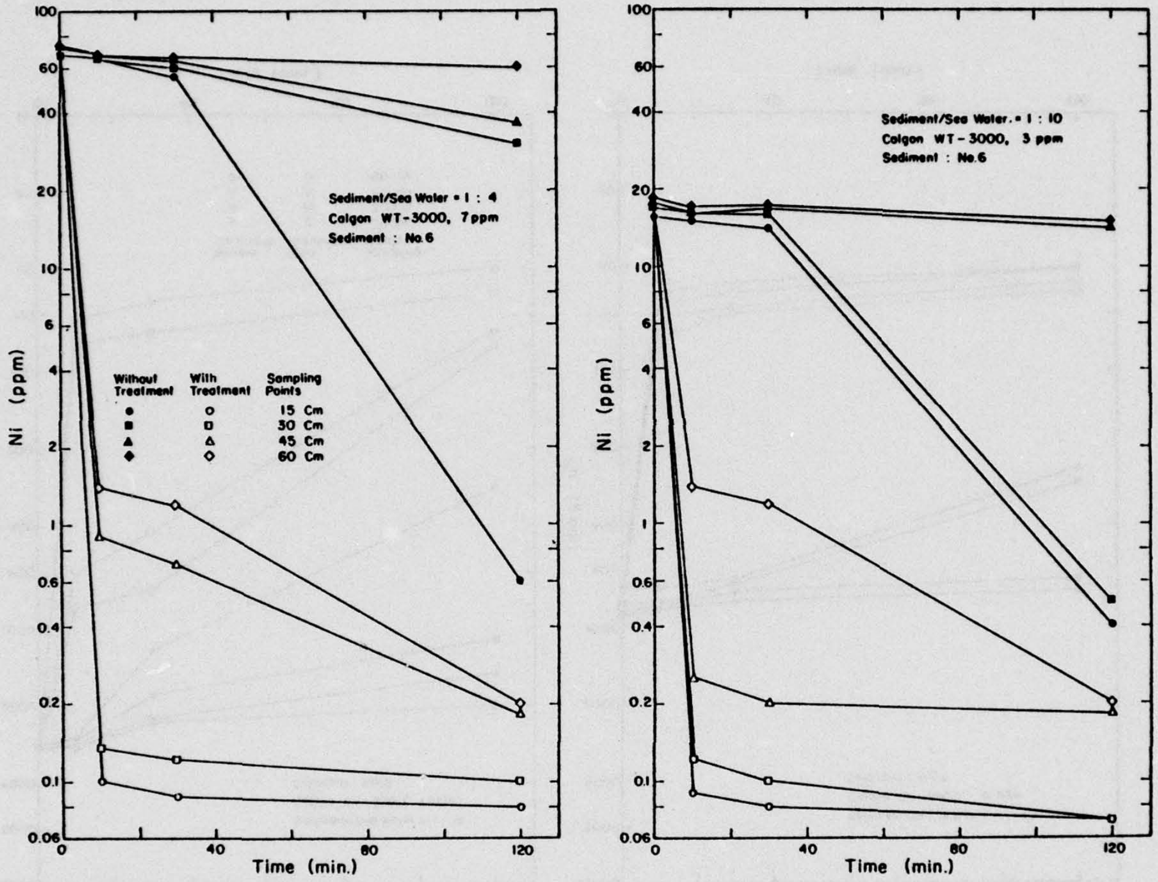

Figure 35. Removal of Ni by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

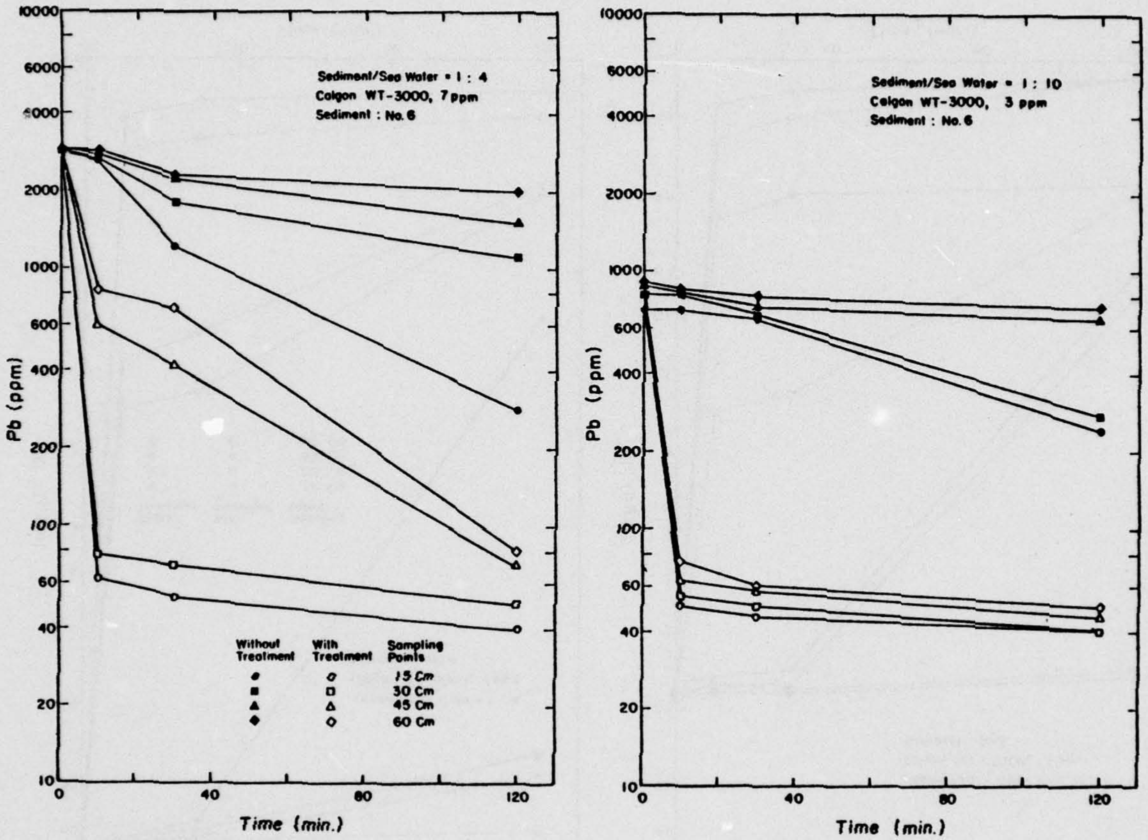

Figure 36. Removal of Pb by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

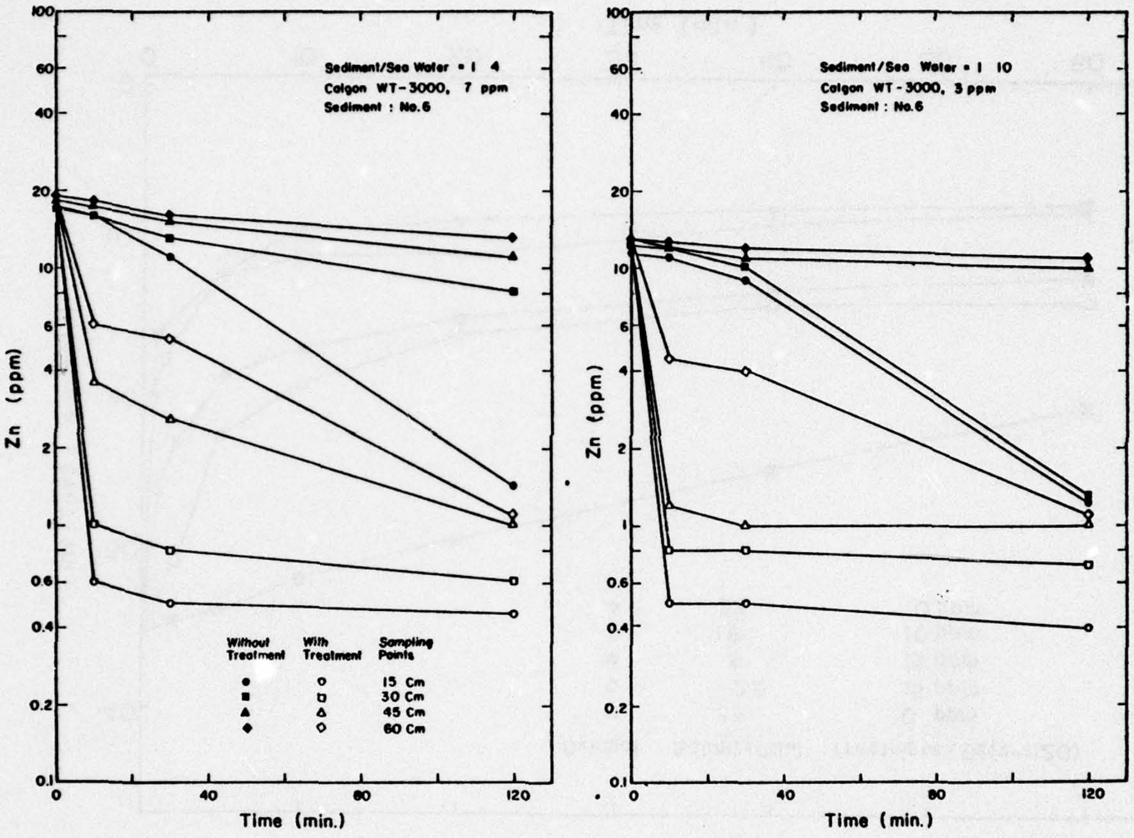

Figure 37. Removal of Zn by Polymer Calgon WT-3000 in the Treatment of Sediment Slurries.

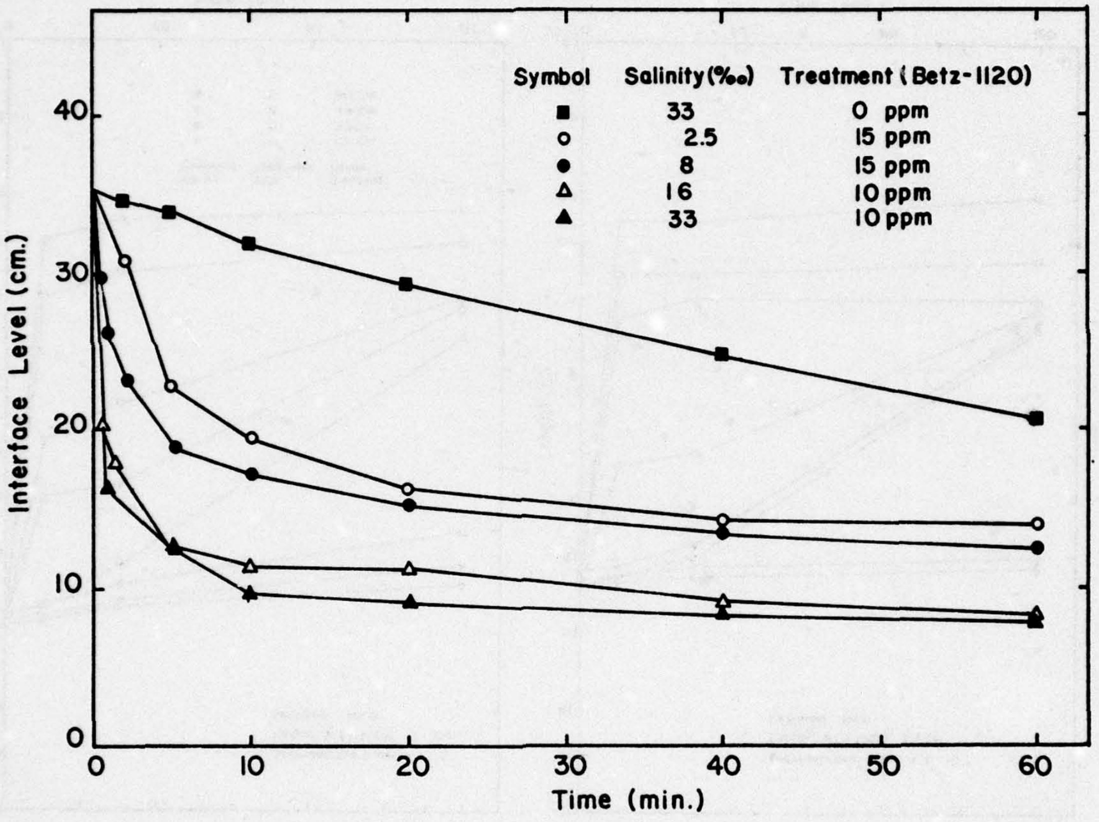

Figure 38. Zone Settling of Sediment/Water Mixture (1:4) Under Varying Salinities for Sediment #7 Using Polymer Betz 1120.

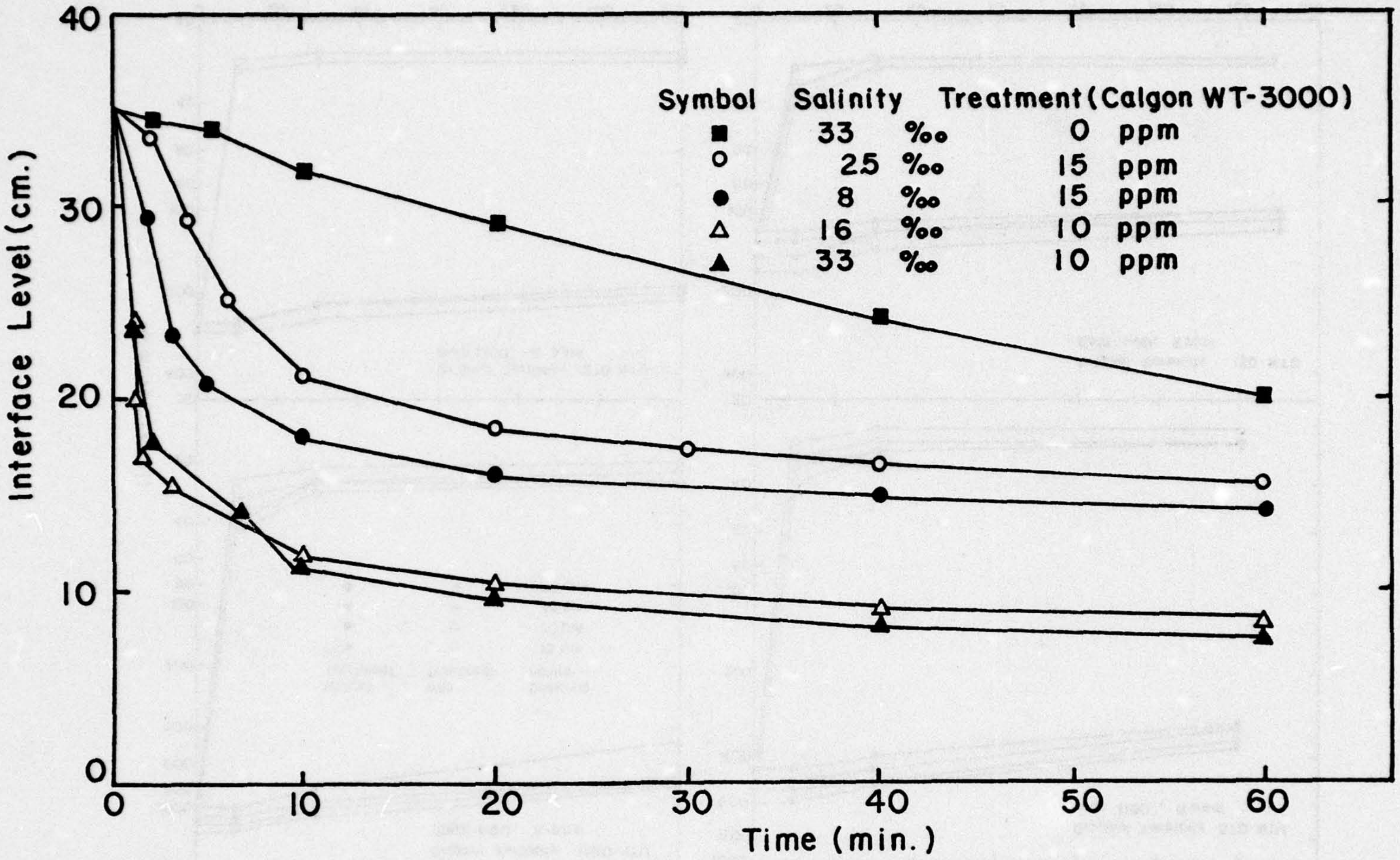

Figure 39. Zone Settling of Sediment/Water Mixture (1:4) Under Varying Salinities for Sediment #7 Using Polymer Calgon WT-3000.

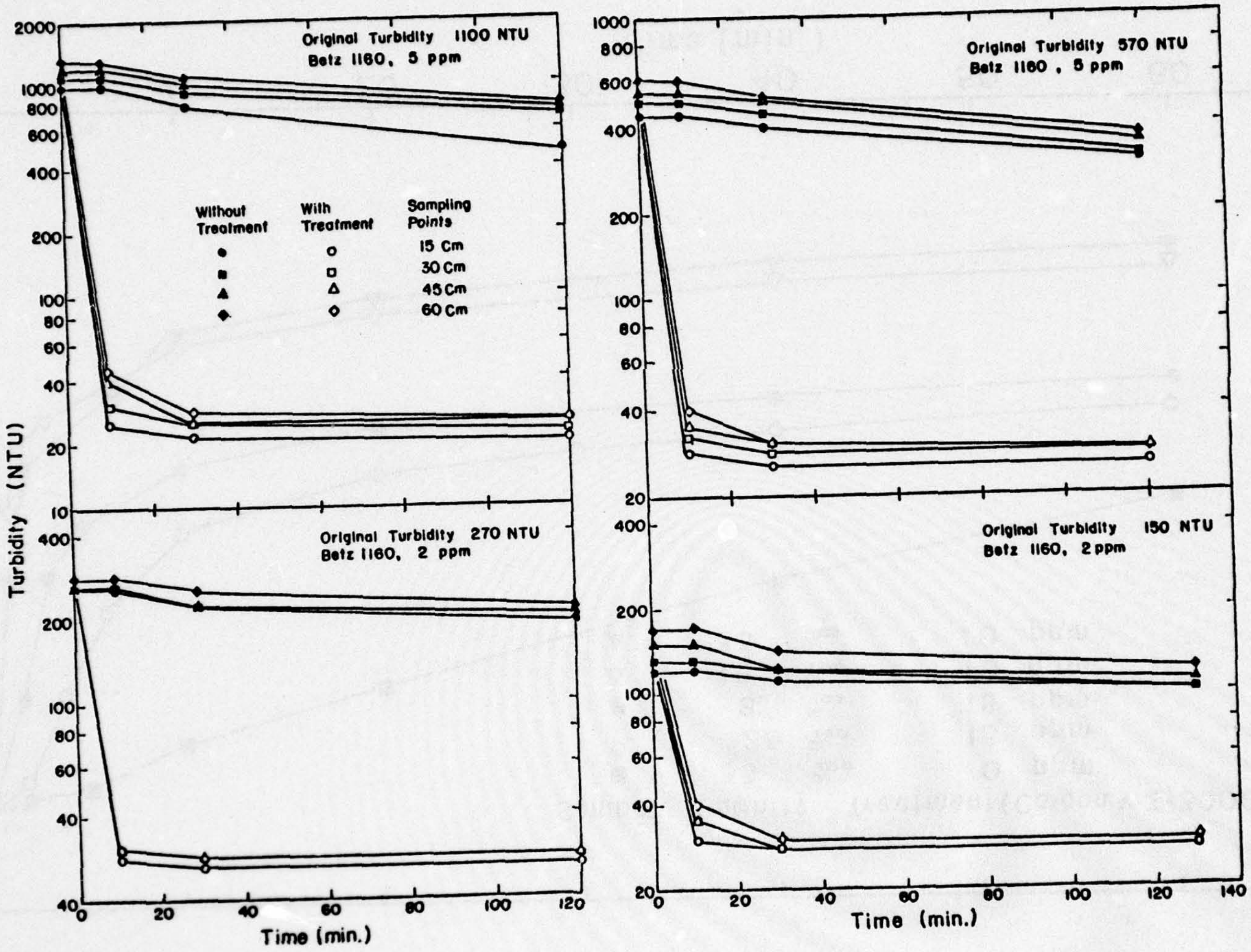

Figure 40. Removal of Suspended Solids by a Cationic Polymer (Betz 1160) in the Treatment of Supernatants.

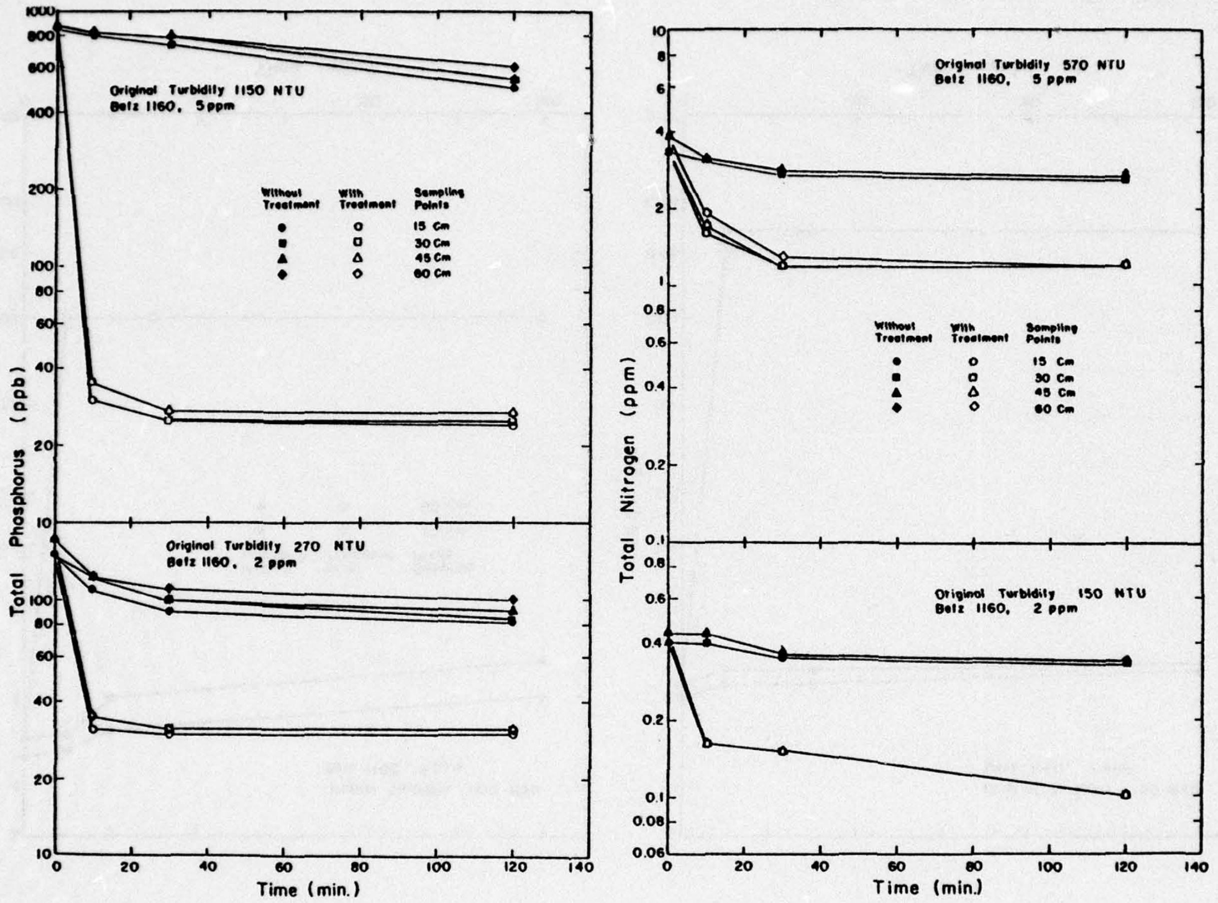

Figure 41. Removal of T-P and T-N by a Cationic Polymer (Betz 1160) in the Treatment of Supernatants.

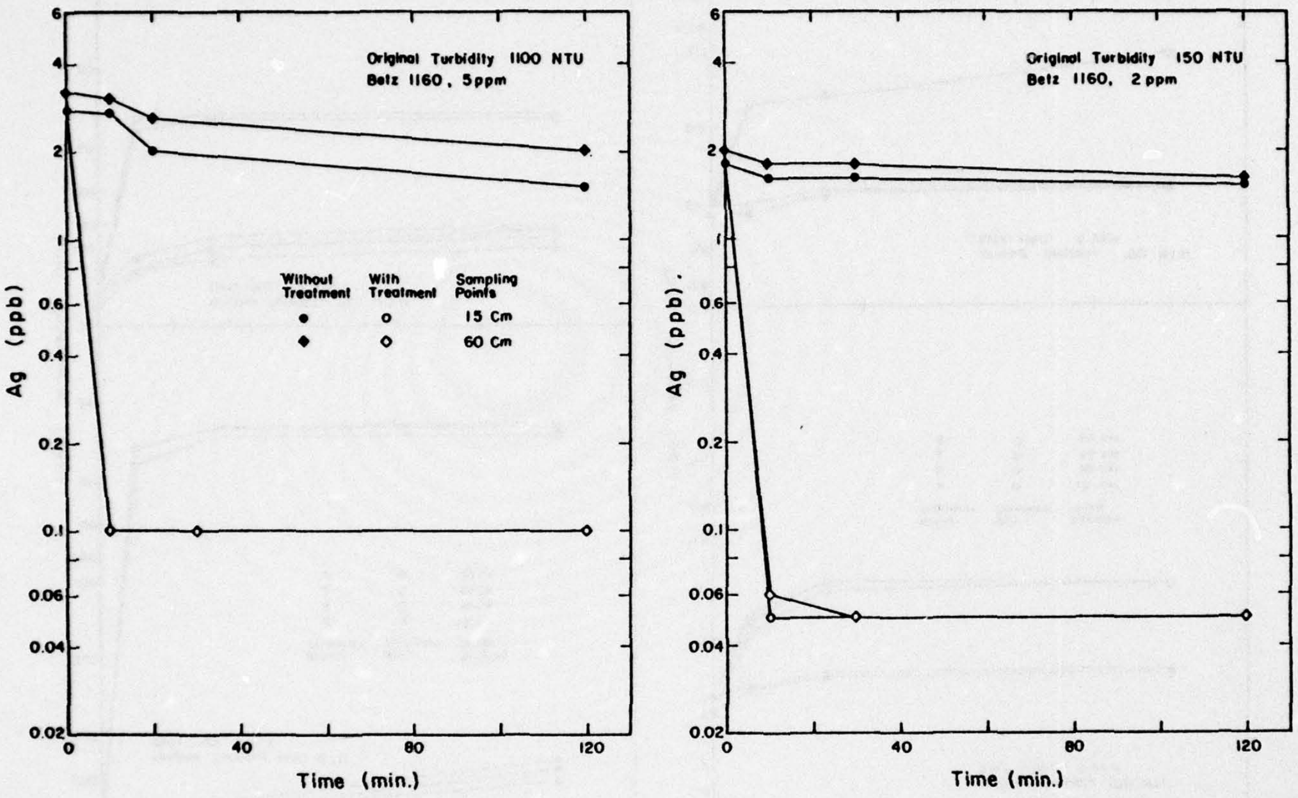

Figure 42. Removal of Ag by a Cationic Polymer (Betz 1160) in the Treatment of Supernatants.

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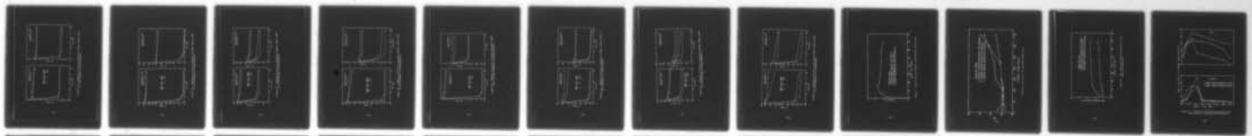

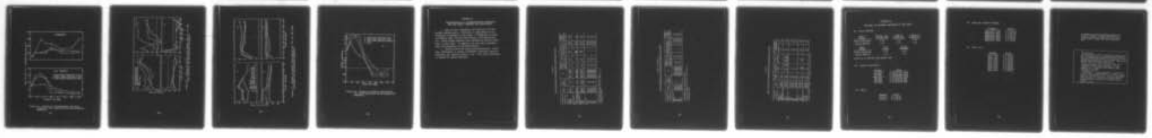

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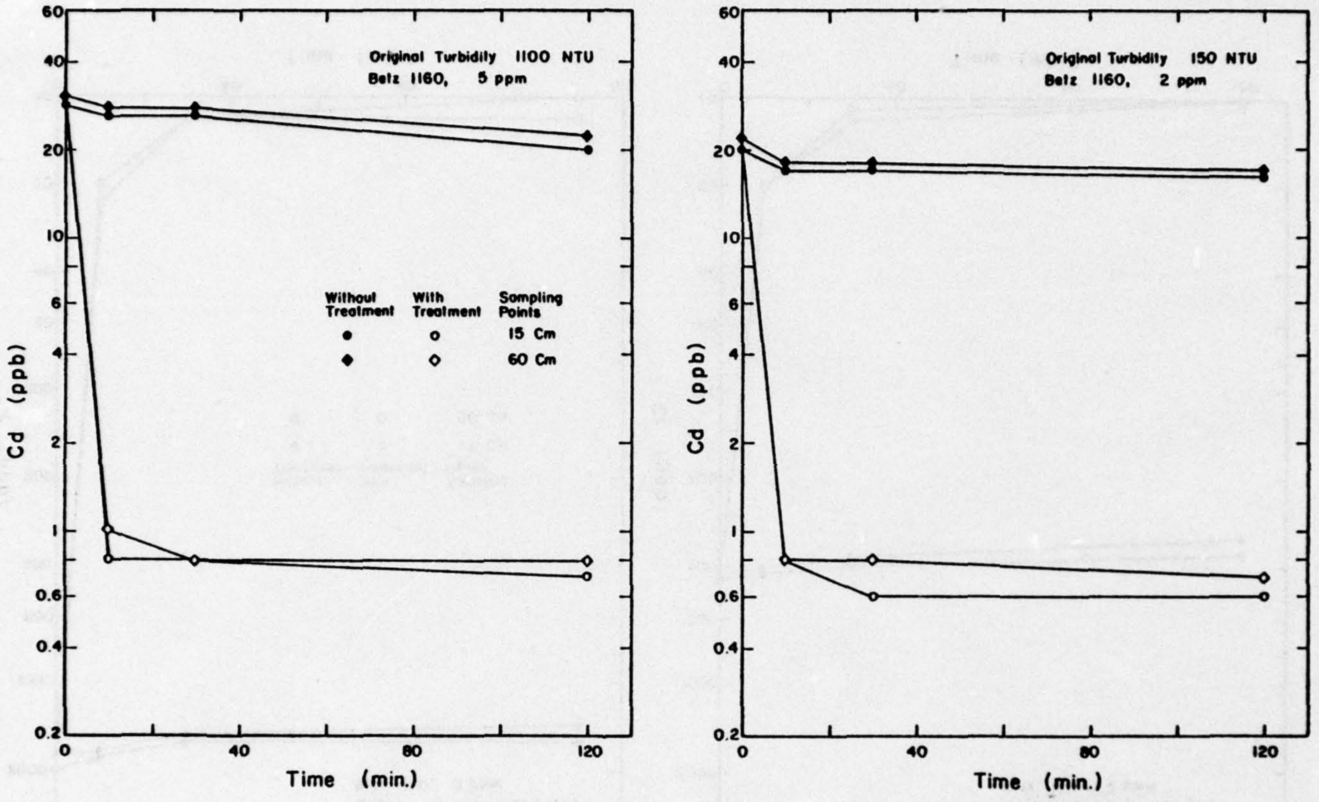

Figure 43. Removal of Cd by a Cationic Polymer (Betz 1160) in the Treatment of Supernatants.

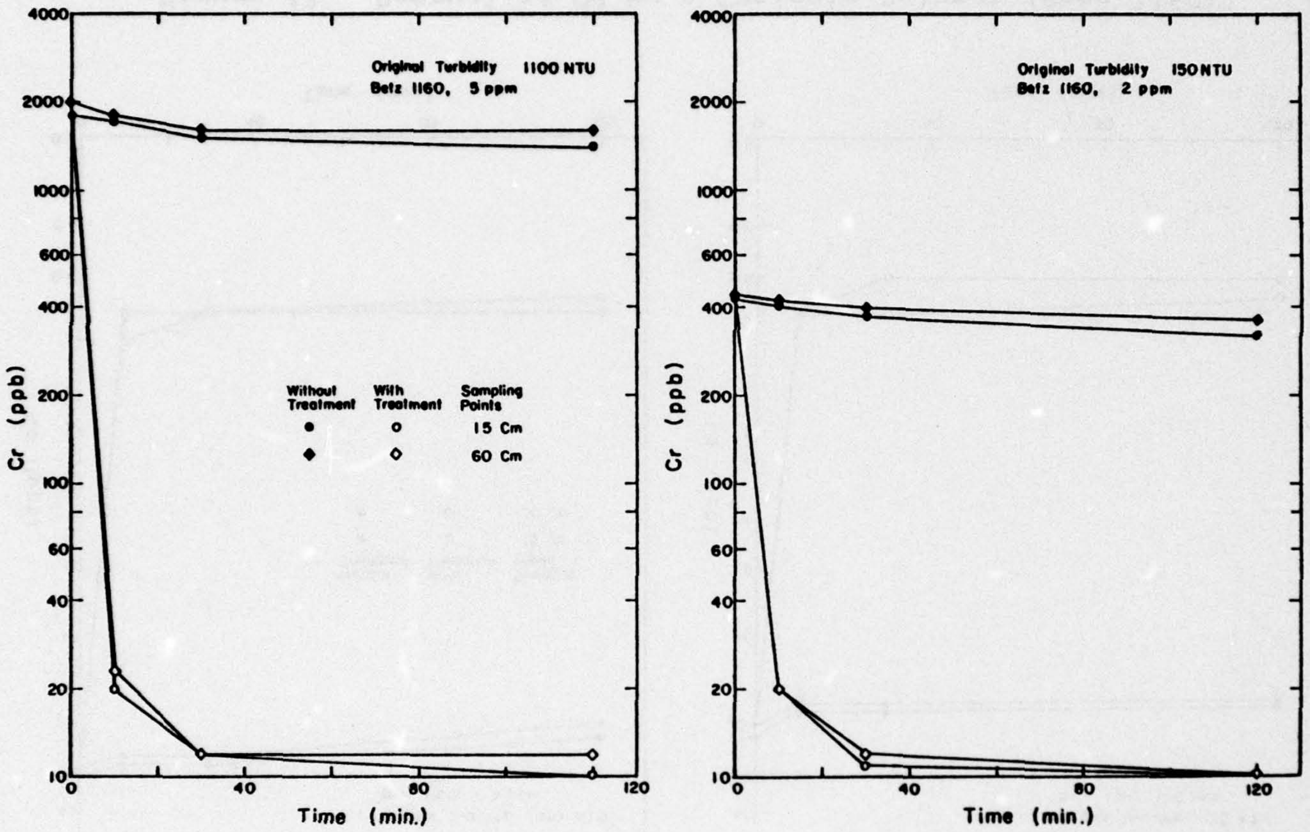

Figure 44. Removal of Cr by a Cationic Polymer (Betz 1160) in the Treatment of Supernatants.

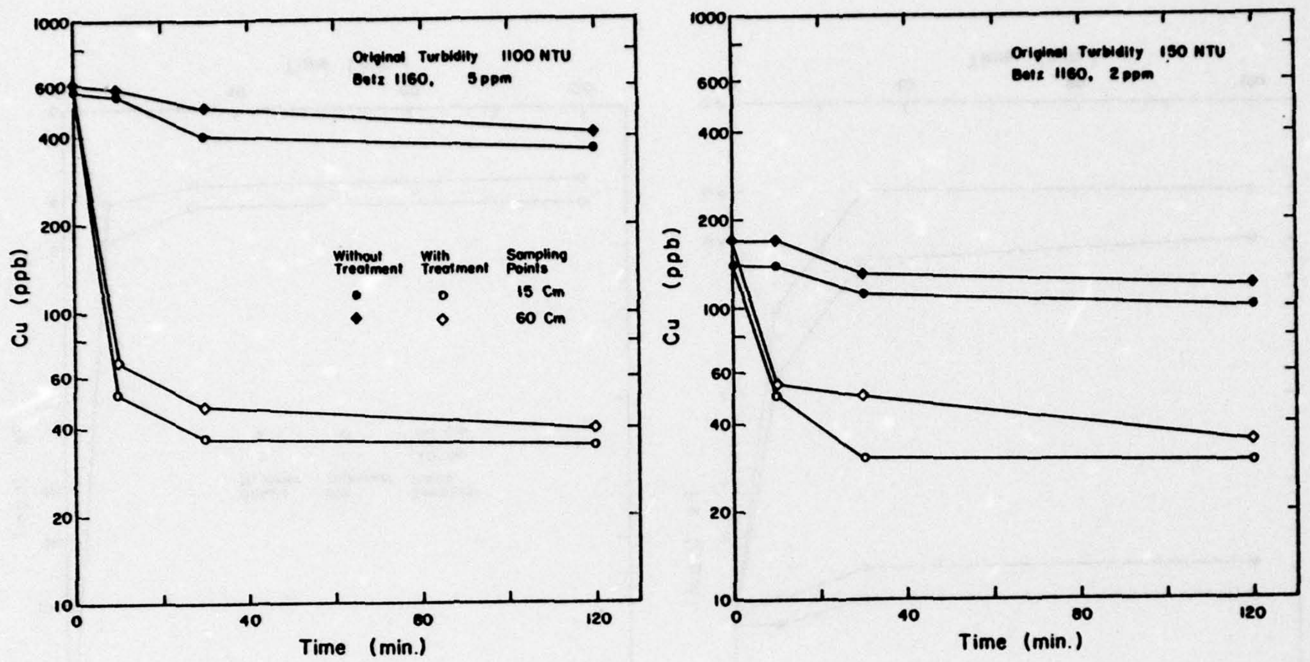

Figure 45. Removal of Cu by a Cationic Polymer (Betz 1160) in the Treatment of Supernatants.

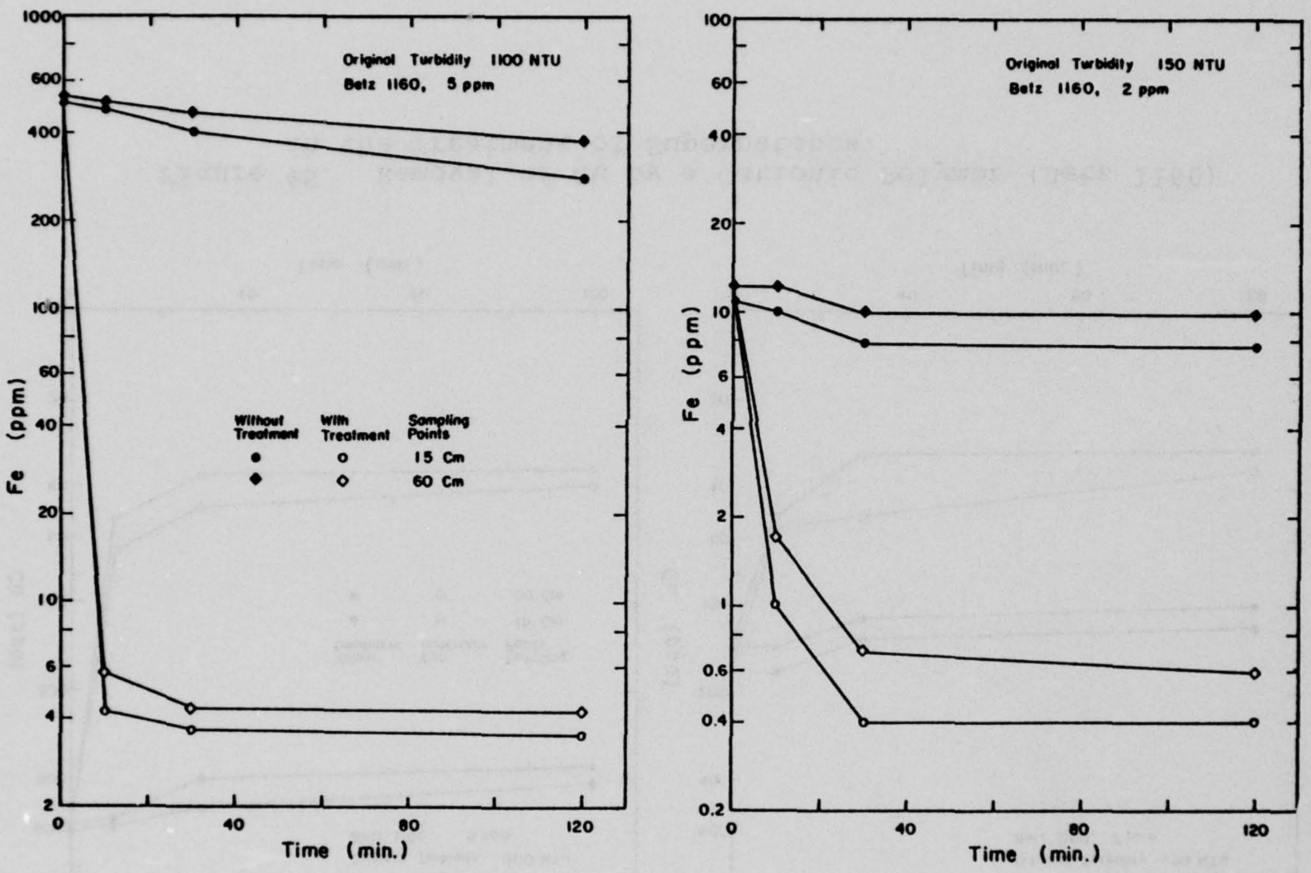

Figure 46. Removal of Fe by a Cationic Polymer (Betz 1160) in the Treatment of Supernatants.

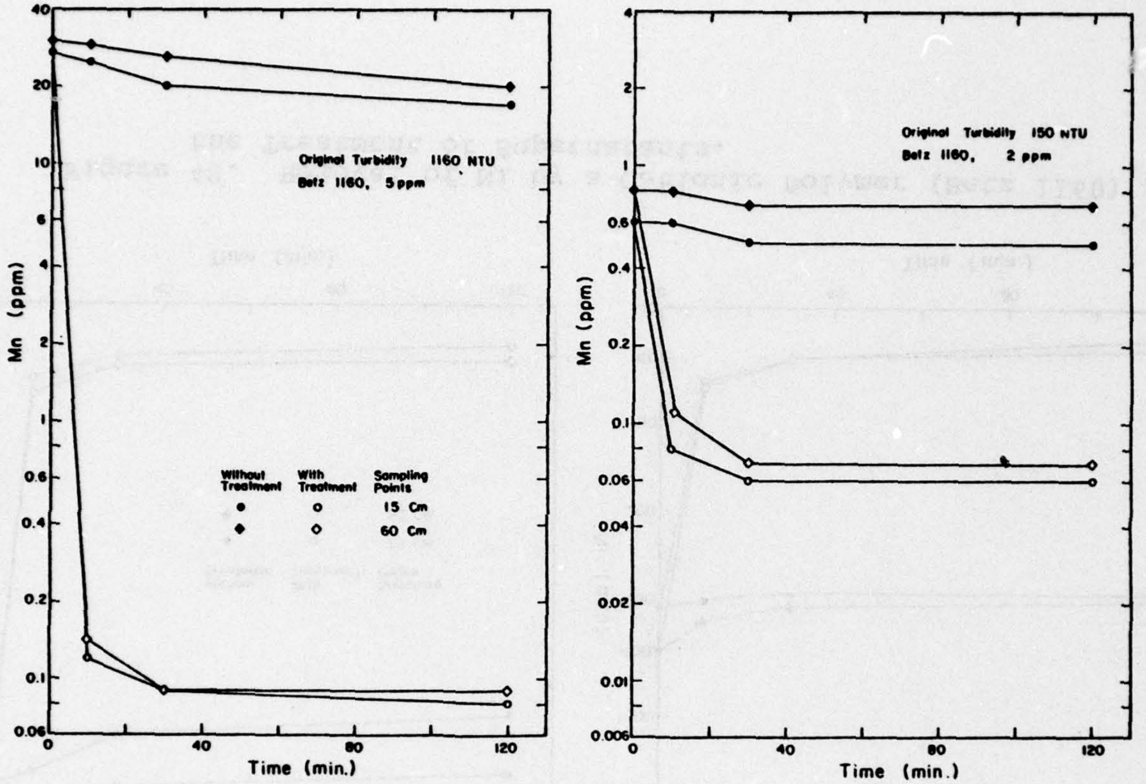

Figure 47. Removal of Mn by a Cationic Polymer (Betz 1160) in the Treatment of Supernatants.

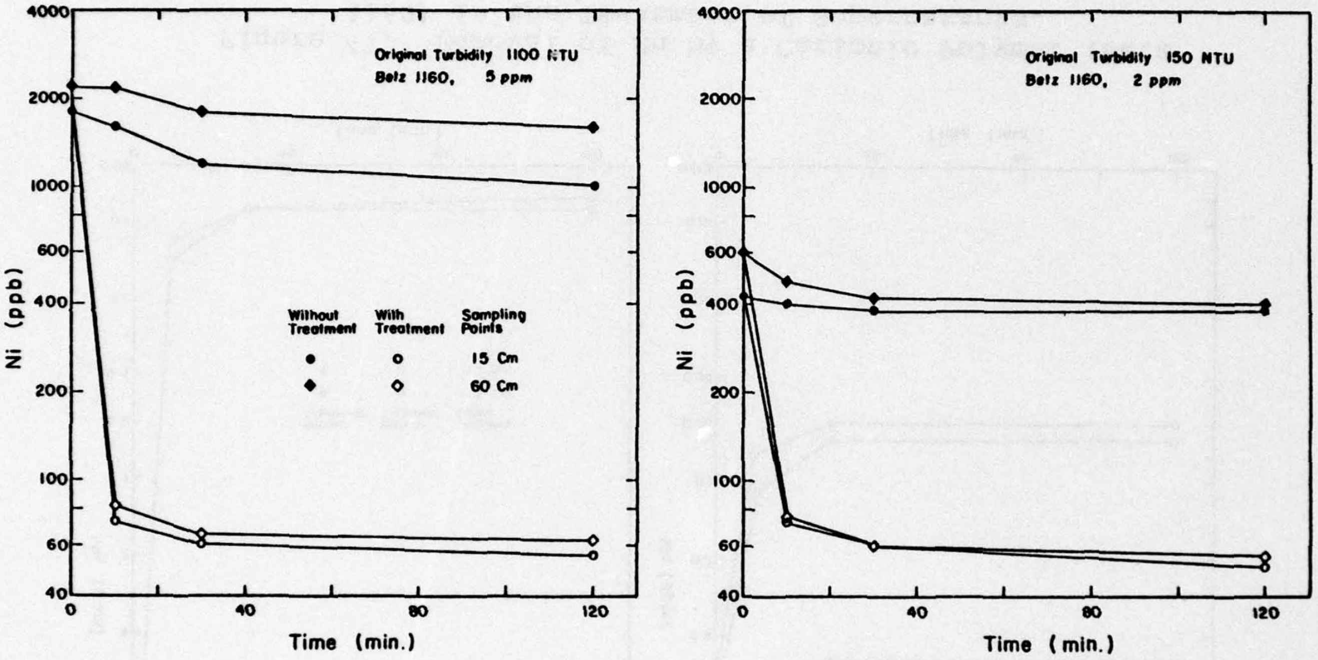

Figure 48. Removal of Ni by a Cationic Polymer (Betz 1160) in the Treatment of Supernatants.

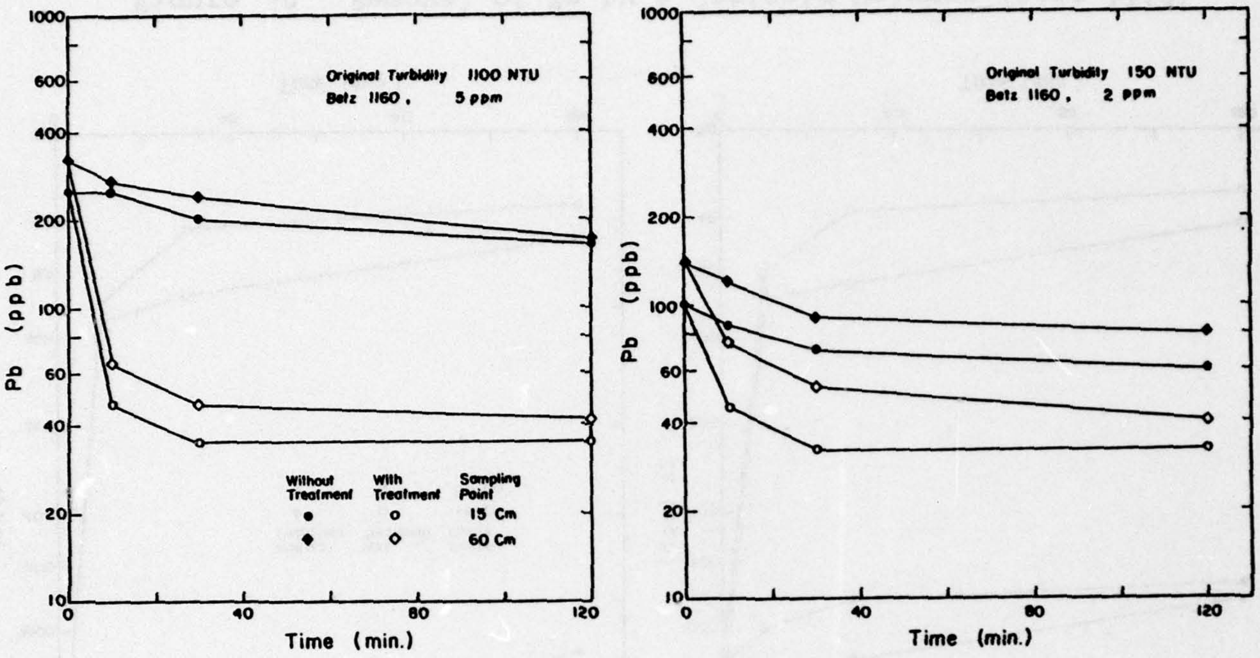

Figure 49. Removal of Pb by a Cationic Polymer (Betz 1160) in the Treatment of Supernatants.

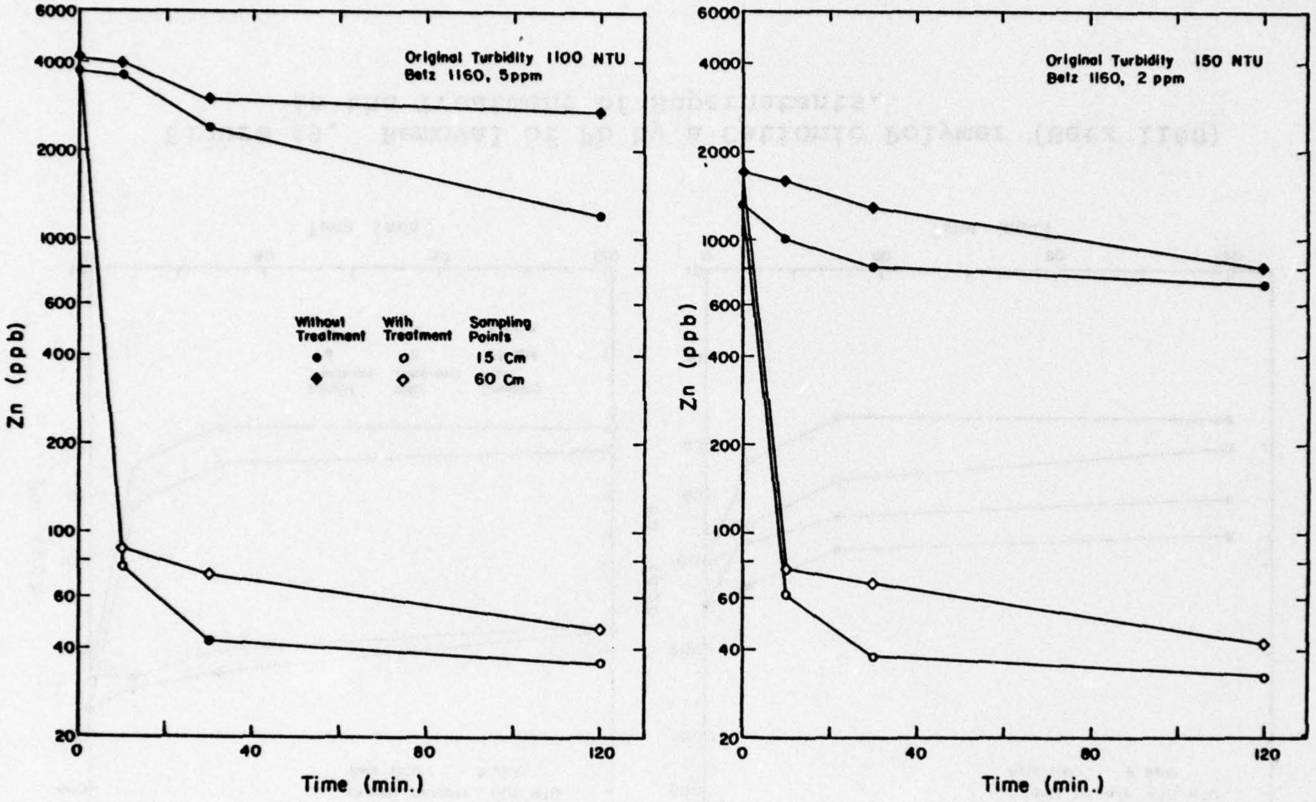

Figure 50. Removal of Zn by a Cationic Polymer (Betz 1160) in the Treatment of Supernatants.

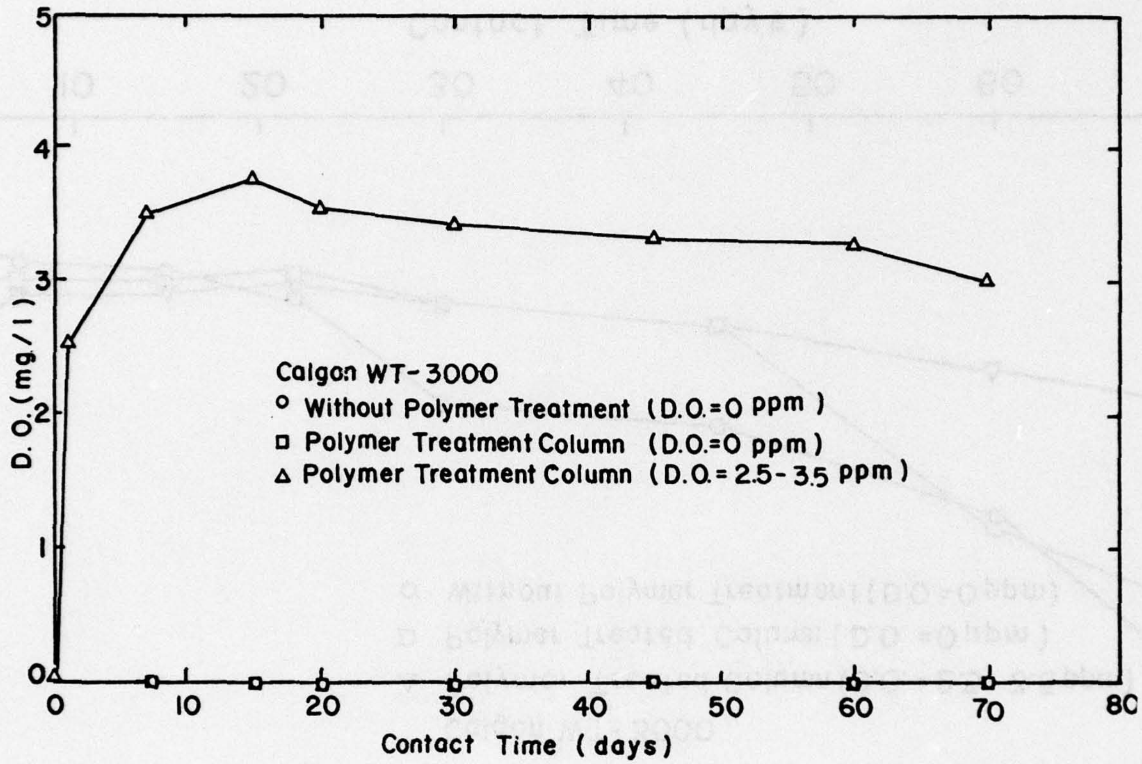

Figure 51. Level of Dissolved Oxygen in the Long-Term Column Study.

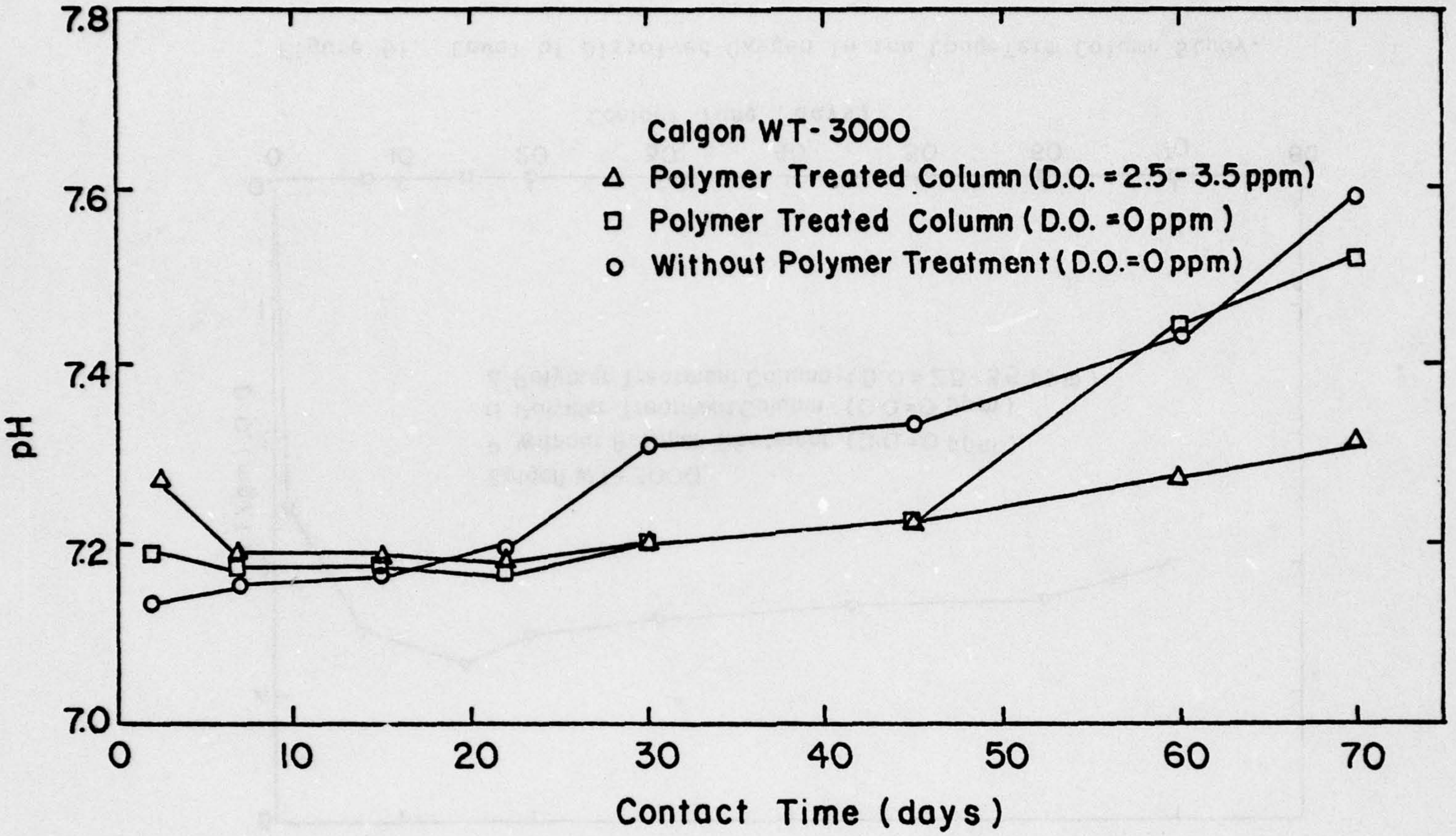

Figure 52. Level of pH in the Long-Term Column Study

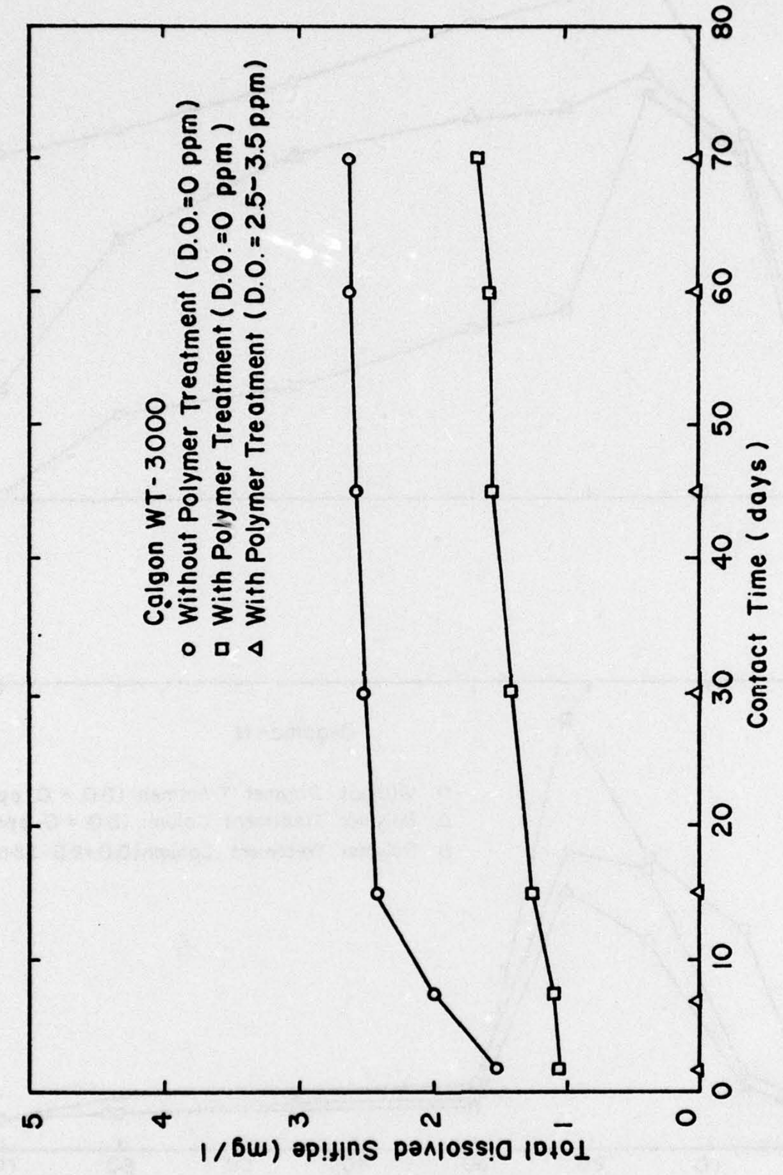

Figure 53. Total Dissolved Sulfide Concentration in the Long-Term Column Study.

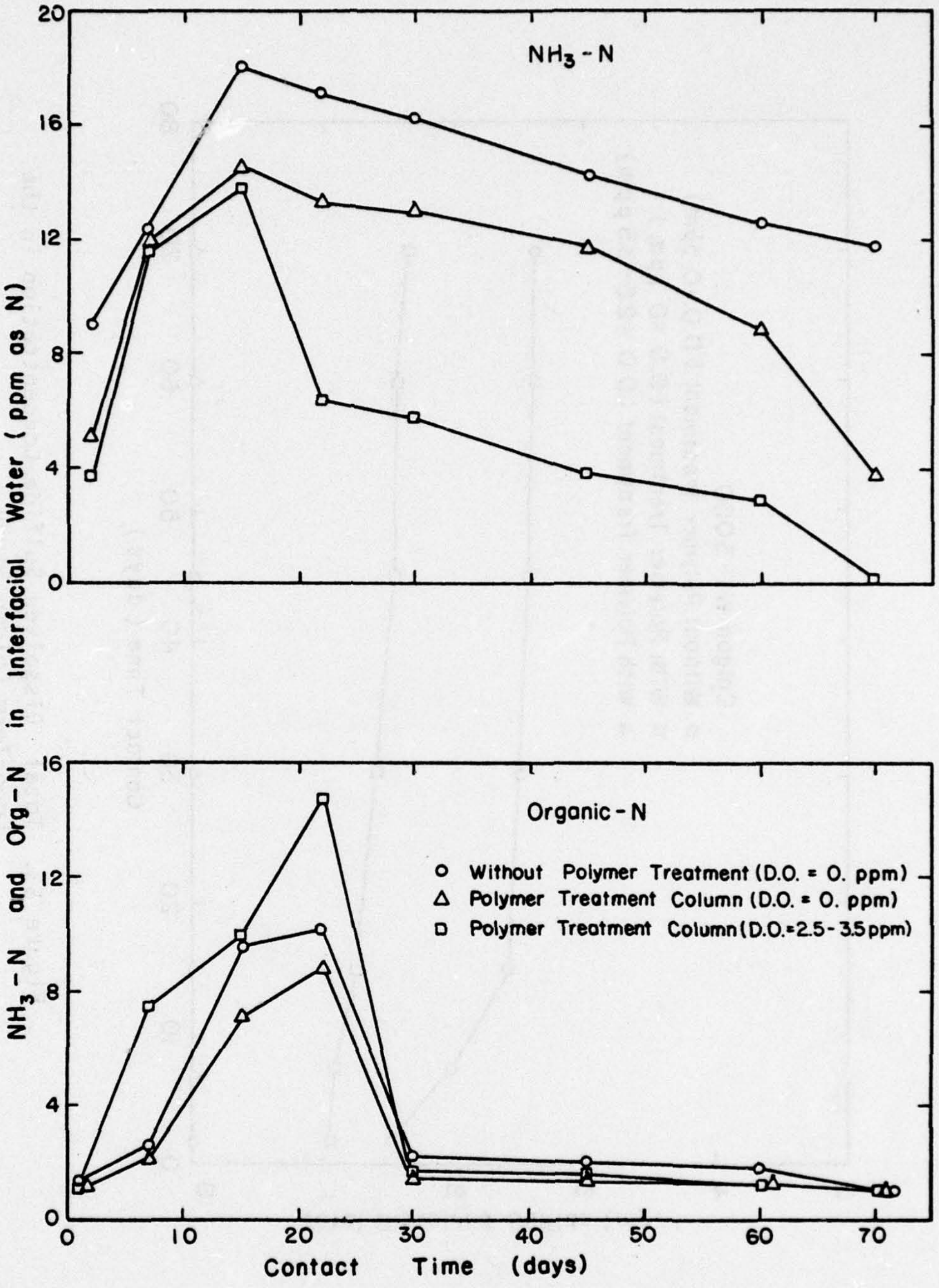

Figure 54. Release of NH_3-N and Organic-N From Coagulated and Noncoagulated Sediments.

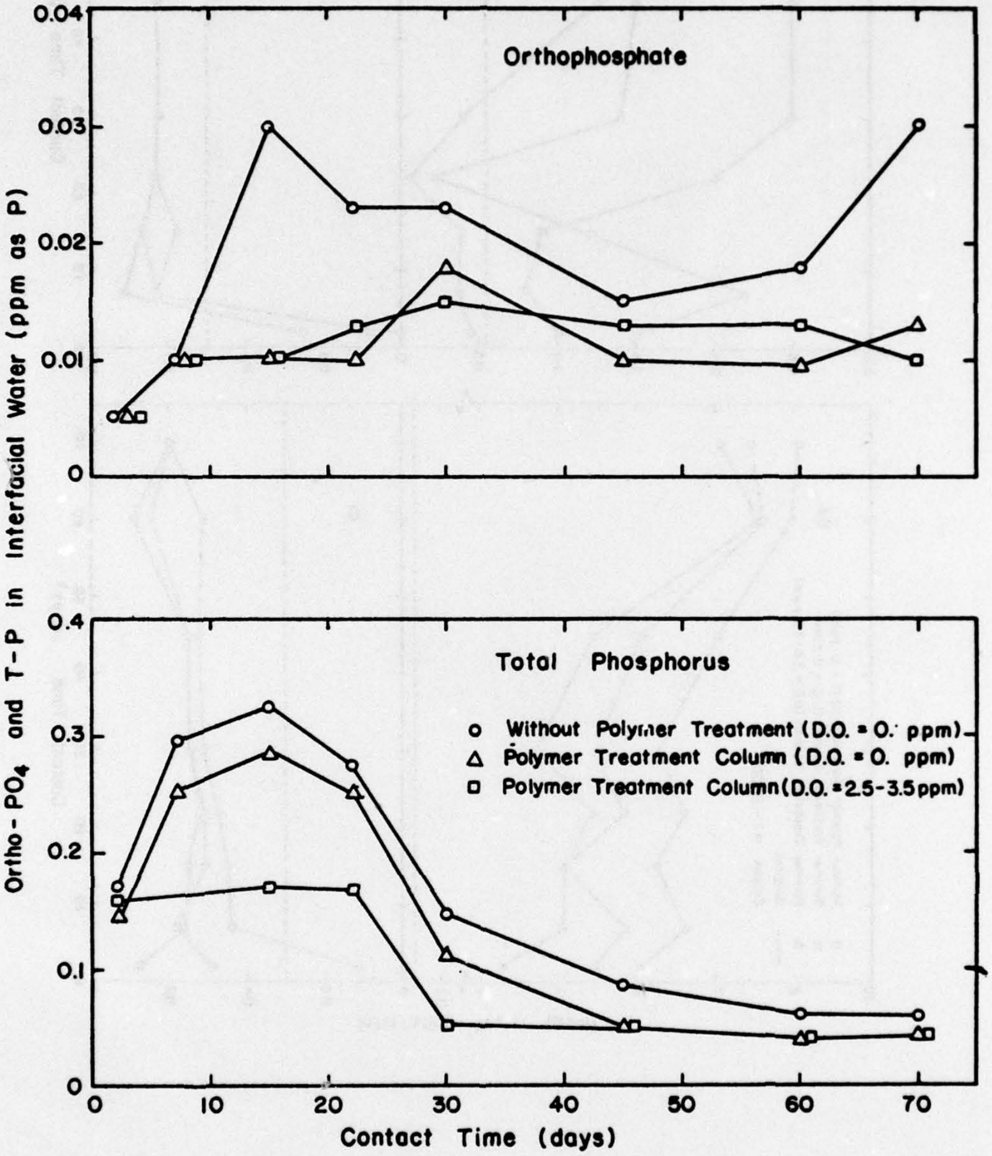

Figure 55. Release of Orthophosphate and Total Phosphorus From Coagulated and Noncoagulated Sediments.

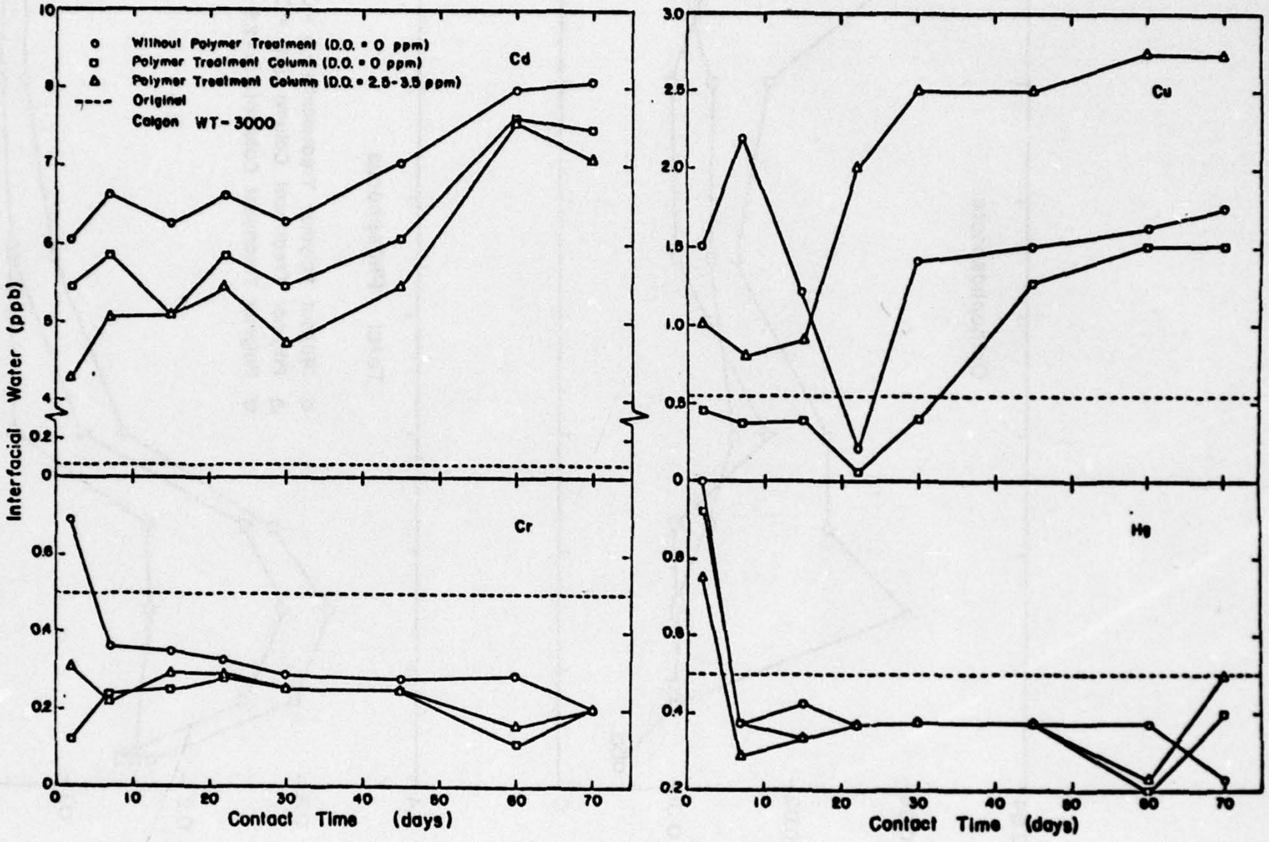

Figure 56. Release of Soluble Trace Metals (Cd, Cu, Cr, Hg) From Coagulated and Noncoagulated Sediments.

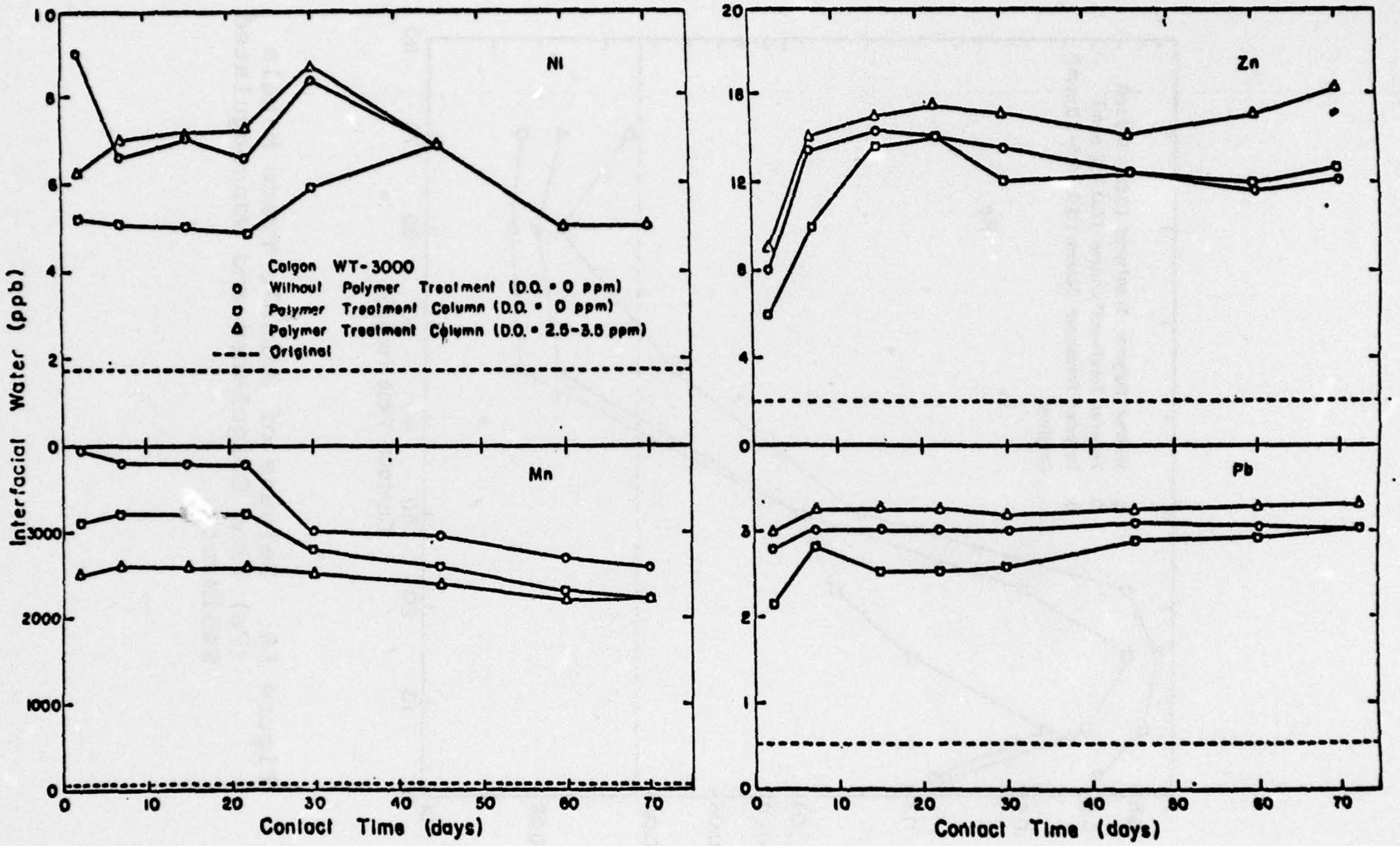

Figure 57. Release of Soluble Trace Metals (Ni, Mn, Zn, Pb) From Coagulated and Noncoagulated Sediments.

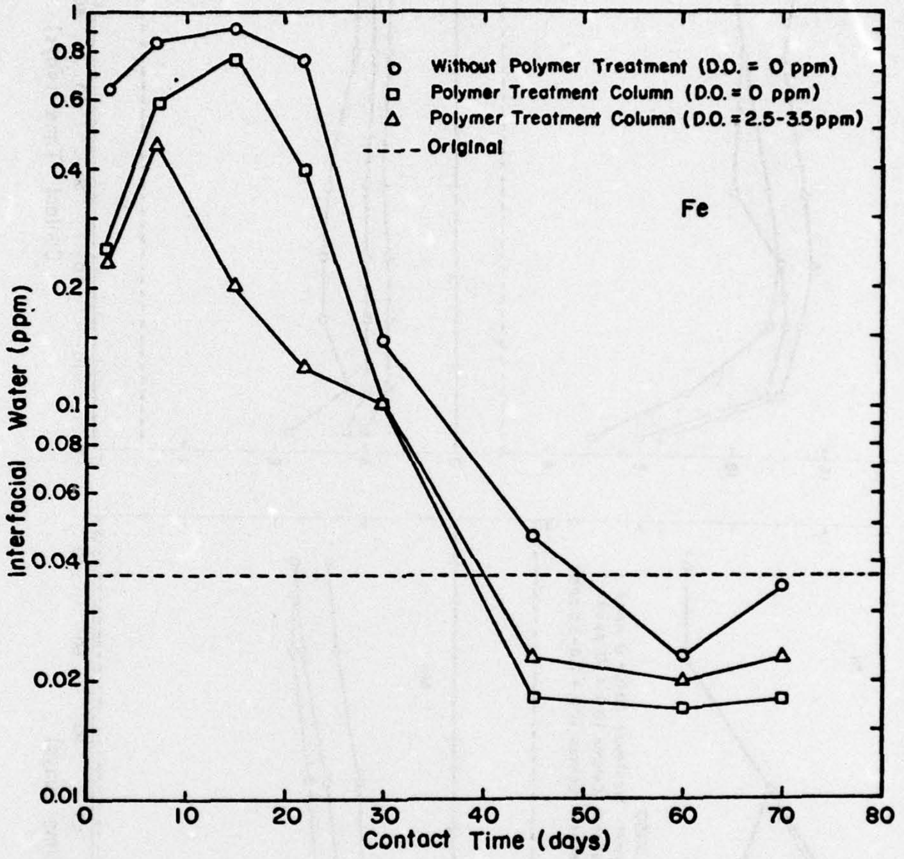

Figure 58. Release of Soluble Trace Metals (Fe) From Coagulated and Noncoagulated Sediments.

APPENDIX A

CHARACTERISTICS OF POLYELECTROLYTE COAGULANTS: DRY AND LIQUID; HANDLING AND APPLICATION

1. Much of this information was received from the polymer manufacturers. Table A1 is a compilation of dry coagulants evaluated in this study. Information is given on chemical type, working bulk density, flow properties, etc. Blank spaces indicate that information was not available in some cases. In general, one will gain knowledge about the properties of polyelectrolytes.

2. Table A2 lists the liquid polyelectrolytes. Pertinent information is listed in different sections; such as viscosity, pH, specific gravity, etc. This vital knowledge is needed for proper handling.

Table A1

General Information on Dry Polyelectrolytes Evaluated in this Study

Polyelectrolytes or Coagulant Aids	Ionic Nature	Bulk* Density (lb/cu ft)	Flow	Time to disperse into solution (hours)	Solution-Room Temperature				Maximum Solution Conc. Recommended %
					% Solution	Viscosity• cp	Sp.† Gr.	pH	
Calgon									
WT-3000	Anionic	20~25	White Powder	2~3	0.25	750	1	7.5	0.25
WT-2690	Nonionic	27	White Powder	1~2	0.2	2~4	1	6.0	0.5
Union Carbide Chem.									
Polyox WSR-301	Nonionic	20	White Powder	1~2	1.0	2000	1	8.0	1.0
Polyox Coagulant	Nonionic	20	White Powder	1~2	1.0	6000	1	8.2	1.0
Amer. Cyanamid Co									
834-A	Nonionic	43~45	White Powder	1~2	0.1	200	1	7.0	0.5
835-A	Nonionic	43~45	White Powder	0.5~1	0.1	90	1	7.6	0.5
905-N	Nonionic	40~42	White Solid	0.5~1	0.1	8	1	5.0	1.0
Betz, Inc.									
1100	Anionic	36	White Powder	1~2	0.1	--	1	9.0	0.1
1110	Anionic	36	White Powder	1~2	0.1	--	1	9.4	0.1
1120	Anionic	36	White Powder	1~2	0.1	--	1	8.3	0.1
1130	Anionic	36	White Powder	1~2	0.1	--	1	9.0	0.1
1140	Nonionic	38	White Powder	1~2	0.1	--	1	7.0	0.1
1150	Cationic	28	White Powder	1~2	0.1	--	1	6.8	0.1
1160	Cationic	28	White Powder	1~2	0.1	--	1	4.0	0.1

* Bulk density can vary from batch to batch
• Varies with temperature, pH, time, batch, rpm, etc.
† Approximate values

Table A1 - Continued

General Information on Dry Polyelectrolytes Evaluated in *this Study*

Polyelectrolytes or Coagulant Aids	Ionic Nature	Bulk* Density (lb/cu ft)	Flow	Time to disperse into solution (hours)	Solution-Room Temperature				Maximum Solution Conc. Recommended %
					% Solution	Viscosity• cp	Sp.† Gr.	pH	
Hercules, Inc.									
831.2	Anionic	--	White Powder	1 ~ 2	0.1	--	1	7.8	0.1
847	Anionic	--	White Powder	1 ~ 2	0.1	--	1	7.6	0.1
821	Anionic	--	White Powder	1 ~ 2	0.1	--	1	7.8	0.1
853	Anionic	--	White Powder	1 ~ 2	0.1	--	1	7.0	0.1
815.3	Cationic	--	White Powder	1 ~ 2	0.1	--	1	5.5	0.1
849	Cationic	--	White Powder	1 ~ 2	0.1	--	1	5.2	0.1

* Bulk density can vary from batch to batch

• Varies with temperature, pH, time, batch, rpm, etc.

† Approximate values

Table A2

General Information on Liquid Polyelectrolytes Evaluated in this Study

Polyelectrolytes or Coagulant Aid	Ionic Nature	Solution Strength (%)	Sp. Gravity (Room Temp) 25^oC	Viscosity cp (Room Temp)	Stock Solution Conc. Recommended	
					% Solution	pH
Calgon						
CAT-Floc T	Cationic	Full	≑ 1	--	0.1	5.0
WT-2690	Nonionic	Full	≑ 1	--	0.1	5.4
Amer. Cyanamid Co.						
573 C	Cationic	Full	1.14 - 1.18	175 - 350	0.1	5.0
581 C	Cationic	Full	1.14 - 1.18	4000 - 6000	0.1	3.6
587 C	Cationic	Full	1.03 - 1.05	100 - 200	0.1	6.0
Hercules, Inc.						
834.1	Cationic	Full	≑ 1	--	0.1	4.4
834.5	Cationic	Full	≑ 1	--	0.1	4.8
848	Cationic	Full	≑ 1	--	0.1	3.9
864	Cationic	Full	≑ 1	--	0.1	4.8
860	Cationic	Full	≑ 1	--	0.1	4.2
863	Cationic	Full	≑ 1	--	0.1	4.8
Betz, Inc.						
1180	Cationic	Full	--	--	0.1	5.0
1185	Cationic	Full	1.095	50	0.1	4.8
1195	Cationic	Full	1.105	80	0.1	5.4
Nalco Chem. Co.*						
72-D-13	Nonionic	Full	≑ 1	--	2.0	7.6
81-C-09	Anionic	Full	≑ 1	--	2.5	9.4
72-C-25	Cationic	Full	≑ 1	--	5.0	9.5

* Activator (0.02%) is needed in the preparation of 72-D-13 and 81-C-09

APPENDIX B

PRICINGS OF POLYMERS EVALUATED IN THIS STUDY

(a) Union Carbide

Resin Grade	Greater than 20,000 lbs.	5,000 to 19,999 lbs.	4 Drums to 4,999 lbs.
Polyox Coagulant	1.49	1.54	1.64
Polyox WSR-301	1.26	1.31	1.41

Resin Grade	1 to 3 Drums	50 lb. Leverpak
Polyox Coagulant	1.79	2.24
Polyox WSR-301	1.56	2.01

Price is in dollars per pound, FOB.

(b) Calgon Corporation

Polymer	Price
WT-2860	$ 250/55-gal drum
WT-2640	$ 155/55-gal drum
CAT-Floc T	$ 245/55-gal drum
WT-2600	$ 7.15/25-lb bag
WT-3000	$ 58.5/25-lb bag
WT-2690	$ 57.0/25-lb bag

(c) Nalco

Polymer	Price
72-D-13	$ 0.69/lb
72-C-25	$ 0.14/lb

(d) American Cyanamid Company

Polymer	Price
Magnifloc 573C	$ 0.45/lb
Magnifloc 581C	$ 0.485 lb
Magnifloc 587C	$ 0.31/lb
Magnifloc 834A	$ 1.91/lb
Magnifloc 835A	$ 1.70/lb
Magnifloc 905N	$ 1.70/lb

(e) Betz, Inc.

Polymer	Price
Betz 1100	$ 2.19/lb
Betz 1110	$ 2.19/lb
Betz 1120	$ 2.19/lb
Betz 1130	$ 2.19/lb
Betz 1140	$ 2.12/lb
Betz 1160	$ 2.03/lb
Betz 1175	$ 0.59/lb
Betz 1180	$ 0.455/lb
Betz 1190	$ 0.59/lb

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Wang, Chun-Ching
Laboratory study of chemical coagulation as a means of treatment for dredged material / by Chun-Ching Wang and Kenneth Y. Chen, Environmental Engineering Program, University of Southern California, Los Angeles, California. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1977.
188, 4, 2 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-39)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW39-76-C-0038 (DMRP Work Unit No. 6B07)
References: p. 77-83.
1. Biostimulation. 2. Chlorohydrocarbons. 3. Coagulation. 4. Contaminants. 5. Dredged material. 6. Sediment. 7. Trace metals. I. Chen, Kenneth Y., joint author. II. Los Angeles. University of Southern California. III. United States. Army. Corps of Engineers. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-39.
TA7.W34 no.D-77-39