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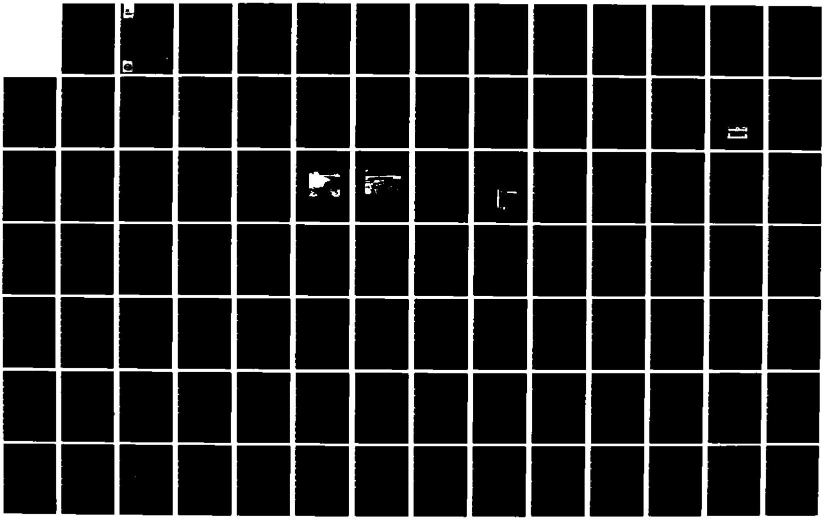

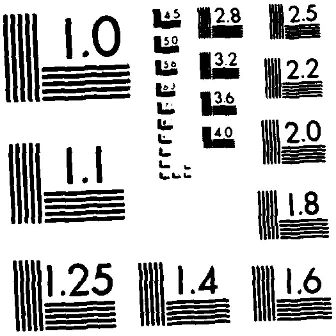

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of Engineers

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**DREDGING OPERATIONS
TECHNICAL SUPPORT**

TECHNICAL REPORT D-83-2

CHEMICAL CLARIFICATION METHODS FOR CONFINED DREDGED MATERIAL DISPOSAL

by

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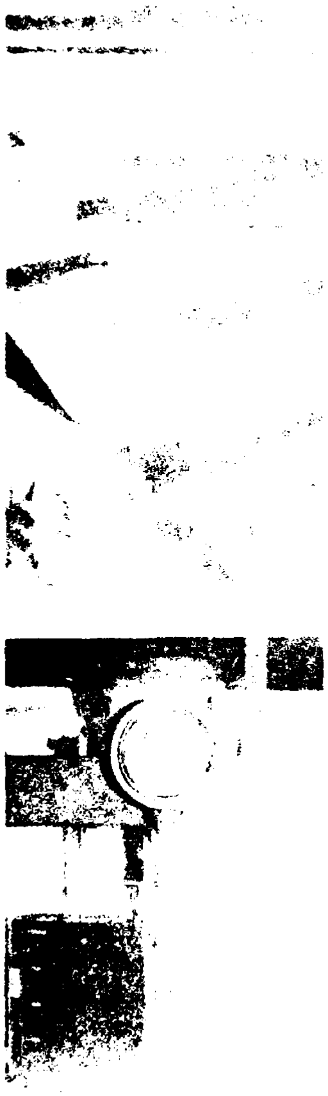

AD-A134 732

July 1983
Final Report

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Washington, D. C. 20314

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following programs:

Dredging Operations Technical Support
(DOTS)

Long-Term Effects of Dredging Operations
(LEDO)

Interagency Field Verification of Methodologies for
Evaluating Dredged Material Disposal Alternatives
(FVP)

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This report presents the results of verification studies on chemical clarification methods for dredged material disposal developed during the Dredged Material Research Program and provides laboratory procedures and design guidelines for designing treatment systems to clarify the effluent from a dredged material containment area. Guidelines are also presented on operating the systems and estimating the treatment costs.

Thirty-five chemicals were screened in laboratory tests to determine which types of polymer were most effective in clarifying suspensions of fine-grained, freshwater sediments. Moderately high molecular weight, highly cationic polyamines performed well on the suspensions tested, which ranged in solids concentration from 0.21 to 2.1 g/ℓ. The required polymer dosage increased with increasing solids concentration.

(Continued)

20. ABSTRACT (Continued)

The required dosage decreased as the mixing conditions were improved.

Three field demonstrations were performed to determine the technical and economic feasibility of clarification by flocculants and to develop a treatment system that is simple, economical, and adapted to the disposal operation. The treatment system that was developed disperses a concentrated, low viscosity liquid polymer in the effluent at the weir of the primary containment area. The polymer is diluted in-line with supernatant from the containment area as it is being pumped to the weir. The weir structure provides the required mixing for flocculation. A small secondary containment area provides settling time and storage volume for the treated material.

Field tests showed that the treatment system was very effective. The solids concentration was reduced from about 2 g/ℓ to 50 mg/ℓ using a polymer dosage of 10 mg/ℓ. The treatment cost for the demonstrations, excluding the cost of constructing a secondary containment area, was about \$0.20/yd^3 of in situ sediment dredged (1981 dollars).

A preliminary laboratory and field investigation was performed to examine the polymer dosage requirements to treat dredged material slurries by injecting polymer into the dredge pipeline. The required polymer dosages were proportional to the concentration of nonsettleable fines in the slurry; that is, the required polymer loading in milligrams of polymer per 1000 Nephelometric Turbidity Units (NTU) of nonsettleable turbidity was the same for treating an influent slurry as for treating a containment area effluent. Therefore, the required dosage, in milligrams per litre, is much higher than for treating effluents.

Laboratory jar test procedures are presented to select an effective polymer (including dosage and feed concentration), to determine the mixing requirements, and to determine the relationship between the influent solids concentration or turbidity and the required polymer dosage. Guidelines are presented for designing the polymer feed system, the weir and discharge culvert for mixing, and the secondary containment area for settling and storage. The polymer feed system is sized to deliver the required polymer dosage at the recommended feed concentration for the range of possible flow rates and influent solids concentration. The weir and discharge culvert are designed to maximize the mixing available for a given head loss through the culvert. The secondary basin is designed to provide a sufficient depth and volume of ponding for good settling and also to provide sufficient storage volume while minimizing the required area. The object of the design is to use the available depth effectively for mixing, settling, and dredged material storage.

The main costs of treatment are for polymer, labor, and construction. The treatment costs are dependent on the specifics of each project: effluent requirements, treatment system design, production rate, polymer selection, and required dosage. The treatment cost, excluding the costs of constructing a secondary cell, would probably range from \$0.08 to \$0.25/yd^3 of in situ material dredged. Higher dredge production rates and lower chemical dosages would lower unit costs.

PREFACE

This study was conducted as part of the Dredging Operations Technical Support (DOTS) Program at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The DOTS Program is sponsored by the Office, Chief of Engineers, U. S. Army, through the Dredging Division of the Water Resources Support Center, Ft. Belvoir, Va. The DOTS is managed by the WES Environmental Laboratory (EL) through the Office of the Environmental Effects of Dredging Programs (EEDP).

The work was performed during the period from October 1978 to September 1981 by the Water Resources Engineering Group (WREG), of the EL Environmental Engineering Division (EED), WES. The principal investigators were the late Mr. Thomas K. Moore, WREG; Mr. Alfred W. Ford, formerly of WREG; Mr. F. Douglas Shields, Jr., WREG; and Mr. Paul R. Schroeder, WREG. This report was written by Mr. Schroeder. The work was conducted under the direct supervision of Mr. Michael R. Palermo, Chief, WREG; and under the general supervision of Mr. Andrew J. Green, Chief, EED, and Dr. John Harrison, Chief, EL. Significant contributions in the conduct of the laboratory and field work were made by many other personnel of WREG. Assistance in the planning, preparation, and performance of the field investigations was provided by the Vicksburg and Nashville Districts. Manager of EEDP was Mr. Charles C. Calhoun, Jr., EL.

Commanders and Directors of WES during this study were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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LIST OF FIGURES

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
acres	4046.873	square metres
acre-feet	1233.489	cubic metres
cubic feet	0.02831685	cubic metres
cubic feet per second	0.02831685	cubic metres per second
cubic feet per second per foot	0.0929	cubic metres per second per metre
cubic yards	0.7645549	cubic metres
Farenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet per minute	0.3048	metres per minute
feet per second	0.3048	metres per second
gallons per minute	3.785412	cubic decimetres per minute
gallons (U.S liquid)	3.785412	cubic decimetres
horsepower (electric)	746.0	watts
inches	25.4	millimetres
pounds (force) per square inch	6894.757	pascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pound-seconds per square foot	478.8	poises
square feet	0.09290304	square metres

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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.

CHEMICAL CLARIFICATION METHODS FOR CONFINED DREDGED MATERIAL DISPOSAL

PART I: INTRODUCTION

Background

1. The disposal of dredged material in confined disposal areas has increased in recent years due to concern for the protection of the aquatic habitat and water quality. The normal practice has been to pump the dredged material as a slurry into a diked area where the material settles out of suspension forming a settled dredged material layer and supernatant water. The supernatant is then discharged over a weir and returned to the waterway. Depending on the salinity of the water, grain-size distribution of the material, and disposal site conditions, the suspended solids concentration of the effluent for disposal of fine-grained dredged material normally ranges between 200 mg/ℓ and 10 g/ℓ. Generally, well-designed containment areas should reduce the solids concentration to below 1 or 2 g/ℓ. These effluent concentrations may exceed State or Federal water quality standards in certain areas; therefore, further treatment may be required to reduce the suspended solids, settleable solids, or turbidity to meet the effluent standards.

2. The suspended solids and turbidity in the effluent from a containment area are colloidal material that does not readily settle by gravity. Chemical clarification is one method to remove these fine particles from water. Many different chemicals are available which, when added to the water, will aggregate the particles into a dense floc that settles quickly. Efficient clarification requires optimum chemical doses and mixing conditions for floc formation. Chemical clarification is a treatment method primarily for the removal of suspended, not soluble or dissolved, material from water.

3. Chemical treatment can be applied at two points in the disposal process. First, the treatment process can be used to polish the effluent from the primary containment area as shown in Figure 1. This

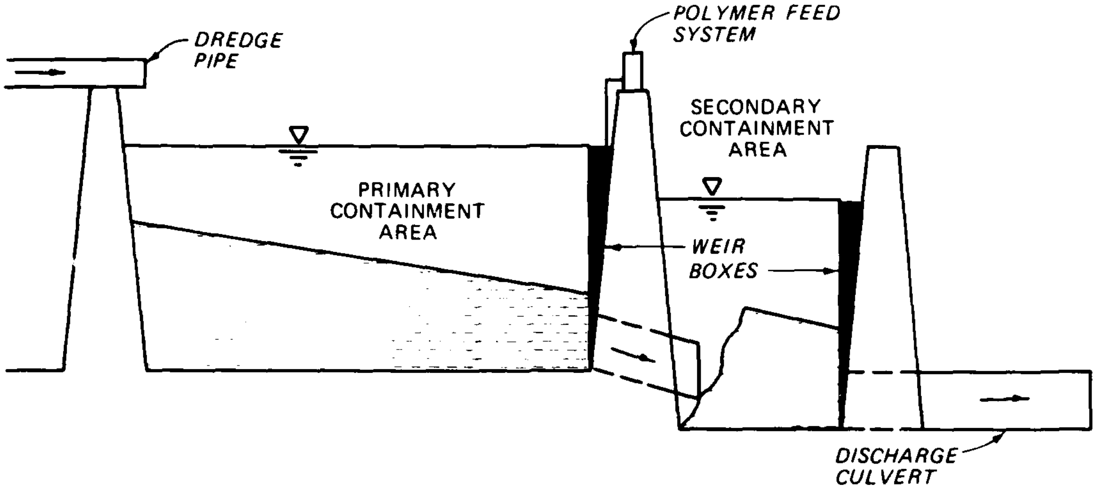

Figure 1. Concept of chemical treatment to clarify confined disposal effluents

system would require a small secondary cell to collect the remaining 1 to 2 g/ℓ of solids in the effluent and a structure to mix the flocculant with the effluent; normally, the weir structure is used. The required chemical doses would be typical of water treatment systems. This system would ensure that discharges sent to the receiving waters would be of good quality.

4. The second method of application would be to add the flocculant directly to the influent slurry by pumping the chemical into the hydraulic dredge pipeline. This would enhance the settling rate within the containment area, but would increase the required chemical dosage considerably. The storage volume requirements would probably also increase since the treated material does not settle as densely. No modifications to the conventional containment area would be needed to operate this treatment system. To date, this method of application is still largely untested and, therefore, its performance is speculative.

Previous Studies

5. The preliminary research and development work on chemical treatment was done under the Corps of Engineers' (CE) Dredged Material

Research Program (DMRP). Studies under the DMRP yielded many important results. Wang and Chen (1977) examined the effectiveness of both conventional coagulants and polymeric flocculants to treat dredged material in jar tests. Over 50 chemicals were tested on sediments from five sites. The sediments were diluted to simulate both slurries and supernatants. The salinity of the samples was varied to determine its effect, but virtually all of the samples had sufficient salinity (greater than 2 ppt) to behave as saltwater sediments. Conventional coagulants (alum and ferric sulfate) were found to be unsuitable for treating dredged material because of high dosage requirements, the need for pH control, and the potential carryover of trace metals in the effluent. Certain polymers worked excellently while others were ineffective even at high concentrations. Anionic polymers were more effective on slurries and high molecular weight, cationic polymers were best for supernatants. The required polymer dosage increased with increasing initial turbidity or solids concentration and decreased with increasing salinity.

6. The study by Jones, Williams, and Moore (1978) developed laboratory procedures for determining the most effective polymer, the optimum dosage, and other design parameters for treating both slurries and supernatants. They also provided guidelines on design procedures and on operation of treatment systems. However, their designs were based on using a conventional clarification system with conventional equipment instead of incorporating the design into the normal containment area conditions. Finally, they performed two field demonstration studies. In one, the effluent from a freshwater dredged material containment area was flocculated by three cationic polyelectrolytes in a conventional physical-chemical pilot plant. The treatment system was very effective. In the other study, a cationic polyelectrolyte was injected into the hydraulic dredge pipeline for a freshwater slurry. The results of the test were erratic due to variations in flow and composition of the dredged material slurry. Adding flocculant increased the settling rate and reduced the supernatant turbidity; however, the supernatant of many

samples was still very turbid. The use of flocculants to treat dredged material was both simple and effective.

Purpose

7. The purpose of this report is to document the results of chemical treatment demonstration projects and to provide guidelines for design and operation of chemical treatment facilities for clarification of dredged material slurries and supernatants. Guidelines are presented on sample collection and preparation, on laboratory tests to select a flocculant and to determine design parameters, and on the design and operation of the treatment system. This work evolved from preliminary studies by Wang and Chen (1977) and by Jones, Williams, and Moore (1978) and is intended to verify and to supplement their work.

8. The specific objectives of this study were as follows:

a. To verify the results and conclusions of previous studies since only limited data were collected. The effectiveness of various flocculants for clarifying freshwater sediments needed to be examined. Both methods of applying flocculants required additional field testing. Laboratory procedures, design parameters, and design methods needed to be compared with actual field conditions. The predicted effectiveness of the treatment methods based on laboratory tests needed to be compared with the results of long-term, full-scale field tests.

b. To develop and evaluate treatment systems and methods to effectively and efficiently treat primary containment area effluents and dredged material slurries. The methods and systems developed in previous studies were traditional and were not modified for the remote, temporary, and intermittent nature of dredging operations. The treatment system must be capable of handling high flow rates and high solids loadings.

c. To simplify the selected treatment system for ease of operation. Due to the temporary nature of dredging, trained, experienced operators are not available to run a treatment plant. Therefore, the system must be simple and dependable, requiring only minimum operation, maintenance, and supervision.

d. To reduce treatment costs. Simplification of the treatment system reduces equipment and labor requirements and therefore costs, but at the same time may increase chemical usage and chemical costs. Costs can also be lowered by selecting the most cost-effective flocculant and by maximizing its effectiveness in the treatment system design.

e. To obtain information on treatment costs. Prior to this study, the probable costs for treating dredged material were largely unknown.

f. To evaluate the removal efficiency of the selected treatment system. The effluent quality following chemical treatment had never been measured under normal field conditions. Therefore, the practical limitations of treatment needed to be determined.

g. To develop guidelines for laboratory testing to determine design parameters for the treatment method, and to develop guidelines for the actual design and operation of the treatment system. Treatment systems for dredged material are quite different from typical water and wastewater treatment plants because of the high sediment loads and the temporary and intermittent operation associated with dredging projects. Therefore, specific guidelines are needed for the design and operation of the treatment system. Also, the dredged material, the dredging operation, and the disposal site characteristics are unique. Consequently, laboratory tests that simulate field conditions are required for each project to select a flocculant and to determine design parameters.

Scope

9. The general approach of this study was to design treatment systems for the clarification of effluents or supernatants based on laboratory tests and field conditions, and then to evaluate the performance of the systems in full-scale field demonstrations. Specifically, three demonstration sites were selected and sediment samples were collected. Laboratory tests and procedures were developed and performed to prepare suspensions of the sediments, select a flocculant, examine the effects of mixing and settling conditions, establish minimum mixing and settling requirements, select the required flocculant dosage, and obtain an estimate of the achievable effluent quality. The project's treatment system was designed and equipment was selected. The treatment system was set up and field tested. The effluent quality was measured as a function of dosage; the efficiency and adequacy of the mixing was evaluated; and the

practical limitations of turbidity and suspended solids removal were determined. Operating experience was gained to develop operating guidelines, and the operation and maintenance requirements were established. The available settling time in the secondary containment area was determined by dye tracer tests, and the adequacy of the settling conditions was evaluated. The storage requirement for settled treated material was determined. Finally, the overall technical and economic feasibility was examined, and recommendations were proposed.

10. A preliminary field investigation was also performed to evaluate the feasibility of injecting polymer directly into the dredge pipeline to treat dredged material slurries. Data were collected on the settling rate of the slurry, on the turbidity and suspended solids concentration of the slurry prior to settling, and on the supernatant after settling for 10 min. The effects of polymer dosing rate and location of polymer injection on clarification were examined.

PART II: AGGREGATION OF DREDGED MATERIAL

11. This section presents a brief summary of background information and theory on aggregation of dredged material. More detailed discussions and literature reviews were previously presented by Wang and Chen (1977) and Jones, Williams, and Moore (1978). The advantages and application of flocculation by polymers as compared with aggregation by conventional aggregants* are also discussed herein.

12. In this report, the terms "aggregation," "coagulation," and "flocculation" will be used in accordance with the system established by La Mer (1964). "Aggregation" refers to any mechanism that causes colloidal particles to agglomerate. "Coagulation" is defined as electrostatic destabilization by the reduction of surface potential and charge of the particles. "Flocculation" is destabilization by the chemical bridging of colloidal particles by polmyers. The polymer adsorbs on the particles forming a dense, three-dimensional floc that settles rapidly. The terms "aggregants," "coagulants," and "flocculants" refer to the chemicals that promote destabilization by the mechanism of aggregation, coagulation, and flocculation, respectively. Colloidal stability is defined as the property of particles to remain in suspension.

Properties and Behavior of Fine-Grained Material

13. The character of dredged material and its suspending medium can strongly affect the settleability of the material and the selection of an aggregant. Saltwater enhances settleability, but may chemically react with the aggregant. The organic content of sediments and the adsorbed ions and other substances on the particle surface may increase the colloidal stability toward certain aggregation mechanisms. These substances may also interact with aggregants and therefore restrict the effectiveness of the treatment. Particle size affects the settling

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* An aggregant is any chemical that promotes clarification and should not be confused with an aggregate.

rate: coarse-grained material settles rapidly and does not require chemical treatment to enhance settleability, while fine-grained materials, clays, are colloidal and require aggregation to achieve good clarification in confined disposal containment areas.

14. At freshwater sites, the effluent quality from confined disposal sites and the required aggregant dose to treat dredged slurries and disposal effluents are strongly related to the concentration of clays in the dredged slurry. This concentration depends on the concentration of the dredged slurry and the clay content of the sediment. The average solids concentration may vary from about 80 to 250 g/ℓ, but 145 g/ℓ is generally used as the norm. The particle-size distribution and therefore the clay content also vary greatly.

15. Colloidal particles are stabilized mainly by two phenomena, electrostatic repulsions and hydration. Clean sediments, free of soluble organics, are normally stabilized by electrostatic forces resulting from the net negative charge on the particles in an aqueous environment. These sediments are the easiest to aggregate. They readily coagulate in saltwater. Polymers are commercially available that will flocculate this material at low dosages.

16. Organic clays and sediments with adsorbed organics are often stabilized in part by hydration. The affinity of these organics for water results in the formation of a sheath or shell of water molecules that encapsulates the colloidal particle. This shell protects the particles in two possible ways. First, the water acts as a mechanical barrier that inhibits aggregation by preventing contact during particle collisions. To penetrate this barrier, part of the solvent must be desorbed from the surface, requiring energy to overcome the forces of hydration. Dehydration is also required so that polymers can adsorb on the particles. Second, it is also theorized that the water dipoles in the shell are oriented by the surface charge. These oriented dipoles repel dipoles similarly oriented on other particles as the two particles approach each other. Suspensions that are stabilized by hydration are more difficult to clarify. By practical means, they can be effectively aggregated by two mechanisms: enmeshment in a precipitate or floc and

flocculation by polymer with strong adsorption energies.

Aggregant Types and Descriptions

17. There are three main types of aggregants: simple salts, hydrolyzable salts, and polymeric flocculants. Each type aggregates colloidal suspensions in a different manner. Simple salts are the classical coagulants of the late 1800's and early 1900's. They were used in the early quantitative studies conducted by Schulze, Hardy, and Freundlich (Alexander and Johnson 1949), which led to the Schulze-Hardy rule. These salts, typically of sodium, potassium, calcium, and barium, form monovalent, divalent, and polyvalent ions of opposite charge to that of the colloidal particles. The coagulants reduce the electrostatic repulsion between the particles.

18. The hydrolyzable salts of iron and aluminum are the primary aggregants used for treatment of surface water for drinking water supplies. These salts interact with water to form many species, all in equilibrium with each other. The dominant species varies as a function of pH. The optimum species for aggregation is the hydroxide precipitate which predominates at neutral pH. Upon addition to water, the salt acts as an acid, lowering the pH and requiring three hydroxides to neutralize a free aluminum or iron ion. Therefore, pH adjustment may be necessary to control the aggregation. The aggregants work by gathering the colloid in the hydroxide precipitate floc. At low pH, the aggregants can coagulate colloidal particles in the same manner as simple salts.

19. Polymers are the newest type of aggregant. As more and more kinds are synthesized, polymers are being used to treat all types of waters and wastewaters. A polymer is composed of many small organic subunits or monomers of one or more kinds linked in a recurring pattern to form a chain. If these monomers have ionizable groups (e.g., carboxyl, amino, or sulfonic groups), the polymer is called a polyelectrolyte. Depending on its monomers, a polyelectrolyte may be either cationic, anionic, or ampholytic. Nonionic polymers contain no ionizable groups. Polymers flocculate colloidal particles by forming a bond with

the particles or by neutralizing the charge on the particles.

Aggregation Mechanisms

20. The destabilization of colloidal suspensions can be accomplished by many different mechanisms. The mode of action is dependent on the nature of the aggregant, the colloid, and the stability forces. Suspensions of hydrophobic particles are aggregated primarily by reducing the electrical double layer repulsion, by chemical bridging or flocculation, and by enmeshing. The main methods for destabilizing suspensions of hydrophilic particles are dehydration, precipitation, flocculation, and enmeshment. Many colloids possess both hydrophobic and hydrophilic properties and therefore the best aggregation mechanism is not always readily apparent. Typically, dredged material would be hydrophobic, but it may possess some hydrophilic properties in the presence of organic substances.

21. Simple coagulation is the destabilization of colloidal suspensions by simple, nonpotential-determining ions. The counterions (ions with the opposite charge of the particles) compress the diffused electrical double layer surrounding the colloidal particles, lowering the electrical repulsive potential and potential energy barrier. Consequently, the van der Waals attractive forces become greater than the repulsion and the particles aggregate. Compaction of the double layer is dependent on both the concentration and charge of the counterions. The coagulation follows the Schulze-Hardy rule, which states qualitatively that the coagulating power of the coagulant increases greatly with the counterion charge. The coagulation is nearly independent of the suspension concentration though the mechanism is more effective at high concentrations of particles. On a practical basis, the mechanism is too slow for widespread application and the particles can be easily redispersed. Also, high salt concentrations are generally required, which would be undesirable in freshwater environments. In brackish and saltwater regions, this coagulation mechanism occurs naturally.

22. A second mode of coagulation is adsorptive coagulation by

potential determining ions. In this case, the counterions are adsorbed on the suspension particles, lowering or neutralizing the surface charge and potential. Thus, the electrical repulsion potential is lowered throughout the diffused layer allowing aggregation to occur. According to Matijević and Allen (1969), the main ionic species responsible for adsorptive coagulation are large complex ions and odd-shaped ions such as metal chelates with bulky ligands, organic ions of irregular shape like surfactants and soaps, and some hydrolyzed metal ions. Other ions that are constituents of the particles, such as hydrogen and hydroxide ions for hydrolyzed particles, are also potential-determining and promote aggregation by the same mechanism (van Olphen 1963). Adsorptive coagulation destabilizes the particles at lower coagulant doses than predicted by the Schulze-Hardy rule. Often adsorptive coagulants at higher concentrations restabilize the suspension by charge reversal. The required coagulant dose, since the aggregation mechanism operates by adsorption, is dependent on suspension concentration, affinity for the coagulant, and, only to a limited degree, on counterion charge.

23. A third mode of coagulation is the destabilization of particles by other particles. Heterocoagulation proceeds by the electrostatic attraction of oppositely charged diffused layers and particles. Mutual coagulation is the aggregation of particles of like charge. Clarification occurs only at high suspension concentrations mainly due to the increase in the particle collision frequency and floc formation. This is the chief mechanism for the clarification of fine-grained freshwater materials in the primary containment area.

24. Enmeshing is a second method of destabilization, whereby colloidal particles are gathered in the precipitate of a metal salt. The particles are then swept out of suspension as the precipitate settles. The volume of precipitate greatly increases the sludge volume to be stored. Enmeshing is the principal mechanism for aggregation by the hydrolyzable salts of iron and aluminum. With these aggregants, enmeshing occurs in the neutral pH range at concentrations of metal salt above the critical supersaturation point of the precipitate.

25. The final mechanism to be discussed is flocculation or

chemical bridging. Polymers or polyelectrolytes adsorb on suspension particles forming bridges between them. The resulting dense, three-dimensional floc settles rapidly entraining other colloidal particles and effectively clarifying the liquid. Mixing is needed to promote contact between polymer chains, particles, and flocs. The polymer, when added at high concentrations, completely covers all of the adsorption sites on the particles, preventing each polymer chain from adsorbing on several particles and bridging. Thus, high polymer dosages protect the particles from aggregation. Excessive high intensity mixing has a similar effect. The mixing shears the polymer from particles, breaking the bridges between particles. The polymer then folds back onto the particle to which it is attached and adsorbs on several more sites on this particle. This prevents the polymer from readsorbing on other particles and forming bridges. The polymer also reduces the number of adsorption sites on the particle available for anchoring other polymer chains. Therefore, an optimum polymer dose and mixing condition exist for flocculation.

Advantages of Polymers for Dredging Operations

26. The use of polymeric flocculants to chemically treat dredged material offers many advantages over other aggregants. Liquid polymers are less expensive to use and easier to handle and feed. They rapidly produce a better quality effluent and work better within normal site constraints. Many of these advantages were documented by Wang and Chen (1977) and Jones, Williams, and Moore (1978) while others were identified in the chemical treatment demonstration projects reported herein. These demonstrations verified the practicability, ease, and effectiveness of using liquid polymers to treat dredged material supernatants.

27. Polymers aggregated dredged material supernatants at much lower dosages than conventional inorganic aggregants in laboratory jar tests. Optimum polymer dosages were generally about 8 ppm while about 200 ppm of the hydrated alum or ferric sulfate salts was required for

effective clarification. Polymers cost approximately \$0.70/lb* and alum or ferric sulfate about \$0.05/lb, but because of the required dosages, the chemical costs for polymers would be about half that for conventional aggregants.

28. Liquid polymers and chemicals are easier and less expensive to handle and feed. The only equipment needed is a storage tank, a dilution tank in some cases, and a metering pump. Dry chemicals require a storage hopper with dust control, a dry chemical dispenser, a dissolving-aging tank, a storage tank, and a metering pump. Besides the savings in equipment, liquid chemicals have lower operation and maintenance costs. At a dredging site, it is simpler to haul and store chemicals in a tank or barrels than to handle dry chemicals and build a elevated storage hopper. Another advantage of the smaller dosages for polymers is that the quantity of chemicals to be hauled, handled, and fed is much less than required for other aggregants.

29. Unlike alum or ferric salts, polymers do not require pH control to be effective. This eliminates the addition of lime or sodium hydroxide, thereby reducing chemicals, equipment, and labor requirements and their costs.

30. Flocculation by polymers is better suited for the mixing and settling conditions present at dredged material disposal sites. Polymer adsorbs rapidly and strongly, and works well under a wide variety of mixing conditions though uniform mixing is preferable. This is important because, typically, very little mixing time is available to promote particle contact and floc formation. Also, the mixing intensity is difficult to control since mixing is normally provided by the weir structure between the primary and secondary areas. Under intense mixing, the floc may shear, but the polymer is capable of rebuilding flocs many times. These flocs continue to grow in the secondary settling basin and then settle rapidly. The secondary basin normally provides 1 to 2 hr of settling time with less than quiescent conditions, primarily due to wind.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) is presented on page 5.

Polymer-flocculated material was not easily sheared and resuspended by wind-induced turbulence during field tests. Other aggregants often have more rigorous mixing and settling requirements. Also, material aggregated by conventional aggregants and resuspended by wind in the secondary basin does not settle again as well as material treated with polymers.

PART III: PRELIMINARY SCREENING OF AGGREGANTS

31. The initial work on evaluating the effectiveness of various aggregants was conducted by Wang and Chen (1977). They cursorily tested more than 40 aggregants on the supernatant of saltwater sediments without performing jar tests. Instead, they used a nonstandard experimental setup to examine the clarification of 200-NTU* suspensions by 4 ppm of each polymer and of 1000-NTU suspensions by 8.5 ppm of each polymer. Therefore, it was felt that a more extensive examination using jar tests was warranted, particularly on freshwater sediments.

32. Forty-seven diverse aggregants were collected for testing. Twelve of the polymers were eliminated at the start because of chemical similarities. The remaining thirty-five chemicals were evaluated in the laboratory. The polymers and their descriptions are listed in Table 1.

33. The initial screening was performed using freshwater clay sediment from the Yazoo River channel modification project located near Belzoni, Miss. Specific information on the properties of the sediment is presented in Part IV with the background information on the first demonstration project. Laboratory screening was performed in two stages. In the first stage, the minimum and optimum aggregant dose was determined by adding aggregant incrementally to a dredged material sample, mixing the sample, and observing the resulting floc formation and clarification. In the second stage, the promising aggregants from the initial screening were examined more closely by jar tests.

34. The initial screening was performed in several steps; each successive step used a higher concentration of dredged material. After each step, the results were evaluated and the aggregants demonstrating inferior performance were rejected. The remaining aggregants were tested further.

35. The initial concentrations of dredged material used in the tests were 0.21 and 0.42 g/ℓ. A 1-ℓ sample was placed in a 1-ℓ beaker and mixed at 100 rpm on a standard Phipps and Bird jar test apparatus

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* NTU = Nephelometric Turbidity Units.

shown in Figure 2. Then, polymer was injected into the sample in increments of 1 to 5 mg until flocs were produced. This dosage is reported as the minimum dosage in Table 2. More polymer was added until the water was clear. The sample was then slowly mixed at 20 rpm for 5 min and allowed to settle quiescently for 10 min. The turbidity of the supernatant was measured to determine the effectiveness. The turbidity is listed in Table 2 along with the total quantity of polymer added which is given as the optimum dosage. Following the test, aggregants requiring dosages greater than 20 mg/ℓ to produce flocs or failing to produce supernatants with turbidities less than 50 NTU were rejected. All of the inorganic aggregants (alum, ferric chloride, and ferrous sulfate) were eliminated as were many polymers, including all of the nonionic and anionic species tested.

36. The effectiveness of the remaining 14 polymers was examined on 0.84-, 1.26-, 1.69- and 2.11-g/ℓ suspensions. These tests were identical to the test just described. The results are included in Table 2. All but one of these polymers consistently worked well at low dosages. However, the more highly cationic and higher molecular weight polymers appeared to perform better.

37. The remaining 13 polymers were further screened by jar tests. The experiments were performed on a six-place Phipps and Bird multiple mixer. One-litre samples of dredged material were placed in one-litre beakers and mixed rapidly to disperse the material. Polymer was then injected into the series of samples at the desired concentrations. The

Figure 2. Laboratory jar test apparatus

samples were mixed at 100 rpm for 1 min to disperse the polymer and to promote polymer-particles contact. A slow mix at 20 rpm for 5 min followed to induce floc formation. The suspensions were allowed to settle for 10 min. After settling, the supernatant was sampled at about 4 cm beneath the surface and the turbidity was measured on a Hach Model 2100A turbidimeter.

38. All polymers were tested on 0.5-g/ℓ suspensions or the Yazoo River sediment. The polymer dosage was varied from about 2 to 24 mg/ℓ in a series of samples. The results are listed in Table 3. All of the polymers performed well, but half of the polymers were eliminated to narrow the investigation to the best polymers. The seven polymers that yielded the lowest turbidities at dosages of 16 and 20 mg/ℓ were examined further.

39. Seven polymers were examined using jar tests with 1.0-g/ℓ suspensions. The polymer dosage ranged from 5 to 30 mg/ℓ. Three of the polymers worked very well and were tested on 2.0-g/ℓ suspensions. Overall, Magnifloc 577C was the best, producing the clearest supernatant at any dosage (Table 3).

40. Several other less intensive screening tests were performed on other sediments using the proven performers of this screening and of the studies by Wang and Chen (1977) and Jones, Williams, and Moore (1978). The proven performers were limited to liquid polymers of low to medium viscosity due to their ease of application in the field. These polymers were Magnifloc 573C, 577C, and 581C; Nalcolyte 7103 and 7132; Calgon M-502; and Hercofloc 863. The polymers selected for the sediments are found in Table 4, and the project locations are shown in Figure 3. Recommended laboratory procedures for selecting a polymer are presented in Part VI.

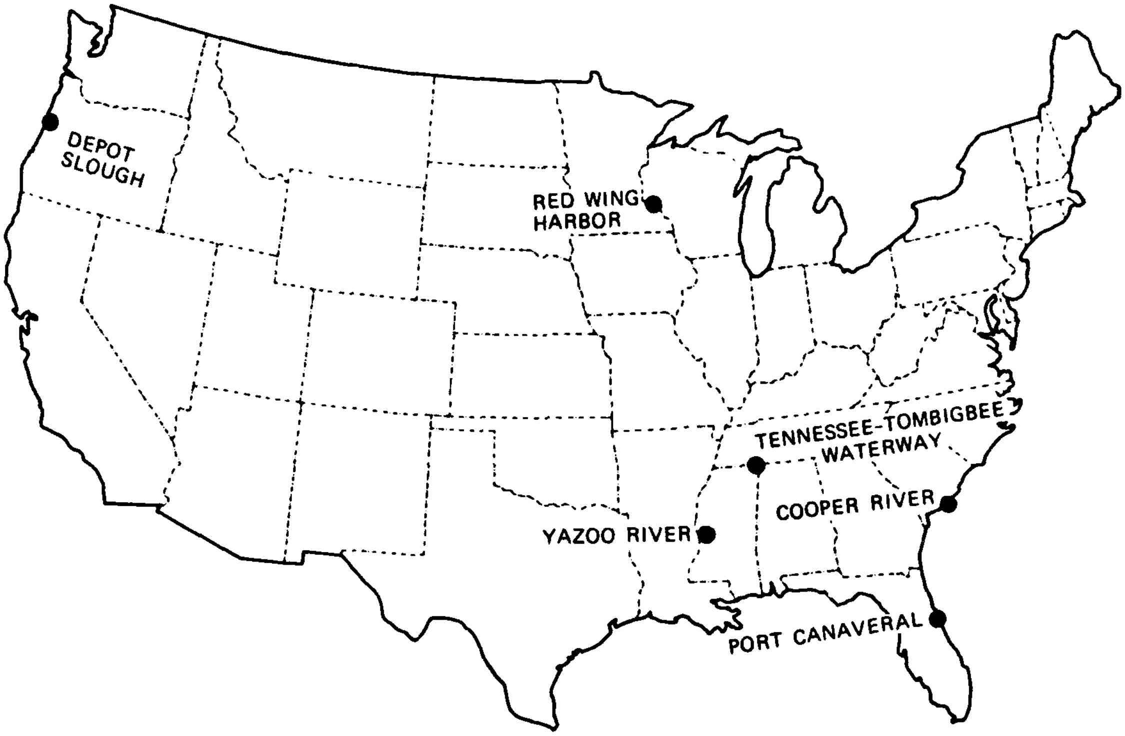


Figure 3. Sediment sites for screening flocculants

PART IV: FIELD DEMONSTRATIONS OF TREATING PRIMARY CONTAINMENT AREA EFFLUENTS

41. Three field demonstration projects were performed to test the effectiveness and design of chemical treatment systems to clarify the effluent from primary containment areas. The studies were also used to evaluate the design procedures, to develop guidelines for operating the systems, and to examine treatment costs. Two of the studies were conducted on the Yazoo River and the third on Yellow Creek, Tennessee-Tombigbee Waterway. The sediments at all three sites were freshwater material with a significant fraction of clays. In absence of treatment, effluent solids concentrations would have been greater than 1 g/ℓ. Therefore, these sites provided an opportunity to evaluate the treatment method under strict conditions. Costs of the three demonstration projects are also discussed herein.

First Yazoo River Demonstration

Background

42. The demonstration was performed at disposal area No. 1 of Upper Yazoo Project Item 2A-1 near Belzoni, Miss., on 28-29 Nov 1979, with the support of the U. S. Army Engineer District, Vicksburg. The previously filled and abandoned disposal area No. 6 of Item 1-C was adjacent to the site and therefore was used as the secondary containment area. The containment area layout is shown in Figure 4. The primary containment area had a surface area of 48 acres and a depth of 12 ft. The secondary area had a surface area of 43 acres, but only a third of the area was ponded and then just to a depth of 1 to 2 ft. The two areas were connected by a 120-ft fixed crest weir with a spillway that fed the overflow directly into the secondary area.

43. The dredging activity was new construction work on a freshwater channel modification. Material dredged from the river banks was about 85 percent fine-grained material, 35 percent clay, and was classified as a lean, sandy, silty clay (CL) with low plasticity. An 18-in. hydraulic dredge was discharging about 27 cfs intermittently into the primary area throughout the study.

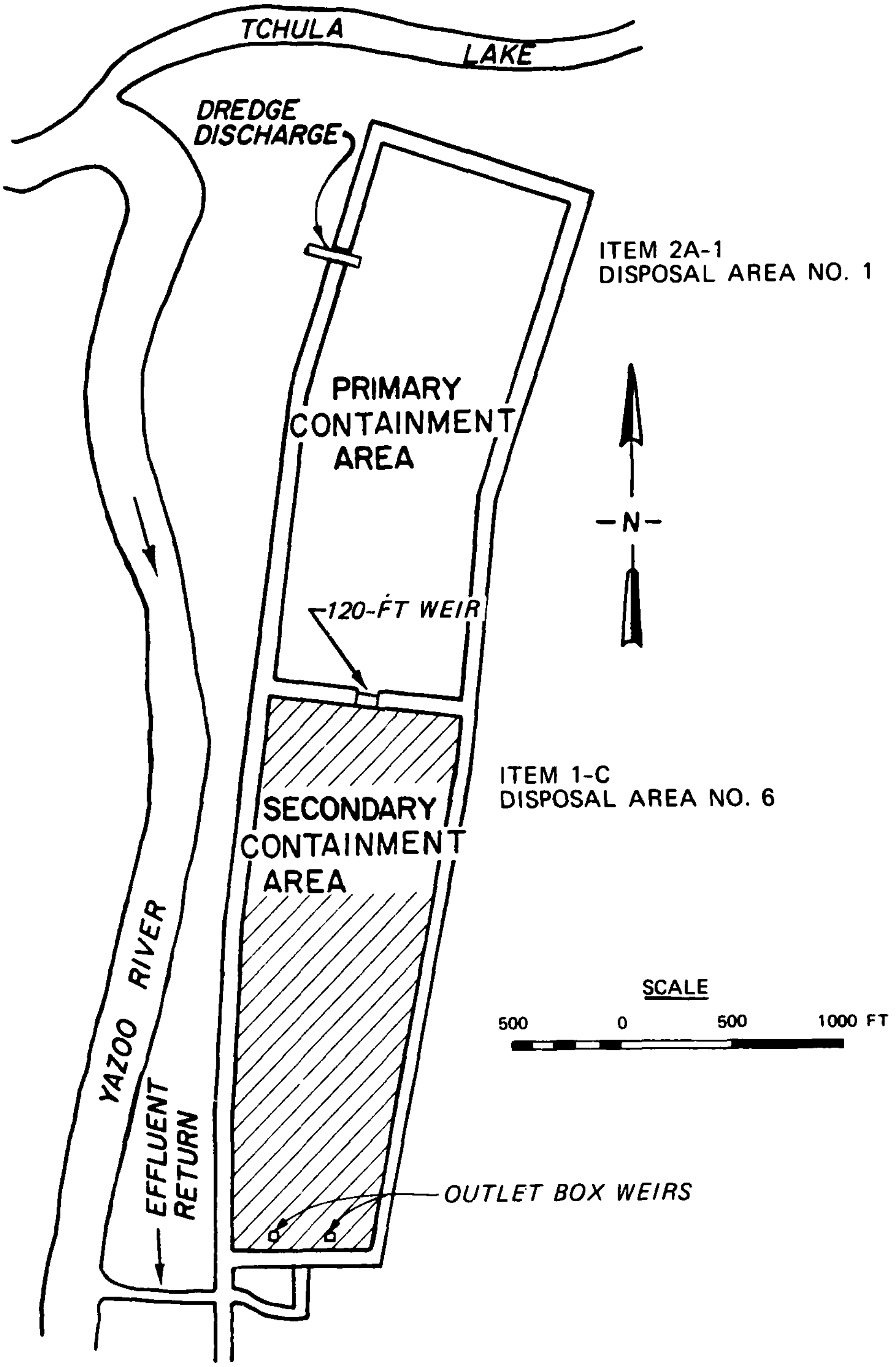


Figure 4. Layout of first Yazoo River field demonstration site

44. The purpose of this study was to demonstrate that clarification by polymer addition could be achieved with moderate doses of flocculant without a traditional treatment plant. This was the first attempt to adapt the treatment process to the dredging operation.

Laboratory results

45. The polymer screening test described in Part III indicated that Magnifloc 577C would be the best polymer. The required polymer dosage, as determined by jar tests, was about 10 mg/ℓ for a 1.0-g/ℓ suspension, 15 mg/ℓ for a 2.0-g/ℓ suspension, and 25 mg/ℓ for a 5.0-g/ℓ suspension. The effluent turbidity was less than 50 NTU when adequate mixing and settling were provided. A minimum of 1 min of turbulent mixing at a mean velocity gradient G of 100 sec^{-1} and 3 min of slow mixing at a G of 20 sec^{-1} was required for the polymer to be quite effective. Mean velocity gradient G is a measure of mixing intensity. Ten minutes of settling provided sufficient time for clarification in the laboratory tests. The polymer was diluted in the laboratory tests to several concentrations with either tap water or distilled water. No difference in the effectiveness of the polymer was observed in jar tests at the various polymer feed concentrations prepared with either type of dilution water.

Chemical treatment design

46. Based on the laboratory results and project information, a chemical treatment system was designed for a 2-day, full-scale demonstration. Three basic operations are performed in a chemical clarification system: polymer addition, mixing, and settling. Each operation was simplified to minimize equipment, labor, and power requirements, and designs were developed to operate within the site constraints.

47. The polymer feed system contained provisions for storage, dilution, pumping, and injection of the polymer. A schematic of the feed system is shown in Figure 5. A 50 percent solution of liquid polymer was stored in 55-gal drums. Seven drums of polymer were used in the demonstration. The polymer was pumped directly from the barrels by a Calgon Moyno Model 2M1 polymer feed pump. The pump speed was controlled by a SCR General Electric Statotrol II controller and a General Electric

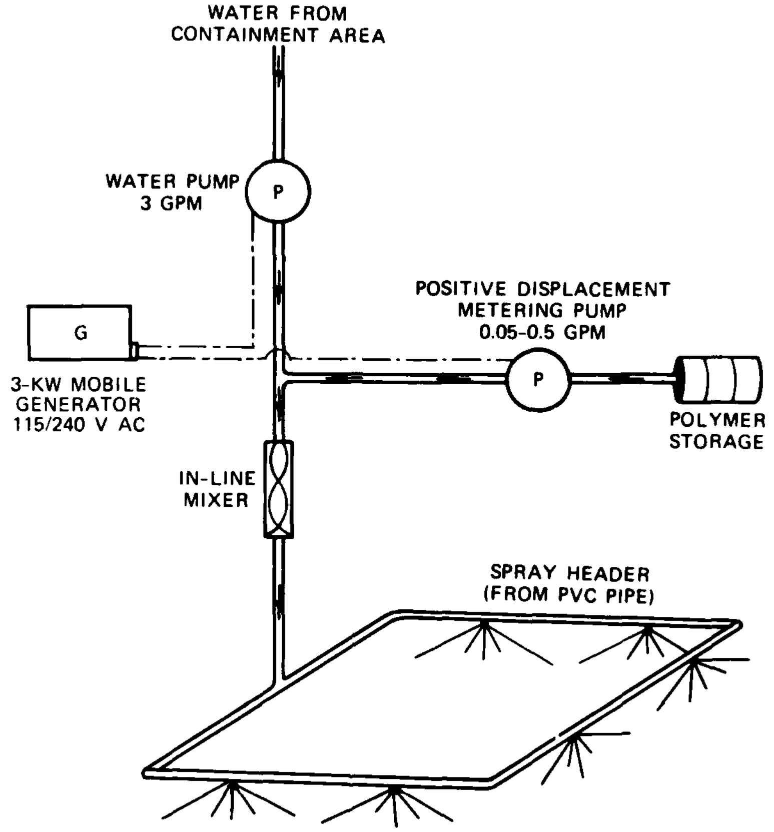


Figure 5. Schematic of polymer feed system for Yazoo River field demonstration

1/4-hp, variable speed, direct current (DC) motor. Power was supplied by a 3-kw, portable, gasoline-powered generator (115/240-v alternating current (AC)).

48. The polymer was diluted with the supernatant from the primary containment area. Supernatant was pumped by a Calgon Moyno Model 2L3 polymer feed pump from a screened intake placed near the weir. The pump was driven by a General Electric 3/4-hp, variable speed, DC motor controlled by a SCR General Electric Statotrol II controller. The dilution water was mixed with the polymer by an in-line mixer as the solution was pumped to the injection rig through 3/4-in. rubber hose. The polymer solution was not aged prior to being fed at a solution concentration of about 6 percent or 60 g/ℓ.

49. The injection system consisted of 1-in. polyvinyl chloride (PVC) pipe mounted on steel stanchions directly behind the weir crest. Small holes were drilled on 2-ft centers along the entire length of the pipe. The holes were oriented so that the polymer would be jetted into the effluent as the water plunged over the weir. Figure 6 shows the injection system in operation.

Figure 6. Polymer injection header for first Yazoo River field demonstration

50. Since good mixing for flocculation requires energy, the mixing system was designed to utilize the energy available from the flow over the weir to the maximum extent possible. A baffled spillway was designed to convert the potential energy of the flow over the weir into sustained turbulent mixing energy. The baffle system extended across the entire length of the weir and 40 ft down the spillway into the secondary area. The 40-ft extension was constructed of concrete on a slope of 1 V to 10 H and had eight rows of parallel baffles with staggered

openings. Additional baffles were placed diagonally to increase the mixing. The effectiveness of the mixing system was evaluated by injecting dye at the weir overflow and observing the dispersion. The test indicated that good mixing could be expected. The baffled spillway is shown in Figure 7.

Figure 7. Mixing spillway for first Yazoo River field demonstration

51. The secondary containment area shown in Figure 4 was used as a settling basin for the flocculated material. This basin was not designed specifically for this project and did not provide sufficient ponding depth and volume for ideal settling and solids retention. Some erosion of the original dredged material at the outlet box weirs was evident. However, the basin was adequate to provide significant removal of suspended solids from the treated effluent. A dye tracer test indicated that the basin provided an average detention time of 7 hr.

Test procedures and results

52. Two demonstration tests were performed: a 3-hr test and a

28-hr test. The short duration test was run to evaluate the effectiveness of the injection and mixing prior to examining the entire design and operation. Polymer was injected into the effluent for 3 hr at a dosage rate estimated to be about 15 mg/ℓ. The long duration test was run to examine the effects of polymer addition on the suspended solids concentration of the effluent from the secondary basin.

53. The exact polymer dosage was virtually impossible to determine due to difficulty in measuring the flow over the weir. The only method available to determine the flow rate was to measure the depth of flow over the weir and then compute the flow using standard weir formulas. The depth of the flow varied continuously due to wind-induced waves. The flow rate also varied considerably due to the intermittent operation of the dredge. The average depth of flow over the weir was generally between 1-1/4 and 1-1/2 in., corresponding to a flow rate of about 20 cfs.

54. The effectiveness of the treatment was evaluated by running batch settling tests on treated and untreated effluents. Samples of the treated effluent were collected at the base of the spillway immediately after the water passed through the baffles. The settling tests were run in 1-ℓ graduated cylinders. Typical results for the treated effluent are shown in Figure 8. The solids settled rapidly and nearly complete clarification was achieved in less than 10 min. The untreated material did not settle appreciably in the column and had not settled in the primary basin, which had a retention time of several days. Figure 9 shows a visual comparison of the treated and untreated samples following 10 min of settling. The tests indicated that the treatment system was highly effective, but better results could be obtained if the mixing was improved. Diagonal baffle boards were added to the spillway to increase the tortuosity and thereby the turbulence and mixing time.

55. The second demonstration test was run for 28 hr to examine the effect of polymer addition on the suspended solids concentration of the effluent from the secondary basin. The polymer dosing schedule and test log for the demonstration are presented in the tabulation on page 32. Polymer was pumped for the first 2 hr at a dosage of 12 mg/ℓ

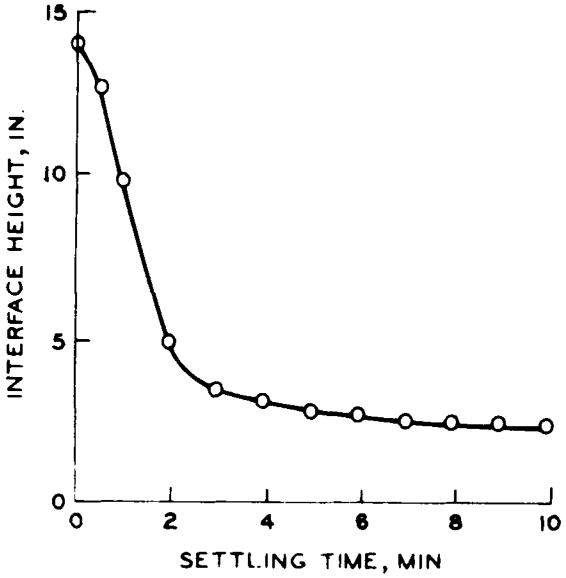


Figure 8. Settling results for treated effluent in a 1-ℓ graduated cylinder, first Yazoo River field demonstration

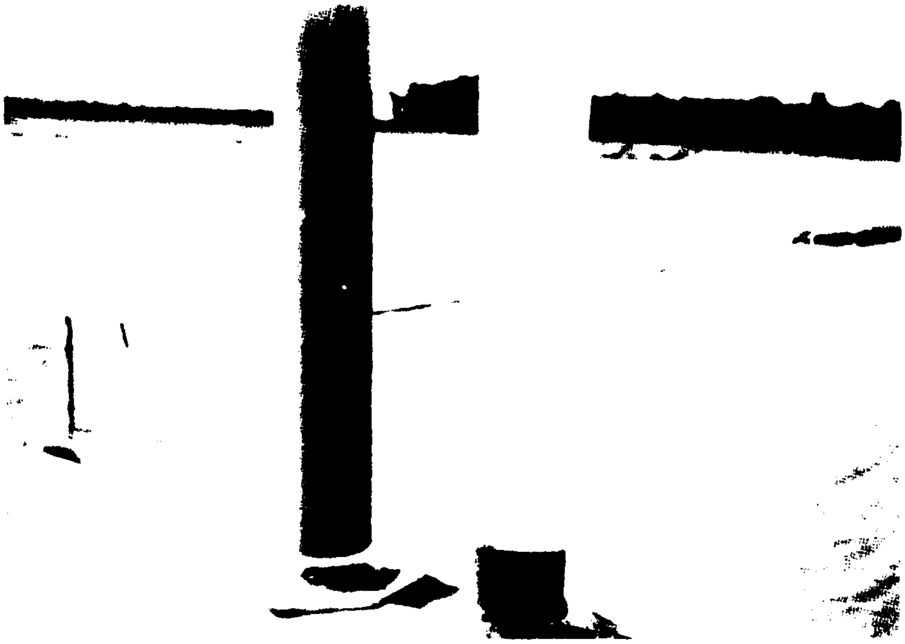


Figure 9. Batch settling tests of untreated and treated effluent samples, Yazoo River field demonstration

Hour	Action	Polymer Dosage mg/ℓ
0	Started polymer pump and hourly samplers	12
2	Dredge stopped	15
4	Stopped polymer pump	0
6	Dredge started	0
8	Started polymer pump	15
10	Adjusted dosage	12
20	Adjusted dosage	15
23.5	Adjusted dosage	24
25	Adjusted dosage	20
27.5	Stopped polymer pump and samplers	0

based on a flow rate of 20 cfs. At this time, the dredge stopped for 4 hr and the flow rate had slowed to about 5 cfs when the dredge started again. Between the second and fourth hours, the polymer dosage averaged about 15 mg/ℓ due to the decreasing flow. Due to the low flow rate, the polymer pumps were turned off for the next 4 hr. Upon resuming operation, the dosage averaged about 15 mg/ℓ for 2 hr at which time the flow over the weir returned to about 20 cfs. Between the tenth and twentieth hours, polymer was fed at a dosage of 12 mg/ℓ. The dosage was then successively increased to 15 mg/ℓ for 3-1/2 hr, to 24 mg/ℓ for 1-1/2 hr, and 20 mg/ℓ for 2-1/2 hr. A total of seven barrels (about 320 gal) of a 50 percent polymer were used in the test.

56. Samples were collected every hour at the primary weir and at both box weirs in the secondary basin. The influent and effluent suspended solids concentrations are plotted as a function of time in Figure 10. The reported effluent concentration is an average of the results at both box weirs. The initial effluent concentration was greater than the influent concentration due to erosion near the outlet weirs.

57. The effluent suspended solids concentration started to decrease after 5 hr and to level off after 19 hr. The dye tracer curve showed that the peak dye concentration arrived at the discharge weirs about 5 hr after injection at the primary weir. The mean retention time was about 7 hr. Therefore, it required about 18 hr to completely flush

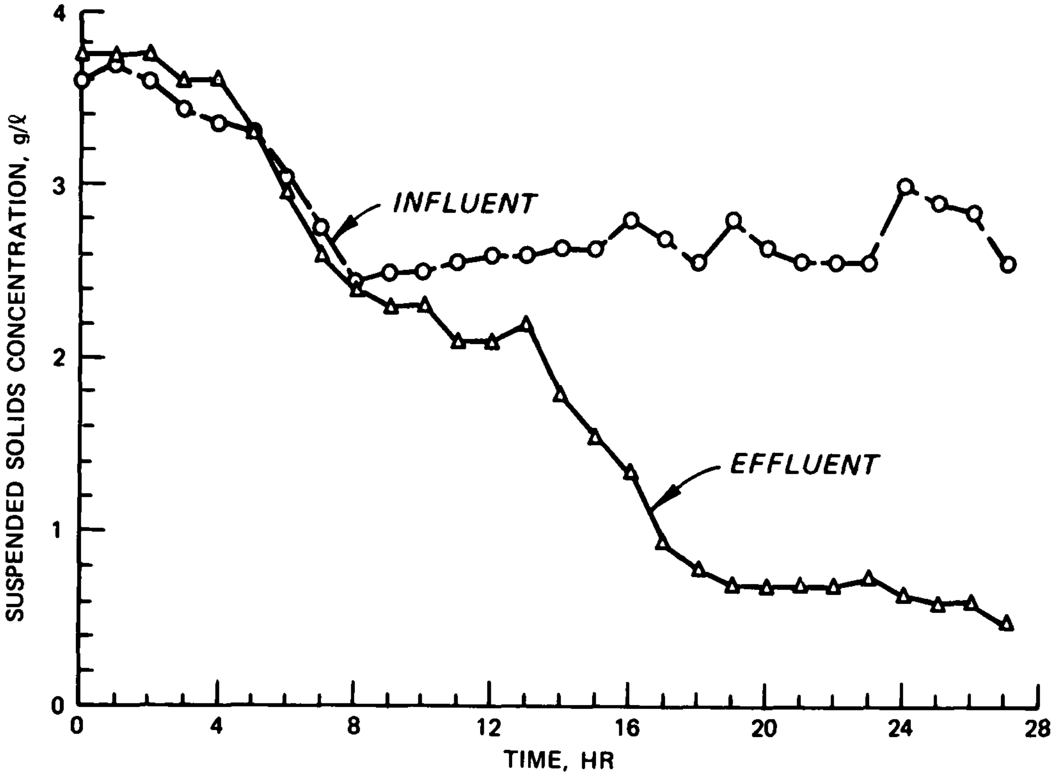


Figure 10. Hourly suspended solids concentrations for first Yazoo River field demonstration

the basin and to reach the steady effluent quality for any level of treatment. The suspended solids concentration decreased steadily until the ninth hour when the concentration increased slightly and then remained nearly constant for 4 hr. This began 5 hr after the polymer addition was stopped and lasted for the same duration as the stoppage. Clearly, it was a result of stoppage. The suspended solids concentration was reduced further between the thirteenth and nineteenth hours. The effluent quality then levelled off until the twenty-fourth hour when the solids level declined slightly. The last samples were collected 27 hr after the start of the test.

58. The data show that the steady-state effluent solids concentration for a 12-mg/ℓ polymer dosage was 650 mg/ℓ. This corresponds to a 77 percent reduction in suspended solids. Data were not taken to determine the suspended solids removal at the higher dosages used at the

end of the tests, but the solids concentration was decreasing at the end. At 8 hr after dosing at 15 mg/ℓ, the suspended solids concentration was 450 mg/ℓ, corresponding to a 83 percent reduction. It is likely that better removals could have been attained if higher dosages had been applied for longer periods and if the secondary basin had been modified to provide more ideal settling conditions.

59. The demonstration was also used to develop operational procedures and to identify operational and design problems. The project demonstrated that reliable power, good equipment, and regular maintenance are needed to ensure good operation. Small portable generators cannot be expected to run for extended periods. The system should be checked periodically and adjusted to account for changing flow rates and influent solids concentration. A better source of dilution water must be used since the water in the primary basin was too dirty and contained dead vegetation that clogged the screened intake and the holes in the injection pipe. Vehicular access must be available to the treatment site. Due to the intermittent operation of the dredge, the polymer feed must be able to operate at very low flows or else the discharge weir must be operable to increase the flow rate or stop the discharge.

Conclusions

60. The following conclusions were drawn:

a. The treatment system was highly effective though the removals were not as great as obtained in the laboratory.

b. The overall design concept was sound.

c. Sufficient energy was available from the difference in elevation between the water surfaces of the two basins to mix the effluent and polymer.

d. Other weir designs may improve the mixing.

e. The secondary basin must be designed to provide better settling conditions.

Second Yazoo River Demonstration

Background

61. The demonstration was performed at containment area No. 3 of Upper Yazoo Project Item 2A-1 near Belzoni, Miss., on 9-12 June 1980

with the support of the Vicksburg District. The containment area layout is shown in Figure 11. The primary area had a surface area of 35 acres and a depth of about 12 ft. An irregularly shaped secondary area was constructed for the demonstration in a depression adjacent to the primary area. The area had a surface area of 1 acre and an average depth of about 4 ft. The outlet from the primary cell was a rectangular fixed crest drop inlet weir structure situated 20 ft into the basin. The structure was 56 ft long and 4 ft wide and constructed of sheet metal except for one 4-ft side that was boarded for use in dewatering. The effluent was discharged from the weir to the secondary cell through a 100-ft-long, 24-in.-diam corrugated metal culvert. The difference in elevation between the water surfaces of the two basins was about 12 ft.

62. An 18-in. hydraulic dredge was widening a channel and pumping the material into the area. The mainly fine-grained dredged material was a freshwater lean sandy silty clay (CL) with low plasticity as was the sediment in the first demonstration. The flow averaged about 25 cfs during the test.

63. This demonstration differed from the first test in three ways. First, the weir structure was not modified to improve mixing. Adequate mixing was available from the 12-ft drop between the areas and the turbulence of the flow through the 100-ft-long corrugated metal culvert. Eliminating the construction of a mixing system greatly reduced the cost of treatment. The only additional construction required for chemical treatment was that of a secondary containment area. Second, the secondary area provided good settling conditions. Finally, the polymer dosages were reduced to lower treatment costs. The demonstration examined the effectiveness of mixing in existing weir structures and of lower polymer dosages with good mixing and settling conditions.

Laboratory results

64. Magnifloc 577C had been selected as the best flocculant for Yazoo River material in the first demonstation and therefore was selected for use in this test. Jar tests were run on 2-g/ℓ suspensions to determine the required polymer dosage and to estimate the achievable reduction in turbidity. The optimum dosage was 6 mg/ℓ, through 4 mg/ℓ

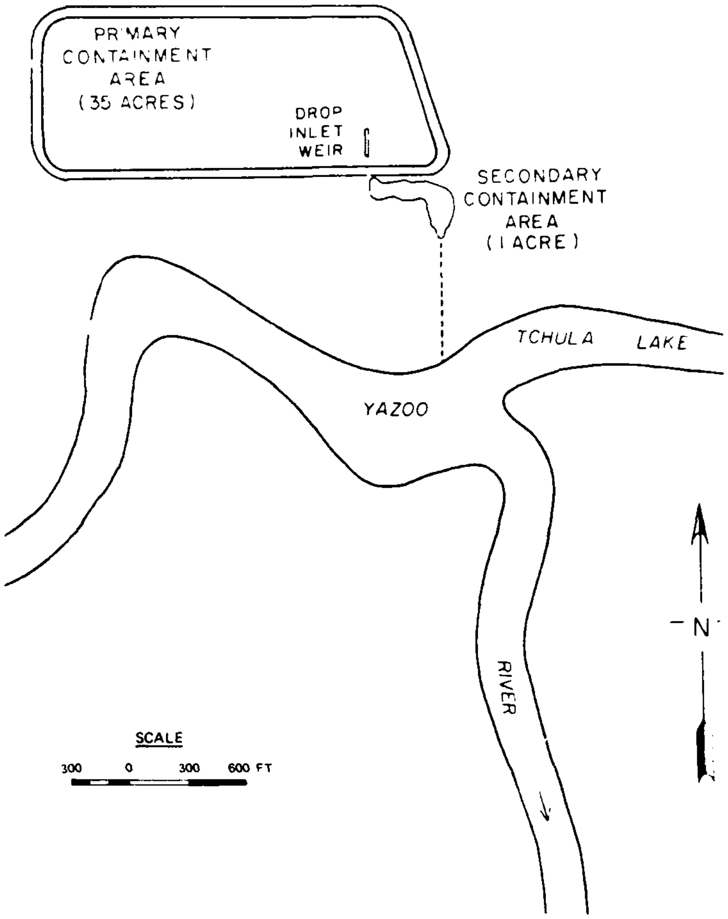


Figure 11. Site layout for second Yazoo River field demonstration

was nearly as effective. The turbidity was reduced to 19 NTU under the excellent mixing and settling conditions available in the laboratory tests. Also, the polymer solution used in these tests was highly diluted and aged. This solution would be slightly more effective than the more concentrated, unaged polymer feed solution used in the field investigation, which does not disperse as uniformly. Based on these considerations, the effluent suspended solids concentration under good field conditions was expected to be reduced to 100 mg/ℓ or less by a well-designed treatment system.

Chemical treatment design

65. The polymer feed system was very similar to the system used in the first demonstration. Prior to the test, the polymer was diluted

to one-third strength and then stored in twelve 55-gal drums. The polymer was fed directly from the drums and diluted in line to a 4 percent or 40-g/ℓ aolution. The pumps, generator, and dilution water intake were the same as described for the first demonstration. The injection rig was a closed loop of 1-in. PVC pipe mounted on the weir box along the weir crest. The polymer was injected down into the weir box through small holes drilled on 2-ft centers along the loop.

66. A mixing system was not designed for this demonstration. The only mixing provided was from the turbulence of the flow through the weir structure. This corresponded to mixing at about a mean velocity gradient G of 950 sec^{-1} for about 13 sec. The weir structure provided excellent rapid mixing but no slow mixing. Slow mixing resulted only from the advective currents in the secondary area.

67. The 1-acre secondary area shown in Figure 11 was used as a settling basin for the treated material. A dye tracer test indicated that the basin provided an average of 60 min of settling time and a minimum of 25 min. The basin had sufficient ponding depth and volume for good settling and solids retention.

Test procedures and results

68. The demonstration was run for 3 days to determine the steady-state suspended solids removal at polymer dosages of 6 and 4 mg/ℓ. The test also examined the variability of the effluent quality with and without treatment. The sampling schedule and test log are presented below. Samples were taken near the primary weir crest and near the outlet

Hour	Action	Polymer Dosage mg/ℓ
0	Started hourly samplers	0
15.6	Started polymer pump	6
16.3	Dredge stopped	8
17.8	Stopped polymer pump	0
22.0	Dredge started	0
22.1	Started polymer pump	6
47.0	Adjusted dosage	4

(Continued)

Hour	Action	Polymer Dosage mg/ℓ
47.3	Generator stopped; polymer pump stopped	0
48.5	Influent sampler stopped	0
50.8	Generator started; polymer pump started	4
56.0	Generator stopped; polymer pump stopped	0
66.0	Stopped effluent sampler	0

from the secondary area every hour during the demonstration. Sample collection started 16 hr prior to the start of treatment to establish the baseline without treatment. The dredge stopped 40 min after polymer addition was initiated. The treatment system was shut down 95 min later due to the reduced flow. The dredge resumed pumping 4 hr and 10 min later and the treatment system and demonstration were then restarted. The stoppage did not affect the results of the demonstration. After 25 hr of dosing at 6 mg/ℓ, the polymer dosage was lowered to 4 mg/ℓ. Shortly thereafter the generator failed and polymer addition was suspended for about 3-1/2 hr. Upon resuming normal operation, polymer was fed at a rate of 4 mg/ℓ until the generator stopped again 6 hr later. Samples were collected for 10 additional hours after treatment terminated.

69. Figure 12 shows secondary containment area influent and effluent suspended solids concentrations as a function of time. The influent and effluent suspended solids concentrations were very similar prior to treatment. Without treatment the secondary area did not provide any additional clarification. The variability in the influent data can be explained by the effects of wind on settling, mixing, and resuspension within the primary containment area. The effluent data were less scattered since the secondary area had a more uniform concentration throughout the basin masking the effects of wind-induced short-circuiting. Also, the area was smaller, which reduced the wind effects.

70. After treatment started at a polymer dosage of 6 mg/ℓ, it took about 3 hr to flush the settling basin and for the effluent suspended solids concentration to level off. During the next 11 hr, the effluent had an average of 62 mg/ℓ suspended solids and a minimum of 32 mg/ℓ. The concentration increased during the next 10 hr of operation

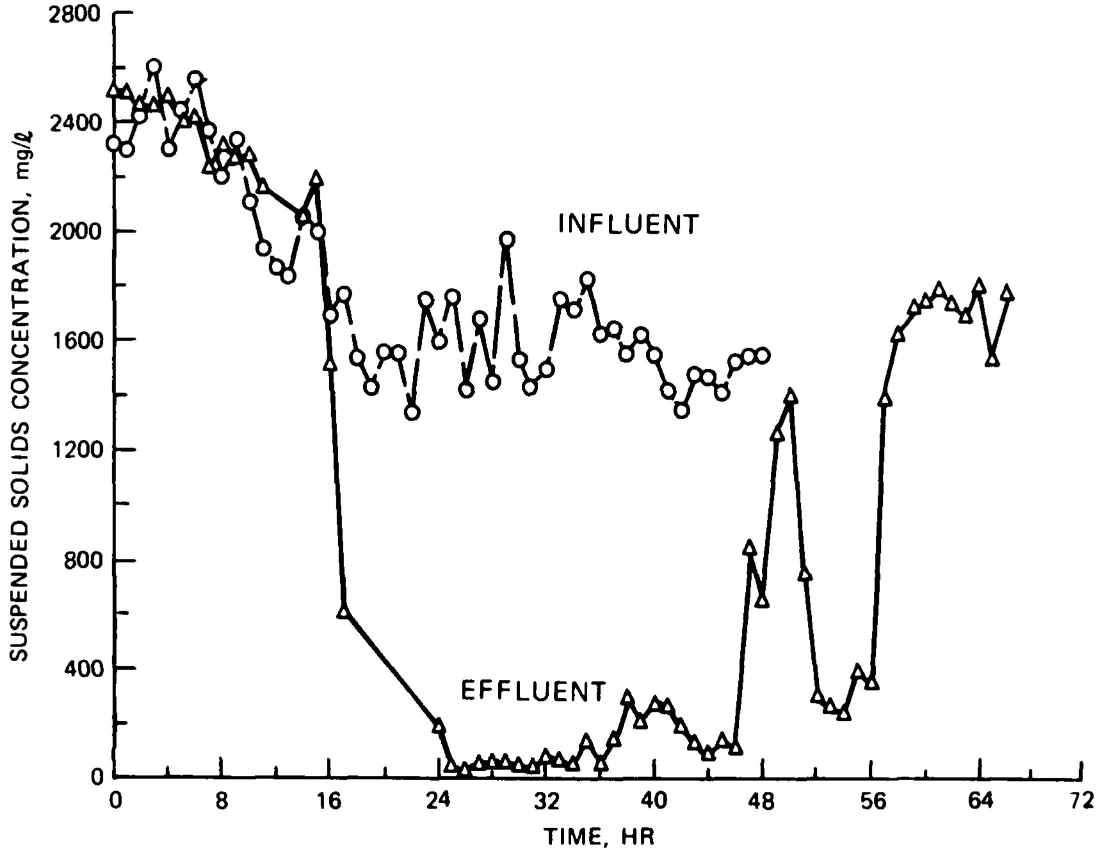


Figure 12. Suspended solids concentrations for second Yazoo River field demonstration

to an average of 189 mg/ℓ. This may have resulted from increased wind or flow rates during the daylight hours or from reduced settling due to the build up of flocculated material in the settling basin or from other unidentified causes.

71. The effluent concentration returned to the level of the influent solids during the 3 hr when the generator failed. After 3 hr of polymer addition at 4 mg/ℓ, the effluent solids concentration levelled off at an average of 315 mg/ℓ for the last 4 hr of treatment. No suspended solids removal was obtained in the secondary basin 2 hr after treatment ended. Influent samples were not collected during the last 18 hr of the demonstration because the sampler battery was too weak to power the sampler.

72. During the period when the polymer dosage was 6 mg/ℓ, the influent averaged 1555 mg/ℓ and the effluent averaged 120 mg/ℓ. This corresponds to a 92 percent removal of suspended solids from the primary effluent by the treatment process. For polymer addition at 4 mg/ℓ, about 80 percent of suspended solids was removed.

Conclusions

73. The treatment system was highly effective, with greater reductions in suspended solids at significantly lower dosages than obtained in the first field test. The better removals resulted from the more intense mixing, greater mixing energy, lower influent suspended solids concentrations, and better settling conditions present in this study. However, these removals were slightly lower than anticipated from the laboratory tests. The required polymer dosage may have been slightly higher than determined by jar tests. More dilute and aged polymer feed solutions like those used in the laboratory tests may have been more effective. Better removals may also have been achieved if slow mixing had been provided. Finally, the demonstration again showed the importance of reliable, rugged equipment.

Yellow Creek Embayment Demonstration

Background

74. A full-scale, long-term demonstration was performed with the support of the Nashville District as part of a maintenance dredging project on the Tennessee-Tombigbee Waterway. The project was located at the Yellow Creek Embayment of Pickwick Reservoir on the Tennessee River near Burnsville, Miss. The layout of the site is shown in Figure 13. The effluent from the primary containment area was treated for the entire duration of the project running from early March 1981 to early June 1981. Chemical treatment was required to meet the strict effluent quality requirements of the project. The maximum allowable effluent turbidity and suspended solids concentration were 100 NTU and 100 mg/ℓ, respectively. In addition, the weekly average effluent turbidity was not to exceed 50 NTU.

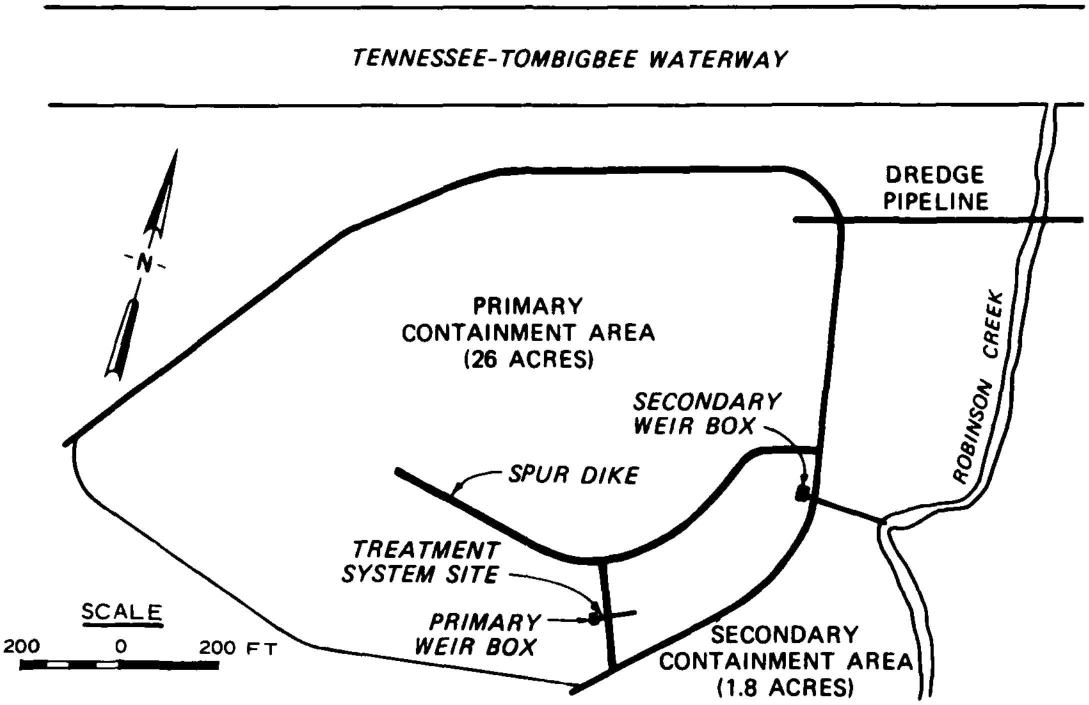


Figure 13. Site layout for Yellow Creek field demonstration

75. Unlike the previous demonstrations, the disposal operation was designed to accomodate full-scale chemical treatment for the entire project. The disposal site was divided into two containment areas, which maximized the utility of the site. The primary and secondary areas had surface areas of about 26 and 1.8 acres and depths of 10 and 8 ft, respectively. Both areas had box weirs with an effective weir length of 18.5 ft. The effluent from the primary cell entered the secondary cell through an 86-ft-long, 54-in.-diam corrugated metal culvert.

76. A 14-in. hydraulic dredge was used for the project. The dredge cleared the embayment of sediment that deposited during construction of the waterway. The material was pumped into the primary containment area through a 6000-ft pipeline at a flow rate of 16 cfs. The dredge operated on an irregular, intermittent basis. The dredged material was predominantly coarse grained and classified as silty sand (SM). About 15 percent of the material was fine grained, and it was material from this fraction that was treated at the primary weir. This material

was classified as a highly plastic clay (CH).

77. The objectives of this demonstration were multifold:

- a. To examine further the available mixing in a conventional weir structure.
- b. To investigate the effect of polymer dosage on effluent quality over a wider range of dosages.
- c. To establish the practical limitations of the treatment system.
- d. To determine the effluent quality that can normally be achieved.
- e. To evaluate the long-term performance of the system.
- f. To acquire long-term operating experience.
- g. To establish operating guidelines.
- h. To determine the storage volume required for flocculated material.
- i. To determine typical chemical treatment costs.

Laboratory results

78. The sediment contained a large fraction of coarse-grained material. Therefore, the samples were sieved through a U.S. Standard No. 40 sieve prior to laboratory testing. Jar tests were then run on 2-g/ℓ suspensions of the sieved material. This material still contained a significant portion of settleable material since 60 percent of the material settled in the test without any polymer addition.

79. Four polymers were screened by jar tests: Hercofloc 863, Magnifloc 577C, Nalcolyte 7103, and Calgon M-502. Each of these polymers had performed well on other freshwater sediments. The jar tests were run using 20 sec of rapid mixing at 100 rpm, 5 min of slow mixing at 20 rpm, and 10 min of settling. Hercofloc 863 was selected as the most cost-effective polymer though all four polymers performed equally well. A 90 percent reduction in solids concentration was achieved with a polymer dosage of 4 to 6 mg/ℓ, and higher removals were obtained with better mixing. The effluent water quality criteria were not met in the tests, but the criteria were not established until after the screening was completed.

Chemical treatment design

80. The polymer feed system was very similar in concept to the system used in the previous two demonstrations. A schematic of the feed system is shown in Figure 14. Initially, full-strength polymer was stored at the site in 55-gal drums. As needed, the polymer was transferred by a barrel pump to two 55-gal feed tanks housed in a small trailer. Thirty-one drums of Hercofloc 863, two drums of Catfloc-T, and twelve drums of Calgon M-502 were fed in this manner. Midway through the project, the feed system was changed to feed Calgon M-502 directly from a bulk storage tank. Approximately 3000 gal was fed from bulk storage.

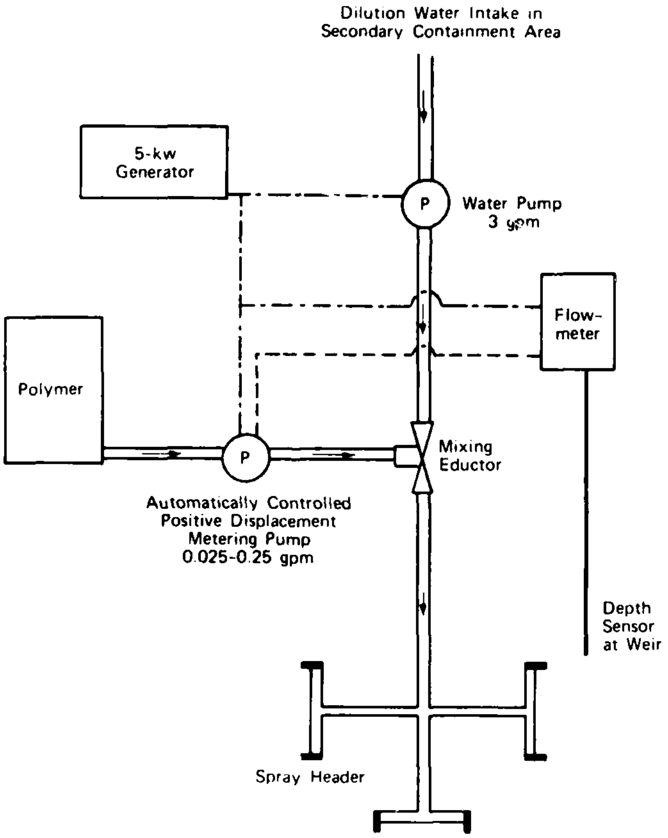


Figure 14. Schematic of polymer feed system for Yellow Creek field demonstration

81. The polymer was fed by a Calgon Moyno Model 2M1B polymer feed pump. The pump speed was automatically proportioned to the flow rate over the weir by a SCR General Electric Statotrol II manual/automatic controller with a remote signal follower. The flow rate signal was fed to the controller by a Sigmamotor LMS-500 flowmeter. This flowmeter sensed the head over the weir and then electronically converted head into flow by using the appropriate weir formula for the weir box that was programmed into the flowmeter.

82. The polymer was diluted with supernatant from the secondary area. The dilution water was pumped at 3.0 gpm by a Calgon Moyno Model 2L3 polymer feed pump from a screened intake suspended near the water surface. The pump was driven by a General Electric 3/4-hp, variable speed, DC motor controlled by a SCR General Electric Statotrol II manual controller. The water and polymer were mixed together by a Calgon bronze water jet eductor as the polymer was being pumped to the injection system. The dilution water and polymer feed lines were constructed of 3/4-in. rubber hose. The polymer feed solution was diluted to about 30 g/ℓ or 3 percent.

83. The injection header was constructed of 1-in. PVC pipe with six nozzles as shown in Figure 15. The header fitted in the weir box about 2 ft above the weir crest. Each nozzle sprayed a stream of polymer across a 3-ft section of weir crest. A strainer was placed in line before the injection header to reduce clogging of the nozzles.

84. A mixing system was not designed for this demonstration. The only mixing provided was from a 2- to 3-ft fall into the weir box and the turbulence of the flow through the weir structure. The frictional losses in the 86-ft-long, 54-in.-diam culvert produced mixing at a mean velocity gradient G of about 25 $\sec^{-1}$ for about 83 sec. The structure provided limited rapid mixing in the weir box and fair slow mixing in the culvert. A 30-in.-diam culvert would have tripled the available mixing.

85. The secondary containment area shown in Figure 13 acted as a settling basin for the treated material. The basin provided an average of 75 min of settling time, but the leading edge of flow reached the

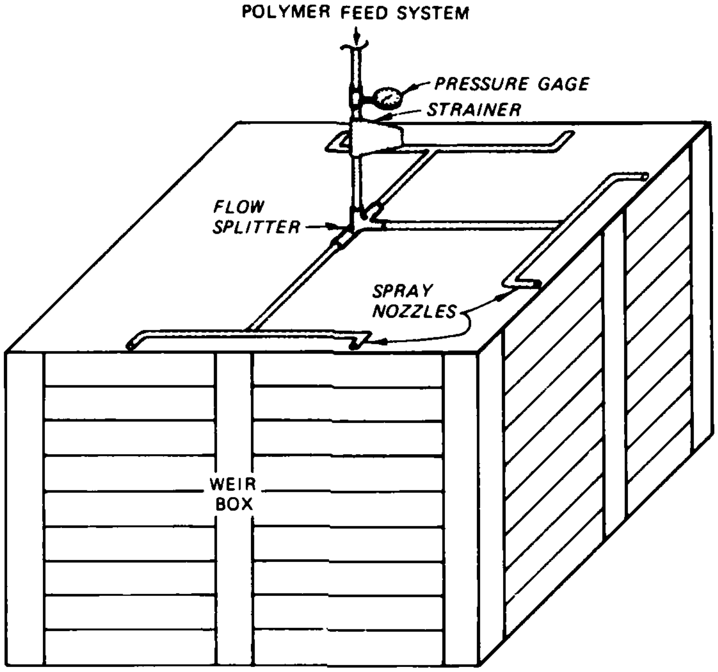


Figure 15. Injection header for Yellow Creek field demonstration

secondary weir in just 13 min. Considerable short-circuiting occurred, but the basin had sufficient volume and detention time for good settling and solids retention. The secondary cell provided enough storage for only half of the flocculated material generated during the project. Therefore, a 6-in., diesel-powered water pump was used periodically to remove settled material from the secondary cell and to place it in the primary cell.

86. The pumps, flowmeter, tools, and supplies were housed in a small trailer parked on the dike between the primary weir box and the inlet to the secondary cell. The trailer also provided shelter for the operators. The equipment and trailer were initially powered by a 5-kw, gasoline-powered Kohler generator. The generator failed after about 6 to 8 weeks of operation, and the power supply was switched to a diesel-powered light plant.

Short-term test procedures and results

87. During the first week of operation, the performance of the treatment system was evaluated under typical operating conditions, and operating guidelines were established. The effects of polymer dosage on turbidity removal were examined to select operating dosages. At the start of operation, Hercofloc 863 was added at a dosage of 13 mg/ℓ for 9 hr to flush the secondary basin and to provide good starting conditions for evaluating the system's performance. Then, the treatment system was run for 6 hr at each of three dosages of Hercofloc 863: 10, 8, and 5 mg/ℓ. During this period, secondary containment area influent and effluent samples were collected hourly to determine the turbidity and suspended solids removals at each dosage. The hourly turbidity values and suspended solids concentrations are reported in Tables 5 and 6, respectively. The dredge stopped operating before a fourth dosage, 13 mg/ℓ, could be examined.

88. The dredge resumed operation 2-1/2 days later. In the meantime, untreated water had leaked through the primary weir box increasing the turbidity of the secondary effluent to 504 NTU and the suspended solids concentration to 440 mg/ℓ. The flow rate of the leakage was too low to provide sufficient mixing to treat the leakage. After the dredge started again, Hercofloc 863 was fed at a rate of 10 mg/ℓ for 15 hr. The dosage was then increased to 13 mg/ℓ for 10 hr. Influent and effluent samples were collected from the secondary containment area every 2 hr to measure the turbidity and suspended solids. The results are presented in Tables 5 and 6, respectively. The suspended solids data are plotted in Figure 16.

89. The effectiveness of a second polymer, Catfloc-T, was examined next. Catfloc-T was fed at 10 mg/ℓ for 5 hr and then at 8 mg/ℓ for 2-1/2 hr. Polymer was not added during the next 5-1/2 hr due to a break in the polymer feed line and the turbidity and suspended solids concentration increased to 870 NTU and 770 mg/ℓ, respectively. The turbidity and suspended solids concentration were measured hourly during this test. The results are presented in Table 7 and the suspended solids data are shown in Figure 16.

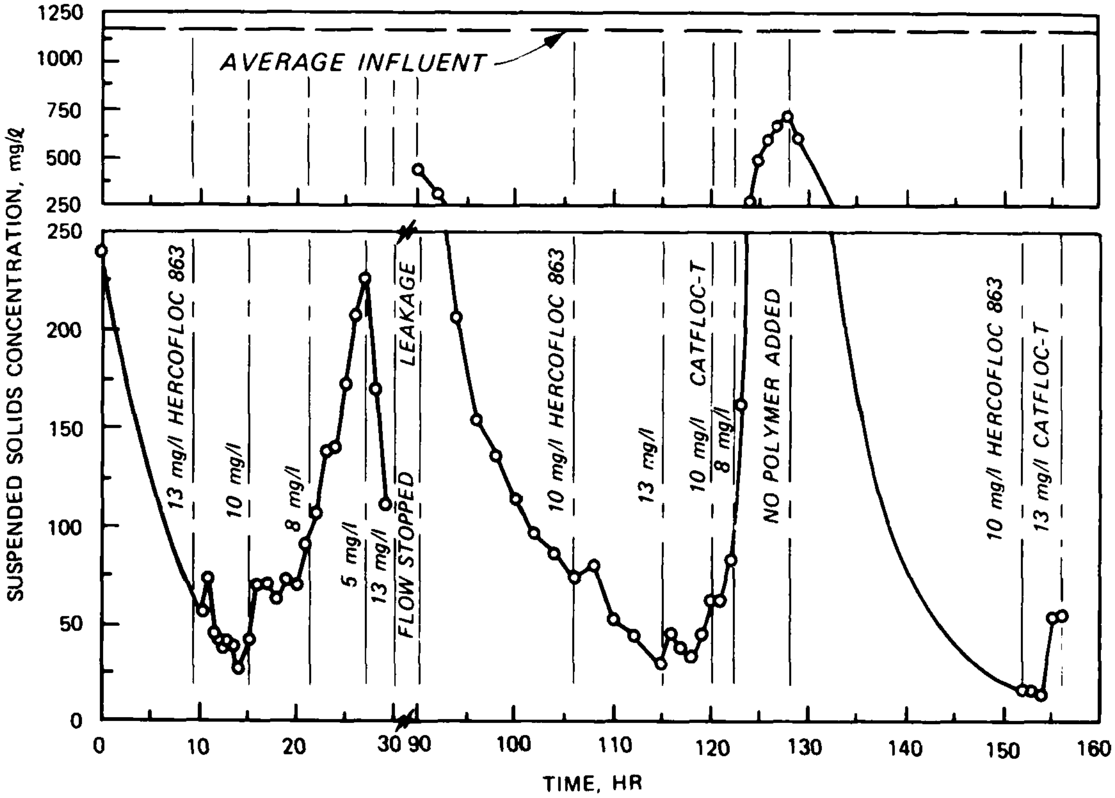


Figure 16. Suspended solids concentrations for Yellow Creek field demonstration

90. Following the break in treatment, the polymer feed was switched back to Hercofloc 863 at 10 mg/ℓ for 24 hr. After 24 hr of continuous operation, the turbidity was reduced to 32 NTU and the suspended solids concentration was lowered to 18 mg/ℓ. The removals improved during continuous operation because a fixed cloud or mass of flocculated material became suspended in the basin. The floc cloud acted as a filter, physically entraining finely suspended material in the large suspended flocs. The large flocs continuously settled from the cloud and were renewed by the treated material entering the cloud. Intermittent operation allowed very fine flocs to be swept out with the effluent since the floc cloud would settle during the downtime and, therefore, would not be able to incorporate fine suspended material in its flocs.

91. The polymer feed was changed to 13 mg/ℓ Catfloc-T following the 24 hr at 10 mg/ℓ Hercofloc 863. This test was the last examining the effect of polymer dosage and type, and ended after 4 hr when the dredge stopped for maintenance. Effluent samples were collected hourly. The results are reported in Table 7 and the suspended solids are plotted in Figure 16.

92. Suspended solids and turbidity results for the tests are summarized below. It was found that: (a) significant removals occurred at all polymer dosages examined, (b) experiments on treated suspensions indicated that better removals could have been obtained with better mixing, (c) Hercofloc 863 performed slightly better than Catfloc-T, (d) the required dosage was 10 mg/ℓ, and (e) treatment at this polymer dosage produced an effluent which, under normal conditions, satisfied the effluent quality requirements.

Polymer Dosage, mg/ℓ	Turbidity Removal, percent	Suspended Solids Removal, percent
	Hercofloc 863	
5	81.8	84.1
8	91.5	93.5
10	95.5	96.9
13	94.6	97.1
	Catfloc-T	
8	91.5	92.1
10	92.9	95.2
13	94.0	95.5

93. The tests showed that the weir structure did not provide sufficient mixing under all flow conditions. Therefore, operating guidelines were established to improve the mixing. Since turbulence through the structure was directly related to flow, the flow was maintained above 6 cfs by adjusting the weir boards when the dredge stopped. When the depth of flow over the weir dropped below 2 in., boards were either

removed to increase the flow rate or added to stop the flow. The rapid mixing in the weir box was also improved by maintaining at least a 2-1/2-ft drop into the box. This plunge at high flow rates provided better turbulence for rapid mixing.

Comparison with laboratory results

94. After completion of the dredging project, laboratory jar tests were run to verify the recommended jar test procedures presented in Part VI of this report using the results of these tests and the short-term field test. The suspensions used in the tests were prepared from settled fine-grained dredged material collected from the primary containment area. Preliminary tests indicated that an increase in dilution or aging of the polymer feed solution from that used in the field test did not alter polymer effectiveness. Therefore, for the sake of convenience, a more dilute, aged polymer solution was used in running the laboratory tests. The solids concentration of the dredged material suspension used in the jar tests was slightly higher than in the field test, but the turbidity was somewhat lower. All other jar tests variables were set to simulate the conditions of the short-term field test.

95. Hercofloc 863 was added to a 1.45-g/ℓ suspension of dosages of 4, 6, 8, 10, and 12 mg/ℓ. Samples were collected following 10 and 75 min of settling and were analyzed for turbidity and suspended solids. Ten minutes represented the minimum time required for settling and 75 min was the mean residence time of the secondary containment area. The initial turbidity was 850 NTU. The results of the verification jar test are listed in Table 8. As in the field test, significant removals were obtained at all polymer dosages examined. The removals following 75 min of settling were only slightly higher than those following 10 min of settling. The suspended solids concentrations and removals for 10 min of settling were very similar to the values obtained in the field test. The turbidity values for 10 min of settling were also very similar to the field test results, but the removals were somewhat lower since the initial turbidity was lower. The turbidity removals for 75 min of settling were closer to the removals obtained in the field test. The results indicate that the laboratory procedures presented in

Part VI simulate the field results very well and are valid.

Long-term operation

96. The long-term operation of the treatment system was conducted by Nashville District personnel assigned to the Burnsville Resident Engineer's office. Following 2 days of training, construction inspectors ran the system for the remaining 1200 hr of production according to the guidelines established during initial testing. The flocculant dosage was set at 10 mg/ℓ for the entire project. The turbidity of the effluent was measured one or two times during each day of operation.

97. The turbidity of the influent to the secondary containment area varied considerably during the project. The frequency distribution is shown in Figure 17. The mean and standard deviation were 1860 and 630 NTU, respectively. The highest turbidity was 3330 NTU and occurred near the end of the project under windy conditions. The lowest value, 640 NTU, was observed following a prolonged period of dredge downtime and intermittent dredging.

98. The secondary effluent turbidity data for the long-term operation are summarized in the histogram shown in Figure 18. The frequency distribution was skewed to the right, having a mode of 35 NTU, a median of 54 NTU, and a mean of 73 NTU with a standard deviation of 60 NTU. The average turbidity reduction by chemical treatment over the duration of the project was 96 percent. The influent and effluent turbidity data are plotted for the duration of the project in Figure 19.

99. The treatment system performed very well, but the effluent turbidity varied greatly. Twenty percent of the observations were abnormally high, greater than 100 NTU. The operating log book was examined to determine the cause, if any, of the higher effluent turbidity for the twenty highest observations. Eleven of these cases resulted from leakage through the system while the dredge was down, and therefore represented only a very small portion of the total effluent volume. The primary weir box should have been sealed to prevent this leakage flow, which was too low to treat. Four of these cases were caused by equipment failure: three due to blown fuses in the controllers, and the other due to polymer feed difficulties. The portable gas-driven generators

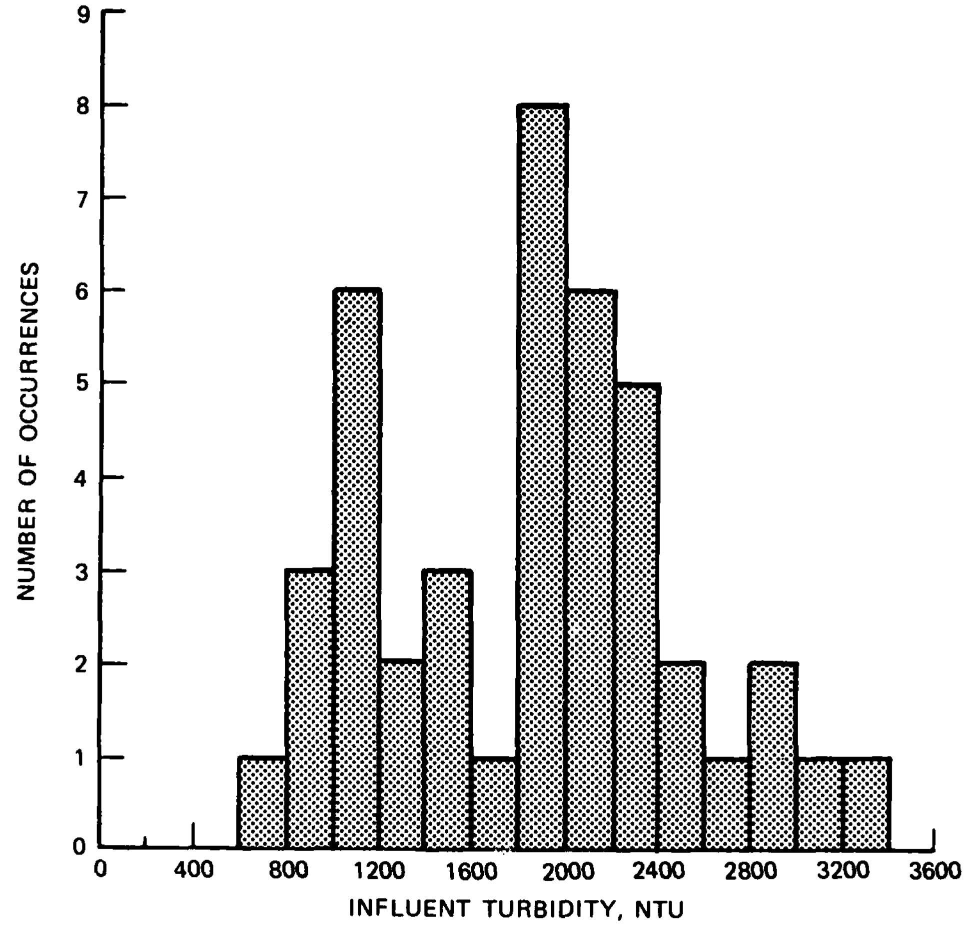


Figure 17. Histogram of turbidity entering the secondary containment area, Yellow Creek field demonstration

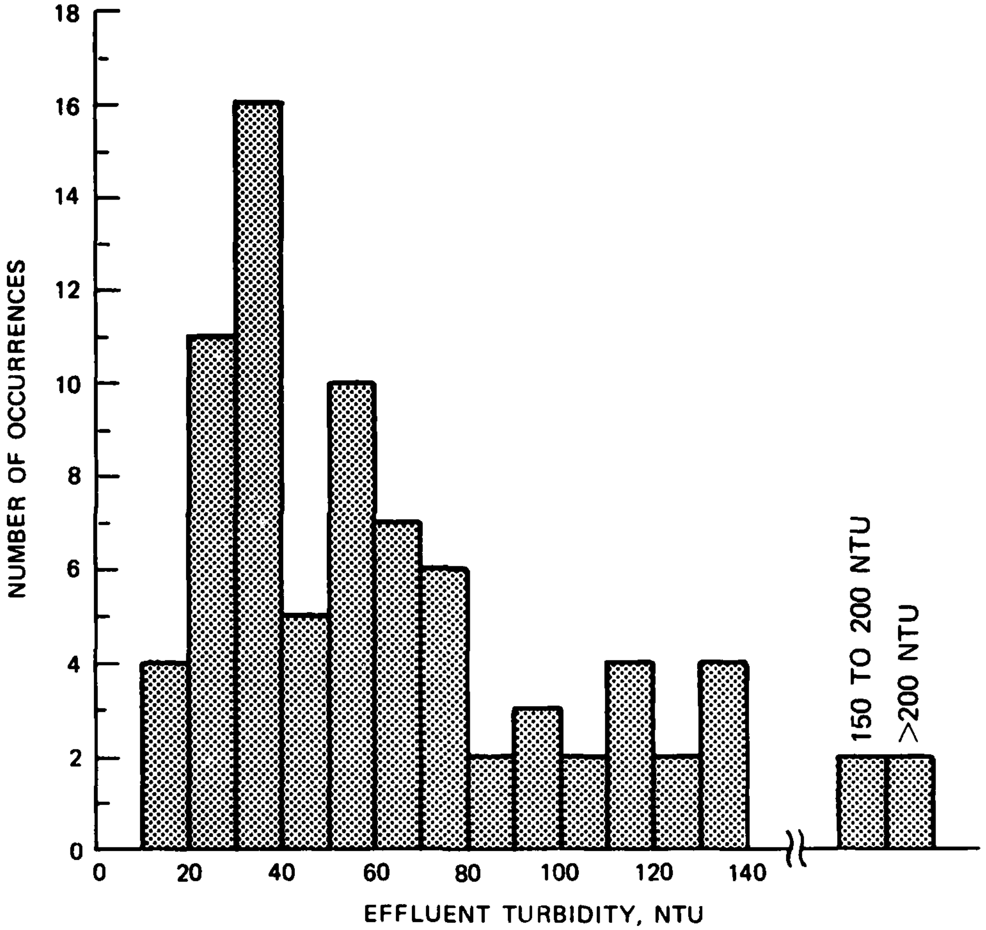


Figure 18. Histogram of secondary effluent turbidity, Yellow Creek field demonstration

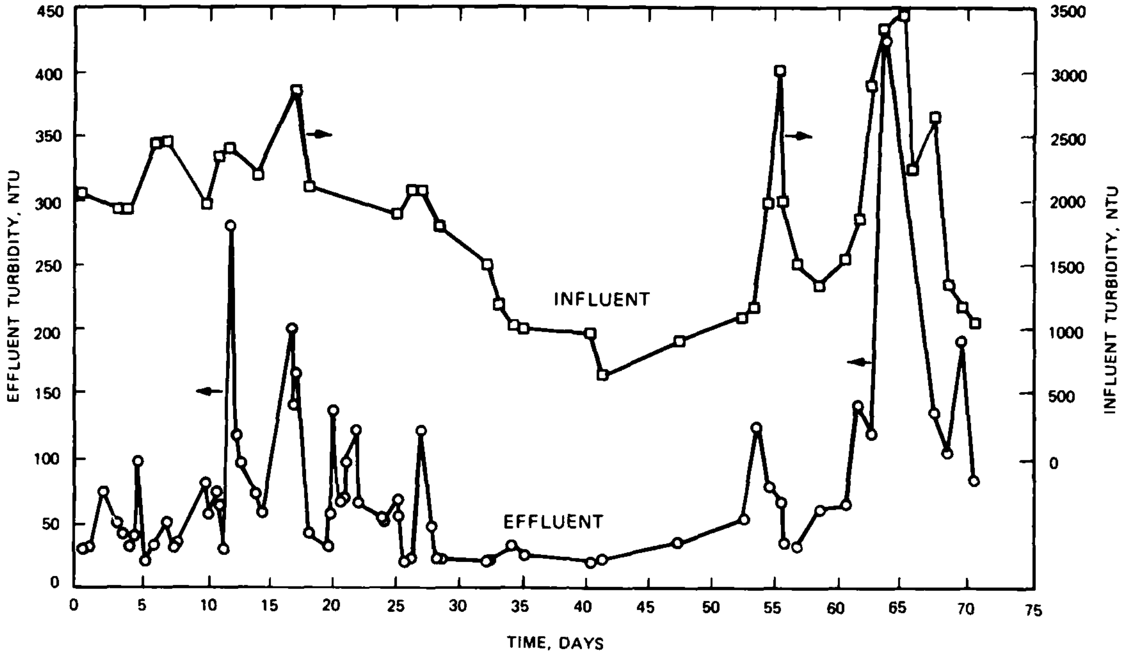


Figure 19. Turbidity data for long-term Yellow Creek field demonstration

provided numerous problems and were not reliable for continuous operation. The generators did not produce constant 115-v, 60-Hz electricity. They often sent surges of greater voltages, which eventually blew the surge protecting fuses on all of the controllers. The polymer feed problem resulted from inadequate pressure at the polymer pump inlet. Consequently, the pump drew in air and pumped polymer at a rate of only 4 mg/ℓ. This occurred when the bulk feed tank was nearly empty, which resulted in an inadequate head to overcome frictional losses caused by the long feed line from the tank to the pump and by the higher viscosity of Calgon M-502. Three of the remaining five high observations resulted from inadequate ponding in the secondary basin after the treated settled material started to accumulate. After raising the water level in the secondary cell, the turbidity returned to the normal range. Subsequently, the settled material was pumped periodically from the basin to prevent reoccurrence of this problem. Finally, the last two cases resulted from inadequate polymer dosage due to unusually high influent turbidity.

100. The long-term operation provided valuable experience for the design and operation of chemical treatment systems. The treatment system performed very well, but the equipment was somewhat unreliable. The system needed to be checked every hour since small problems would appear periodically. For example, the spray nozzles or dilution water intake would clog, the generator would stop, a fuse would blow in the controllers, or a pulley belt would start slipping. The system needed to be as foolproof as possible. The operation was simple, but, since problems did occur, it was important that the operators understood the system, the treatment mechanism, and the effects of all variables. Common sense, initiative, and some mechanical and physical ability were the chief attributes required for operators. Finally, the equipment should have backup systems and should be quickly repairable near the job site.

Storage of flocculated material

101. Near the end of the dredging project, the solids concentration was measured as a function of depth at five locations throughout the secondary cell. The locations, A through E, are shown in Figure 20. Samples were collected at 1/2-ft intervals. The results are given in Table 9. Settled material had been pumped from the area several times before, the most recent time being 2 weeks prior to the sampling.

102. Recently settled flocculated material near the interface between the supernatant and settled material had a solids concentration of about 50 g/ℓ. The concentration increased with increasing depth at a rate of about 25 g/ℓ/ft. Material in the bottom foot, which had been compacting or consolidating for about 3 months, had a solids concentration of about 190 g/ℓ. The average concentration of settled material, which had a residence time of about 3 weeks, was about 100 g/ℓ. Chemically treated fine-grained material did not settle nearly as densely as untreated fine-grained material, which generally consolidates to a concentration greater than 300 g/ℓ.

Conclusions

103. The following conclusions were drawn:

a. The treatment system was highly effective, reducing the effluent turbidity by an average of 96 percent throughout the entire duration of the project.

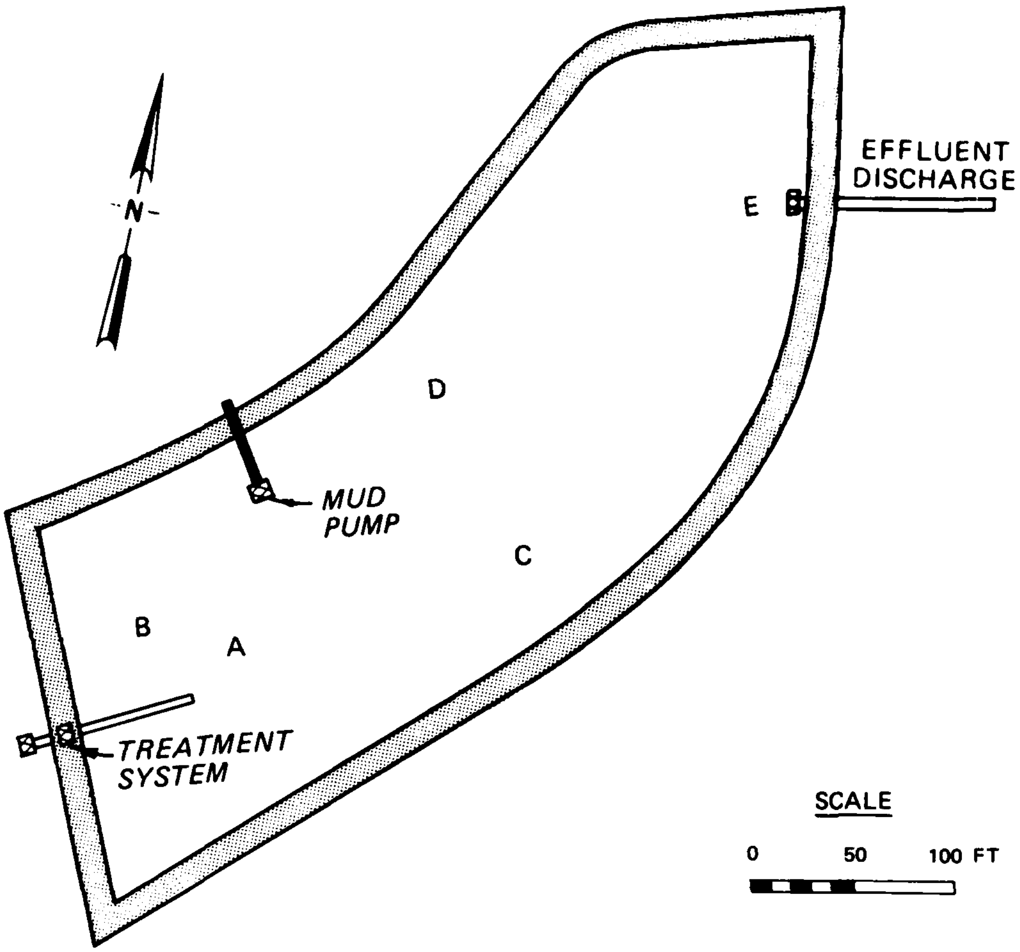


Figure 20. Sampling locations in secondary containment area, Yellow Creek field demonstration

b. The required 10-mg/ℓ polymer feed dosage was higher than determined in the laboratory; but, at the site, the concentration of fine-grained material to be treated was greater, less mixing was available, and better effluent quality was achieved.

c. The treatment system was capable of producing an effluent with an average turbidity near 50 NTU under normal operation.

d. The system performed best during continuous operation.

e. Improved treatment efficiency would have resulted if the weir structure had been designed to prevent leakage and to provide better mixing.

f. A reliable power supply must be acquired.

g. The treatment operation required a capable, trained operator to check the system regularly; to operate and maintain the equipment; and to solve problems when they appeared.

Costs of Chemical Treatment Demonstrations

104. The demonstrations provided information for estimating the costs of future chemical treatment projects. Major costs were identified and quantified to the extent possible. Costs can be categorized as engineering and design, nonexpendable equipment, construction, expendable supplies, operating labor, and repairs. Some of these costs are independent of the project; others are a function of project duration and/or volume to be dredged.

105. The first two demonstrations provided limited data due to the brevity of the tests. Their costs are summarized in Table 10. The total cost excluding nonexpendable equipment and construction costs was about \$80/hr or \$0.25/yd^3 of in situ material dredged for the first demonstration and about \$55/hr or \$0.14/yd^3 for the second demonstration, assuming that production was continuous and directly related to flow.

106. The long-term demonstration provided the best information on costs. The costs are listed in Table 11. Excluding construction, the cost averaged \$0.20/yd^3 or about \$55/hr of production. The cost breakdown is given in Table 12. Labor and polymer costs were the main components of the recorded costs for treatment, but the unknown construction costs might also be significant.

PART V: EVALUATION OF PIPELINE INJECTION TREATMENT METHOD

107. Only preliminary laboratory and field studies have been performed to evaluate the feasibility of injecting polymer into the dredge pipeline to clarify dredged material slurries. Laboratory tests were run on 100- and 120-g/ℓ slurries of settled dredged material from a containment area along the Yazoo River near Belzoni, Miss. The effects of polymer addition on the settling rate of the material and on the solids concentration of the supernatant were examined. The field study was performed at the dredging site near Burnsville, Miss., described in Part IV. The study examined the effects of polymer dosage, dredged material variability, and injection location on the turbidity and solids concentration reduction achieved during 10 min of settling. The studies provided an estimate of the required polymer dosage but did not determine the ultimate effect of polymer injection at a given dosage on effluent quality from a containment area, ponding volume required for effective sedimentation, and storage requirements.

Laboratory Study

Background

108. Six 5-gal buckets of settled dredged material were collected from an Upper Yazoo Project containment area near Belzoni, Miss. Two buckets of coarse material were grabbed near the inlet of the basin and four buckets of fine material were collected near the weir. The fine-grained material was classified as a silty clay (CL) with low plasticity. The material was blended together to form mixtures of 50 percent fine and 50 percent coarse material, 75 percent fine and 25 percent coarse, and 100 percent fines. These mixtures were diluted with tap water to produce the 100- and 120-g/ℓ slurries used in the tests.

Test procedures

109. Six 1-ℓ samples of each slurry were placed on a Phipps and Bird multiple mixer. The samples were mixed at 100 rpm for 1 min to

ensure that the slurry was homogeneously suspended. Magnifloc 577C was then added to the samples. The polymer dosages for the series were 0, 2, 4, 8, 16, and 32 mg/ℓ. Next, the 120-g/ℓ slurries were mixed at 100 rpm for 10 sec and at 20 rpm for 5 min; the 100-g/ℓ slurries were mixed at about 150 rpm for 10 sec and at 50 rpm for 5 min. At this time the samples were poured into 1-ℓ graduated cylinders and allowed to settle. After the material started settling, the height of the interface was read periodically to determine the settling rate. Also, samples were collected at the midpoint of the supernatant to determine the suspended solids removal. The mixing intensity used in these tests was too low to be representative of conditions in a dredge pipeline.

Results

110. Jar tests on 2-g/ℓ suspensions of the three mixtures indicated that Magnifloc 577C was very effective. Dosages of 8, 6, and 4 mg/ℓ performed best on suspensions of 100, 75, and 50 percent fines, respectively. The dosage was directly proportional to the percent fines in this concentration range.

111. The settling data for the three 120-g/ℓ slurries are listed in Table 13. The polymer dosages examined in this test did not affect the settling rate of the slurries. At each time period the interface height of each sample at the various dosages was very similar. The settling rate and the concentration of the settled material decreased with increasing concentration of fines in the slurries.

112. The solids concentration of the supernatant was measured only for the slurry with 50 percent fines. The results are given in Table 14. At each time period except the last, the supernatant concentration was about the same at all polymer dosages examined. After 5-1/2 hr of settling, the solids concentration was reduced to 40 mg/ℓ at polymer dosages of 16 and 32 mg/ℓ while at lower dosages the concentration was reduced to 280 mg/ℓ. This concentration was very low for freshwater clay sediments in the absence of polymer. The polymer at dosages up to 32 mg/ℓ did not significantly clarify the supernatant of 120-g/ℓ slurries.

113. The results of the settling tests on 100-g/ℓ slurries were

very similar. The interface heights are given as a function of time in Table 15. After 5 hr of settling, the slurries at all polymer dosages had settled the same amount and continued to settle uniformly throughout the remainder of the tests. Polymer at dosages up to 32 mg/ℓ had no apparent effect on the settling rate or on the concentration of settled material for slurries containing large quantities of fines.

114. The supernatant solids concentrations of the three slurries are given as a function of settling time and polymer dosage in Table 16. The solids concentration decreased with decreasing concentration of fines in the slurry, and increasing settling time and polymer dosage. The average percent reductions of suspended solids in the 100-g/ℓ slurry relative to the control at the same time period are listed in Table 17. These reductions are the percent removal due to polymer addition relative to the solids concentration remaining in the supernatant of the slurry without polymer addition. As an example, the relative percent removal for the 100 percent fine-grained, 100-g/ℓ slurry with 16 mg/ℓ at 3.4 hr is computed as follows:

$$\frac{(6.45 - 4.77)\text{g/}\ell \times 100 \text{ percent}}{6.45 \text{ g/}\ell} = 26 \text{ percent}$$

The computed values at all time periods for the sample were averaged together and these averaged values are reported in Table 17. The results indicate that the effectiveness of a polymer dosage decreased as the concentration of fines in the slurry increased. The removals increased with increasing polymer dosage but less than proportionately. At 32 mg/ℓ, the maximum removal was only 42 percent. Therefore, very high dosages (100 mg/ℓ or more) would be needed to produce excellent results in this type of test.

115. In the jar tests on 2-g/ℓ suspensions, it required about 3 mg of polymer per gram of fines to achieve excellent removals. The maximum dosing rate used in these tests was about 0.64 mg/g or one fifth of the rate required for suspensions of low solids concentration. If proportional rates were required at all sediment concentrations, a 100-g/ℓ slurry of fines would require 300 mg/ℓ of polymer. It appeared

that the dosage requirement in terms of milligrams of polymer per gram of material decreased with increasing slurry concentration but not enough to keep the required polymer dosage low.

Conclusions

116. Polymer dosages up to 32 mg/ℓ did not increase the settling rate or density of freshly settled material. The polymer did slightly enhance the clarity of the supernatant. The suspended solids concentration increased as the concentration of fines increased. The required polymer dosage was related to the quantity of clay in the slurry. The results of these experiments indicated that very high dosages would be needed to treat slurries of fine-grained material. However, field conditions would differ considerably from the conditions used in those tests in that more mixing and longer settling time would be provided in the field. Pipeline injection may be a viable alternative only for sediments with a very small clay fraction.

Field Study

Background

117. The study was performed at a dredging site on the Tennessee-Tombigbee Waterway near Burnsville, Miss. The location, dredging operation, and dredged material are described in detail in Part IV. The material was 10 to 15 percent fine grained and contained only about 3 to 7 percent clays. The slurry concentration was about 200 g/ℓ. This material was quite different from the material used in the laboratory study described earlier. The flow rate was 16 cfs.

118. The purpose of the test was to determine the feasibility of pipeline injection under typical field conditions. The effects of the variability of the flow rate and influent solids concentration on the effectiveness of a polymer dosage were examined. Polymer was injected at two locations along the pipeline to investigate the effects of mixing time on polymer effectiveness. The effects of polymer dosage on the removal of suspended solids and turbidity were examined to determine likely polymer dosage requirements for pipeline injection.

Laboratory results

119. Jar tests were run on 2-g/ℓ suspensions of about 50 percent fines. Detailed results are given in Part IV. Excellent suspended solids removal was obtained with a 4-mg/ℓ dosage or a dosage of 4 mg of polymer per gram of fines. Therefore, the required dosage for the slurry would proportionately range from about 24 to 100 mg/ℓ.

Chemical treatment system

120. Full-strength polymer was stored in two 55-gal drums and fed directly to the pipeline without dilution. The polymer was pumped by a Calgon Moyno Model 2M1 polymer feed pump and pump speed was controlled by a SCR General Electric Statotrol II manual controller. The polymer was fed through 3/4-in.-diam rubber hoses. The hose was attached to a valved nipple welded to the pipeline. Two nipples were provided: one 20 ft upstream of the booster pump located 6000 ft from the discharge point, and the other 4000 ft from the discharge point. The injection locations are shown in Figure 21 and a schematic of the feed system is shown in Figure 22. Power was supplied by a 3-kw, portable, gasoline-powered generator.

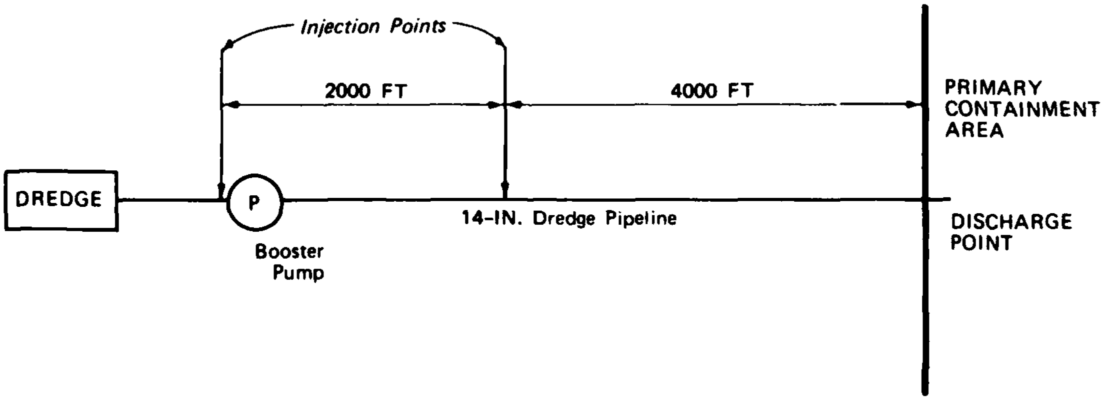


Figure 21. Polymer injection locations, Yellow Creek pipeline injection field study

Test procedures

121. Three polymer dosages were examined at each of the two injection sites: 13, 26, and 39 mg/ℓ. These dosages assumed a constant flow of 16 cfs. The polymer flow rate was constant, but the dredge

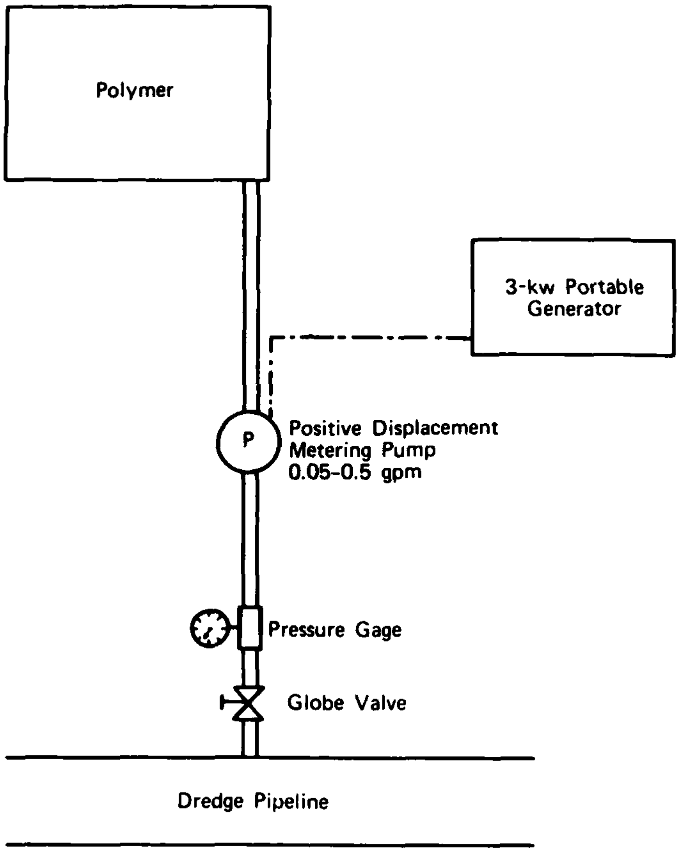


Figure 22. Schematic of polymer injection system, Yellow Creek field study

discharge rate may have varied throughout the test.

122. At the start of testing at each dosage, a sample without polymer was collected from the end of the dredge pipeline using a pipeline sampler. The sand was allowed to settle while the fine-grained material was suspended by stirring. Then, the fines were poured into a 1-ℓ graduated cylinder and a sample was collected to determine the turbidity and solids concentration of the suspension. The suspension in the column was allowed to settle quiescently for 10 min. A sample of the supernatant was decanted into a sample cup for measurements of the turbidity and solids concentration. These latter measurements were termed "nonsettleable" turbidity and solids concentration. The interface height, if present, of the settling material in the cylinder was

read every 1 to 2 min until the settling rate had decreased considerably.

123. Polymer was then injected into the dredge pipeline at a constant rate for about 40 min. It took less than 7 min for the polymer to travel through the pipeline and reach the discharge point. A sample was collected after 15 min of polymer injection and then two or three more samples at intervals of 7 to 10 min. Each sample was treated in the same manner as described above for the sample without polymer. After the last sample was taken, the treatment system was shut off for 20 min to flush the polymer from the pipeline between testing of other dosages. The same procedures were used for all three dosages at both injection sites.

Results and discussion

124. The turbidity and suspended solids concentration of the samples before and after settling for 10 min are given in Table 18 along with the removal percentages. The influent concentration of fines varied greatly and, therefore, the removals at each dosage and at the two injection points varied greatly. In the absence of polymer, approximately 35 percent of the turbidity and 75 percent of the suspended solids concentration were removed during the 10 min of settling.

125. Based on the results in the absence of polymer, the nonsettleable influent solids concentration was set to equal 25 percent of influent solids and the nonsettleable turbidity was estimated to equal 65 percent of the influent turbidity. The removals of nonsettleable solids and turbidity are given in Tables 19 and 20, respectively. The actual polymer loading applied to each sample calculated in terms of milligrams of polymer per gram of nonsettleable solids and milligrams of polymer per 1000 NTU of nonsettleable turbidity are also listed in these tables. These definitions and units of polymer loading are comparable to the loadings expressed in the laboratory study as milligrams of polymer per gram of fines.

126. The percent removal of nonsettleable solids at both injection points was plotted as a function of polymer loading in Figure 23 and the nonsettleable turbidity removal in Figure 24. The removal increased with increasing polymer loading. Polymer injection at 4000 ft

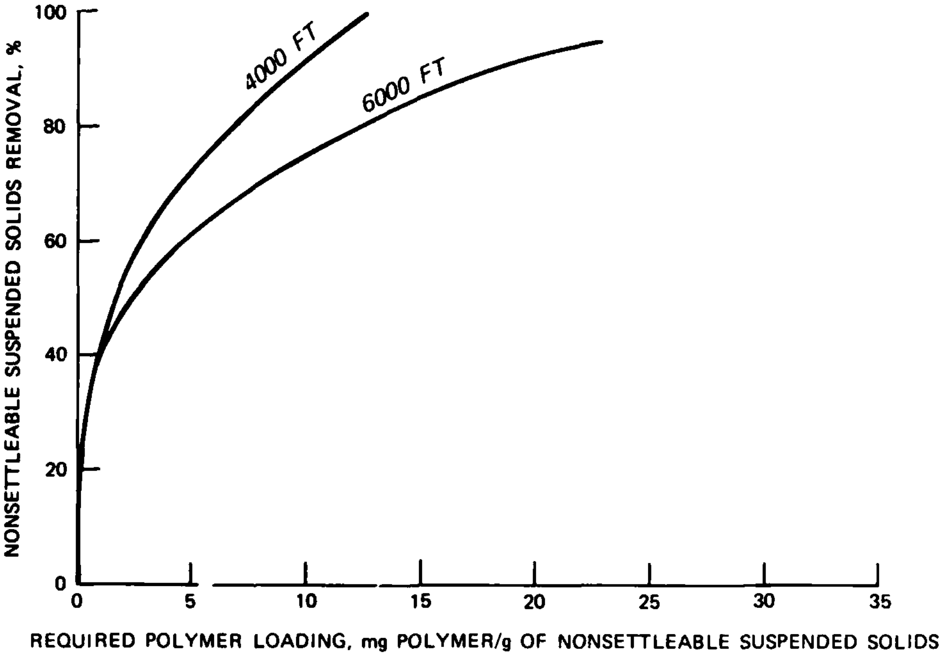


Figure 23. Polymer loading for suspended solids removal by pipeline injection, Yellow Creek field study

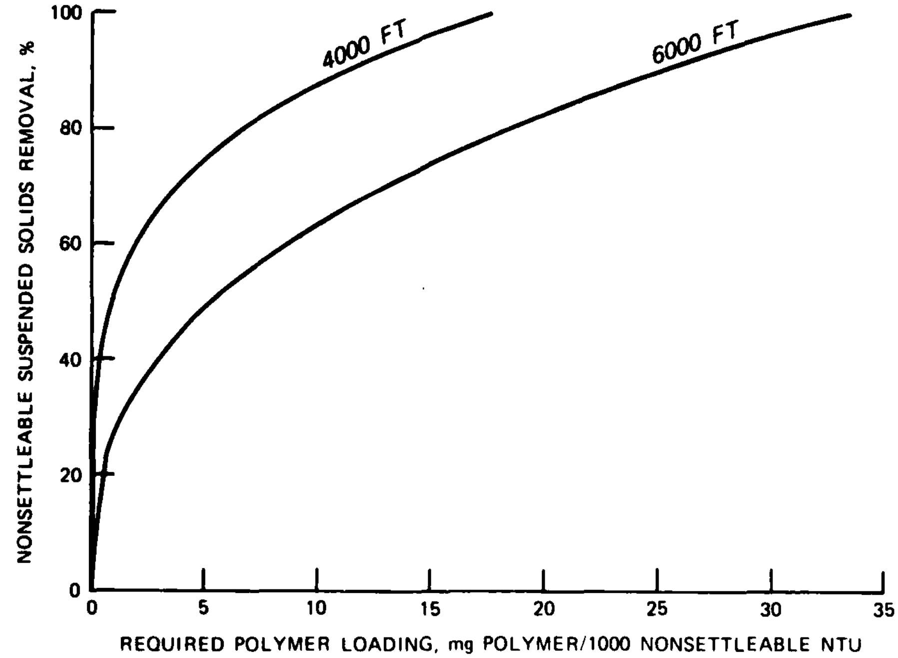


Figure 24. Polymer loading for turbidity removal by pipeline injection, Yellow Creek field study

from the discharge point was more effective than injection before the booster pump at 6000 ft from the discharge point. The mixing intensity available in the pipeline corresponds to a mean velocity gradient G of 900 sec^{-1}. The total mixing expressed in terms of nondimensional product of mixing intensity and duration Gt was 240,000 at 4,000 ft and 360,000 at 6,000 ft. The optimal mixing for flocculation by polymer is generally about 30,000, which corresponds to injection at 500 ft from the discharge point. Better removals would be expected if the injection location was optimized.

127. A comparison of polymer dosage requirements between the removal of turbidity and solids and between the two injection sites is presented below. One milligram of polymer per 1000 nonsettleable NTU is equivalent to about 0.8 mg of polymer per gram of nonsettleable solids. At 4000 ft the removals of suspended solids and turbidity were equal at a given dosage. At 6000 ft the removal of solids was greater than the turbidity removal at the same dosages. Under optimal mixing, the turbidity and suspended solids removals would be similar to each other. The required polymer dosage to achieve a given removal by injection at 4000 ft was about half as large as the dosage required for injection at 6000 ft.

	Required Polymer Loading at Injection Location	
Nonsettleable Solids Removal, %	4000 ft	6000 ft
60	2.8	4.6
80	6.8	12.4
100	12.7	26.3
Nonsettleable Turbidity Removal, %		
60	2.0	8.6
80	6.8	18.5
100	17.7	33.4

128. The curves in Figures 23 and 24 showed that the increase in removal decreased as the dosage increased. This type of diminishing

return is typical of flocculation by polymers and leads to high dosage requirements for large removals. This can also be somewhat favorable considering the variability of the influent because the removal percentages would not decrease as much for an increase in the influent solids and turbidity. The effects of this type of diminishing return decreased with better mixing.

129. For this project, the required polymer dosage for excellent removals with good mixing appeared to be about 4 mg of polymer per gram of nonsettleable solids or 5 mg of polymer per 1000 NTU of nonsettleable turbidity. This polymer loading rate is the same as required to treat the effluent at the primary weir. In the field demonstration, the effluent averaged 1900 NTU and the required polymer dosage was 10 mg/ℓ. In terms of milligrams per litre, the required pipeline injection dosage at the optimum location would have ranged from 8 to 50 mg/ℓ due to the variability of the influent. The dosage for average conditions would have been 20 mg/ℓ. If fed continuously at 20 mg/ℓ, the removal would have ranged from nearly complete removal to about 70 percent. Of course, the ultimate removal that would be realized at the primary weir is unknown since pipeline injection has never been tested long enough to determine its effect on containment area effluent quality.

130. The pipeline injection treatment system was simple and required little labor to maintain and operate since it had few components. The most difficult part of the operation would be selecting the polymer dosage. Immediate results can be seen at the discharge point but it would take at least a day to determine the effects at the primary weir. The effluent quality is particularly difficult to predict due to the variability of the influent.

Conclusions

131. The following conclusions were drawn:

a. Full-strength liquid polymer was injected into the dredge pipeline and good removals were obtained at moderate dosages for this dredged material which had only a very small fraction of fines.

b. Better removals might have been observed if the injection point was located closer to the discharge point since the mixing was excessive.

c. The required polymer dosage was proportional to the concentration of fines in the dredged slurry.

d. The required polymer loading rate in milligrams per gram or milligrams per 1000 NTU was the same as needed to treat effluents at the primary weir.

e. The dosage in milligrams per litre was considerably greater for pipeline injection than for effluent treatment because the concentration of fines was larger in the pipeline.

f. The effects of injecting polymer into the dredge pipeline on effluent quality, storage requirements, and containment area design parameters for water quality are still untested and unknown.

PART VI: DESIGN AND OPERATING GUIDELINES FOR TREATING DREDGED MATERIAL EFFLUENTS

132. This section of the report presents procedures and guidance for designing and operating a chemical treatment system to clarify the effluent from a dredged material containment area. Laboratory procedures are presented to prepare representative suspensions, to select the best polymer and dosage, and to evaluate the effects of mixing and variable solids concentration on the effluent quality. Then, procedures are given to design the polymer feed system including storage, dilution, and injection; to design the weir and discharge culvert to provide adequate mixing and minimize operating problems; and to design the secondary basin to provide good settling and storage for treated material. Guidance for operating the treatment system is given to maintain good performance throughout the dredging project. These procedures are best performed in conjunction with the design of the primary containment area as presented in Engineer Manual (EM) 1110-2-5006 (Headquarters, Department of the Army 1980), but these procedures may also be used for projects with existing or predesigned containment areas. A flowchart of these procedures is shown in Figure 25.

Project Data

133. The following information should be obtained prior to performing jar tests and designing the chemical treatment system:

- a. Inflow rate based on past experience or on anticipated dredge size and a flow velocity of 15 fps. Large dredges may have higher velocities.
- b. Effluent quality requirements based on legal constraints.
- c. Salinity of water column determined by past experience or laboratory tests.
- d. Sediment grain-size analysis determined by laboratory tests.
- e. Sediment plasticity (Atterberg limits) determined by laboratory tests.

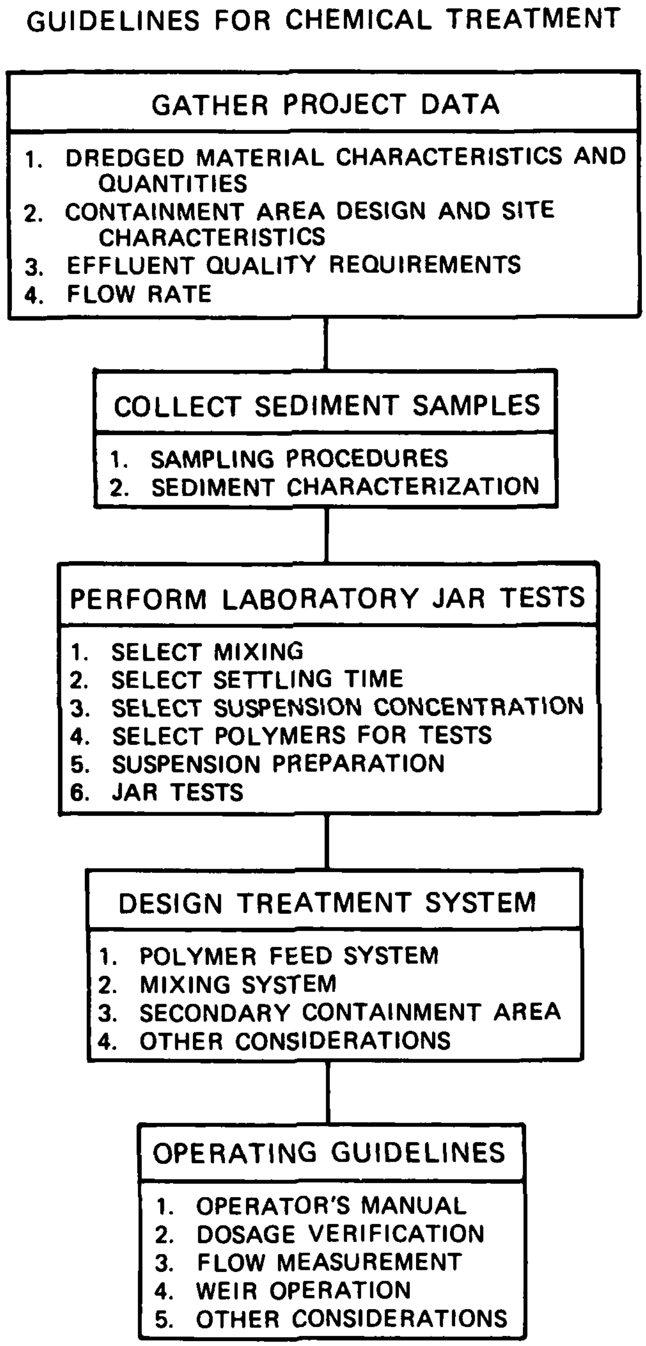


Figure 25. Flowchart of design procedures for chemical treatment

f. Unified Soil Classification System classification of sediment based on laboratory results of plasticity and grain-size analyses.

g. Primary and secondary containment area layouts and designs based on available sites.

h. Depths of containment areas and available difference in elevation between the two containment areas to be used for mixing.

i. Weir designs and effective weir length based on the designs.

j. Ponding depths based on designs and operation.

k. In situ volume to be dredged based on hydrographic surveys.

l. In situ water content of sediment determined by laboratory test.

m. Solids concentration of the dredged material slurry based on past experience or assumed to be 145 g/ℓ.

Sediment Sampling and Characterization

Sediment sampling

134. The sediment samples used in the laboratory jar tests must be representative of the material to be dredged in order to ensure the validity of the laboratory results. The same samples used in the settling tests for sizing the fine-grained dredged material containment area may be used for the jar tests. Sampling should be performed in accordance with the following recommendations from EM 1110-2-5006 (Headquarters, Department of the Army 1980):

a. Use a grab-type sampler capable of sampling up to a depth of about 12 in. Petersen or Shipek samplers have been used satisfactorily.

b. Take sediment samples at a sufficient number of locations to adequately define spatial variations in the sediment character.

c. Collect at least 5 gal of sediment samples at each sampling station.

d. Collect samples in airtight and watertight containers and place in a cold room (6° to 8°C) as soon after sampling as possible until organic content of samples can be determined. If organic content is above 10 percent, the samples should remain in refrigeration until testing is completed.

Sediment characterization tests

135. The sediment properties affect the settling properties of dredged material and, consequently, the solids concentration of the effluent to be treated at the primary weir. Therefore, the sediment must be characterized before running laboratory tests on chemical treatment.

136. Salinity. The salinity of the sediment water and the bottom water used to suspend and transport the dredged material must be measured or obtained from historical records. In estuarine environments, the salinity may vary with depth, flow, wind, tidal cycle, and season. Therefore, it is important to know the expected range of salinity during the dredging project.

137. Salinity may be measured in two ways:

a. Conductivity. The salinity may be measured directly by a salinity-conductivity meter that electronically converts temperature-adjusted electrical conductivity into salinity.

b. Dissolved solids or nonfiltrable residue. A detailed procedure is presented in Standard Methods for the Examination of Water and Wastewater (American Public Health Association (APHA) 1976). Briefly,

(1) Filter water through a filter which has a pore size of 1 μ or less.

(2) Pipette a known volume (about 25 ml) into a weighed dish and evaporate the sample 4 to 6 hr in a drying oven at 103°-105°C.

(3) Cool the dish in a desiccator and then weigh immediately.

(4) Salinity (in parts per thousand) = $\frac{\text{mg residue}}{\text{m}\ell\text{ sample}}$

138. Grain-size analysis. The grain-size distribution may vary considerably at different locations. As the fraction of fines increases

in a freshwater sediment, the effluent solids concentration from the primary containment area would also increase, affecting the chemical treatment requirements. Therefore, the test is important both for ensuring that the sample is representative and for predicting the solids concentration of the water to be treated. The procedures are given in Appendix V of EM 1110-2-1906 (Headquarters, Department of the Army 1970).

139. Plasticity analyses. Plasticity analyses are necessary to classify the fine-grained fraction using the Unified Soil Classification System. The system is described in Technical Memorandum No. 3-357 prepared at the U. S. Army Engineer Waterways Experiment Station (1953) and the procedures for the analyses are described in EM 1110-2-1906 (Headquarters, Department of the Army 1970).

Solids concentration tests

140. The suspended solids concentration is the most frequently measured parameter in the laboratory procedures. This measurement is made during preparation of suspensions and evaluation of treatment effectiveness. There are three methods to measure suspended solids: total solids, filtration, and centrifugation. Each is applicable under different circumstances. The total solids method measures both suspended and dissolved solids. The dissolved solids concentration, if significant, must be measured separately and subtracted from the total solids concentration. The filtration method directly measures suspended solids. The centrifugation method is a blend between the other two methods. It attempts to measure suspended solids by measuring the total solids after washing the dissolved solids out of a known volume of sample. The procedures outlined below are adapted from the methods given in EM 1110-2-5006 (Headquarters, Department of the Army 1980).

141. Total solids method. This test is used when the suspended solids concentration is large, compared to dissolved solids. It may be used in other cases where the dissolved solids or salinity is known or measured separately. To ensure accuracy, the test should generally be used only for suspensions with a suspended solids concentration greater than 1 g/ℓ. These steps should be followed:

a. Obtain tared weight of a sample dish.

b. Thoroughly mix sample and pour into sample dish.

c. Weigh dish and sample and place in drying oven at 105°C until sample has dried to a constant weight (about 4 to 6 hr).

d. Cool in desiccator and then weigh immediately.

e. Calculate suspended solids concentration C , in grams per litre, as follows:

$$C = \frac{(\text{Wt. S.S., g}) \times 1000}{[(\text{Wt. S.S., g})/\text{S.G.} + (\text{Wt. H}_2\text{O, g})]} \tag{1}$$

where

Wt. S.S.= {(weight of dry sample and dish, g) - (weight of dish, g) - [(Wt. H_2O, g) × (S, ppt or g/ℓ)/1000]}

S = salinity, ppt, or dissolved solids, g/ℓ; if unknown in freshwater environments, use zero

S.G. = specific gravity of solids; use 2.67 if unknown

Wt. H_2O = [(weight of wet sample and dish, g) - (weight of dry sample and dish, g)]

142. Filtration method. This method should be used for suspensions having suspended solids concentrations of less than 1.0 g/ℓ. Any quantitative filtering apparatus using a filter paper that has a pore size of 1 μ or less can be used for the test. The two most common setups use either a Gooch crucible with a glass fibre filter paper or a membrane filter apparatus. These steps should be followed:

a. Weigh filter.

b. Filter a measured volume of sample. The volume should be sufficient to contain 5 mg of suspended solids.

c. Filter 10 ml of distilled water twice to wash out dissolved solids.

d. Place filter in drying oven at 105°C until the sample has dried to constant weight (usually 1 to 2 hr).

e. Cool in desiccator and weigh.

f. Calculate suspended solids concentration C , in grams per litre, as follows:

$$C = \{[(\text{weight of filter and dry solids, g}) - (\text{weight of filter, g})] \times 1000 \div (\text{volume of sample, ml})\} \tag{2}$$

143. Centrifugation method. This method is recommended for samples from saltwater environments that have a suspended solids concentration greater than 1 g/ℓ. It is particularly useful when the dissolved solids concentration or salinity is unknown but expected to be significant (greater than 10 percent of the suspended solids concentration). This method is preferable to the total solids method when the dissolved solids concentration is several or more times greater than the suspended solids concentration. These steps should be followed:

a. Centrifuge a measured volume of sample until the liquid and solids have separated, yielding clear supernatant (several minutes should be sufficient).

b. Pour off supernatant being careful not to lose any of the solids.

c. Resuspend settled solids in distilled water by diluting the sample to its initial volume.

d. Repeat steps a through c twice to wash out all dissolved solids.

e. Pour sample into preweighed dish and then wash all remaining solids in the centrifuge tube into the dish using distilled water.

f. Place dish in drying oven at 105°C until sample has dried to constant weight (usually 4 to 6 hr).

g. Cool in desiccator and weigh.

h. Calculate suspended solids concentration C , in grams per litre, as follows:

$$C = \{[(\text{weight of dish and dry solids, g}) - (\text{weight of dish, g})] \times 1000 \div (\text{volume of sample, ml})\} \qquad (3)$$

Laboratory Jar Tests

General approach

144. Jar tests have been used to evaluate the effectiveness of various aggregants under a variety of operating conditions for water treatment. The procedures and evaluation process have been outlined by Black et al. (1957) and Hudson (1981). However, conducting jar tests and interpreting the results to determine design parameters are not simple tasks because there are many variables that can affect the tests.

Only experience can assist in applying the following jar test procedures to a specific project. The reader is referred to a report by Jones, Williams, and Moore (1978) for a discussion of equipment requirements and the importance of flocculant type, flocculant concentration, flocculant addition methods, temperature, mixing and test equipment, and intensity and duration of mixing on the jar test results.

145. Jar tests are used in these procedures to provide information on the following design considerations:

a. Most effective flocculant.

b. Optimum dosage of flocculant.

c. Optimum feed concentration of flocculant.

d. Effects of dosage on removal efficiencies of turbidity and suspended solids.

e. Effects of concentration of influent suspension on removal efficiencies.

f. Effects of mixing conditions on removal efficiencies.

g. Effects of settling time on removal efficiencies.

146. The general approach used in these procedures is as follows:

a. Using site-specific information on the sediment, dredging operation, containment areas, and effluent requirements--select mixing conditions, suspension concentration, settling time, and polymers for testing.

b. Prepare stock suspension of sediment.

c. Test a small number (four to six) of polymers that have performed well on similar dredged material. The tests should be run on 2-g/ℓ suspensions, which is a typical concentration for effluents from a well-designed containment area for freshwater sediments containing clays. If good removals are obtained at low dosages (10 mg/ℓ or less), then select the most cost-effective polymer. If good removals are not obtained, examine the polymer under improved mixing and settling conditions and test the performance of other flocculants.

d. After selecting a polymer and its optimum dosage, examine the effect of polymer feed concentration over the range of 1 to 30 g/ℓ, typical concentrations used in the field, at the optimum dosage.

e. Determine dosage requirements for the expected range of turbidity and suspended solids concentration to be treated at the primary weir.

f. Examine the effects of the range of possible mixing conditions on the required dosage of flocculant for a typical suspension.

g. Examine the effects of settling time on the removal of suspended solids and turbidity from a suspension of average concentration using the selected dosage and likely mixing conditions.

147. The purpose of the approach described is to select an effective polymer for a suspension of a standard concentration, 2 g/ℓ, which is a typical effluent solids concentration. In this manner, the effectiveness and dosage requirements of various polymers are easy to compare. The other test variables are set to simulate anticipated field conditions. After a polymer is selected, other variables are examined: polymer feed concentration, solids concentration of suspension to be treated, mixing, and settling time. The approach may be changed to fit the needs and conditions of the specific study.

148. The details of each test typically are modified to satisfy the constraints and conditions of the project and test. This procedure generally requires judgment from experience with jar tests and chemical treatment. The following procedures should be satisfactory in most cases.

Selection of test conditions

149. Mixing intensity and duration. Prior to testing, the mixing intensity and duration for the jar tests should be selected based on project conditions. Assuming mechanical mixing will not be used in the treatment system, the amount of mixing should be based on the available head between the two containment areas, that is, the difference between the water surfaces of the two areas which can be maintained throughout the project (see Figure 26). The depth of the secondary area must be sufficient to provide 2 to 3 ft of storage and 2 to 3 ft of ponding for good settling. Preferably, 2 to 3 ft of head should be available for mixing. The object is to convert the head into mixing energy in the culvert(s) joining the two containment areas. The amount of head loss is a function of flow rate, culvert diameter, and length. Table 21 presents typical mixing values Gt for good culvert mixing designs under a

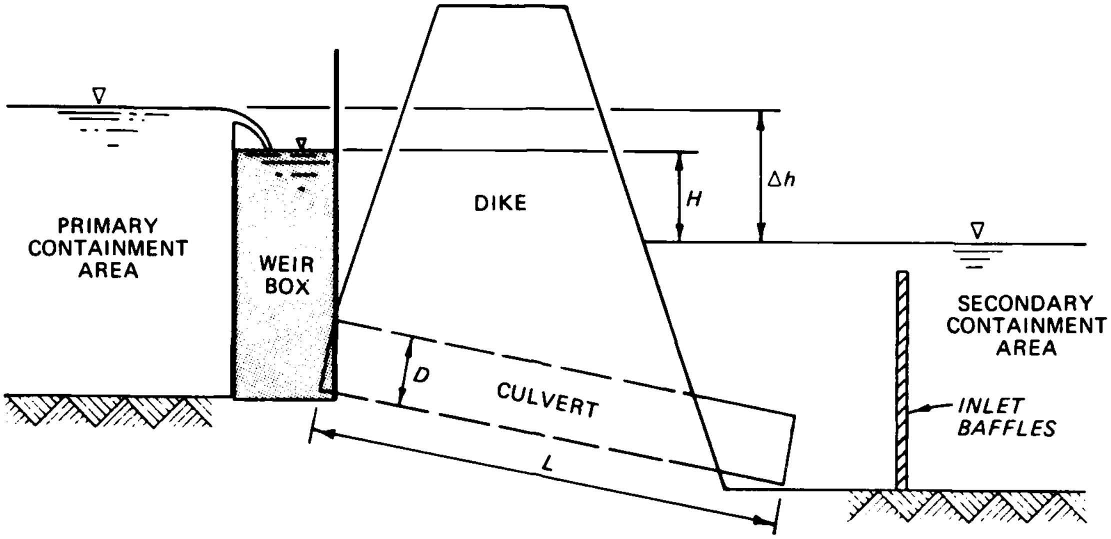


Figure 26. Example weir mixing system

variety of conditions assuming a maximum of five culverts and a maximum culvert length of 100 ft. The mixing intensity in terms of the mean velocity gradient G for the design conditions in Table 21 varied from about 250 to 500 sec^{-1} The effectiveness of polymers increased as the mixing Gt increased to about 30,000.

150. The designer may select a Gt value from Table 21 for an example with similar flow and mixing head, but preferably the designer should calculate the head loss, mixing intensity, and duration for the existing or designed culvert according to the following procedure for pipe flow (Streeter 1971). Assuming a submerged inlet and outlet and corrugated metal pipe,

$$H = \left(1.5 + \frac{Lf}{D}\right) \frac{v^2}{2g} \tag{4}$$

where

H = head loss, ft

L = culvert length, ft

f = friction factor

= $185\ n^2/D^{1/3}$ (n = Manning's coefficient, 0.025 for corrugated metal pipes)

D = culvert diameter, ft

v = maximum velocity through culvert, ft/sec

$= 4\ Q_{max}/\pi D^2$

Q_{max} = maximum flow rate, units

g = gravity, 32.2 ft/sec^2

The mean velocity gradient G can be calculated as follows (Jones, Williams, and Moore 1978):

$$G = \sqrt{\frac{\gamma_s f \bar{v}^3}{2gD\mu_s}} \tag{5}$$

where

γ_s = specific weight, 62.4 lb/ft^3

$\bar{v}$ = average velocity, ft/sec

μ_s = absolute viscosity, 2.36×10^{-5} lb-sec/ft^2 at 60°F

The duration t of the mixing is determined by

$$t = \frac{L}{\bar{v}} \tag{6}$$

The net mixing Gt is the product of the mean velocity gradient (intensity) and the duration. The mixing increases with increases in head loss, culvert length, and duration and with decreases in culvert diameter. Long, multiple, small-diameter, corrugated culverts provide the best mixing conditions. Good mixing requires a Gt of about 30,000, though a Gt of about 8,000 provides adequate mixing.

151. An alternative to using long, small-diameter, corrugated culverts to effectively convert the available head into mixing would be to install static mixers in the culvert. Static mixers are fixed obstructions which, when placed in a culvert, efficiently increase the turbulence produced by the flow. The mixers increase the head loss without using smaller diameter or longer culverts. When using these devices, care must be taken to accurately determine the head loss to ensure that good mixing is provided while not exceeding the available head.

152. After determining G and t for field conditions, use the same G and t for rapid mixing conditions in the laboratory jar test. If the G is greater than the G available on the jar test apparatus, mix at maximum speed and increase the duration to obtain the same Gt . The relationship between G and revolutions per minute of a jar test apparatus is shown in Figure 27. For slow mixing, mix at 20 rpm (G = 10 sec^{-1}) for 300 sec to simulate the exit loss conditions as the water dissipates its kinetic energy upon entering the secondary cell.

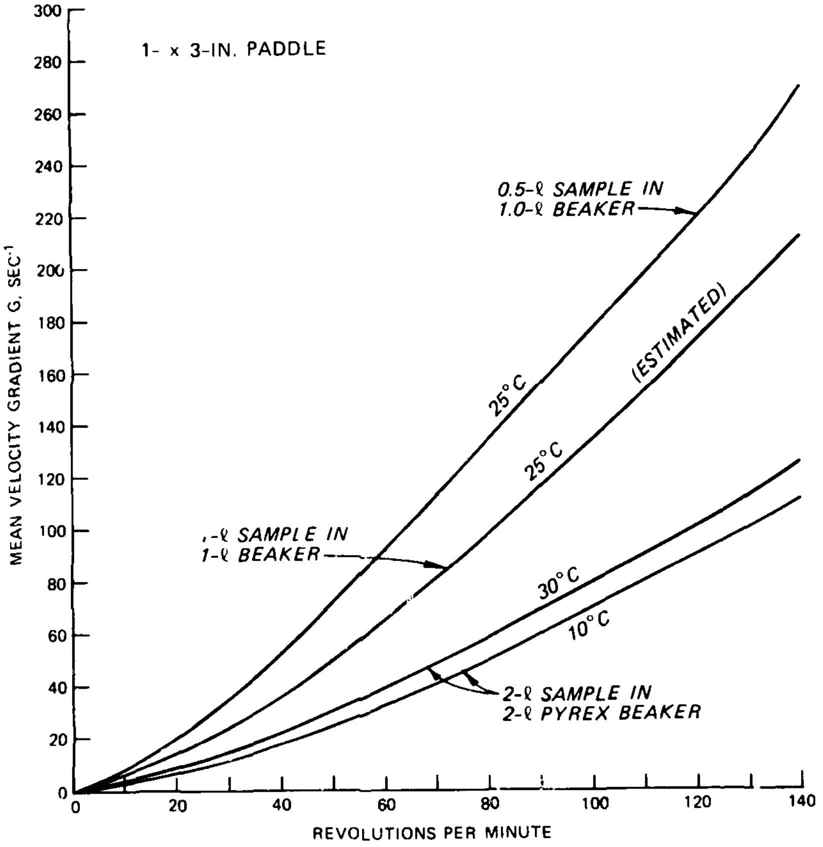


Figure 27. Velocity gradient G calibration curves for jar test apparatus

153. Suspension concentration. The next step is to predict the average solids concentrations and turbidity of the suspension to be treated at the primary weir. This can be estimated from past records of dredging at the site or from nomographs developed by Walski and Schroeder

(1978). Two nomographs were developed: one for freshwater clays that undergo flocculent settling, and the other for freshwater silts and saltwater sediments that undergo zone settling. The nomographs relate the flow rate, effective weir length, and ponding depth (depth of water above interface of settled material at the weir) to the suspended solids concentration of water discharged over the weir. These relationships are considered valid for well-designed primary containment areas that are properly sized for the efficient retention of suspended solids by gravity sedimentation. Procedures for containment area design considering both flocculent and zone settling are found in EM 1110-2-5006 (Headquarters, Department of the Army 1980). The nomographs are shown in Figures 28 and 29.

154. Selection of which nomograph to use is based on the salinity and soil classification. If the material is a silt (either ML, MH, or OL), use Figure 28. If the material is a clay (either CL, CH, or OH), it is necessary to determine the salinity of the suspending water. If the salinity is greater than 3 ppt, the sediment should be considered to be from a saltwater environment and Figure 28 should be used. If the salinity is less than 1 ppt, the clay will settle as a freshwater clay and Figure 29 should be used. For salinities between 1 and 3 ppt, the settling properties of a 100-g/ℓ slurry of sediment in natural water should be examined to determine whether it displays zone settling or flocculent settling. For zone settling, use Figure 28, and use Figure 29 for flocculent settling.

155. To use the nomographs, draw a horizontal line at the design flow rate. At the point where it intersects with the effective weir length of the design, draw a vertical line down to the ponding depth to be maintained at the weir. Then, draw a horizontal line from the point of intersection to the left vertical axis and read the suspended solids concentration in grams per litre. This concentration is an estimate of the average suspension concentration.

156. Settling time for flocculated material. The next variable to establish is settling time. Flocculated (chemically treated) material settles at a rate of about 0.25 ft/min (Jones, Williams, and Moore

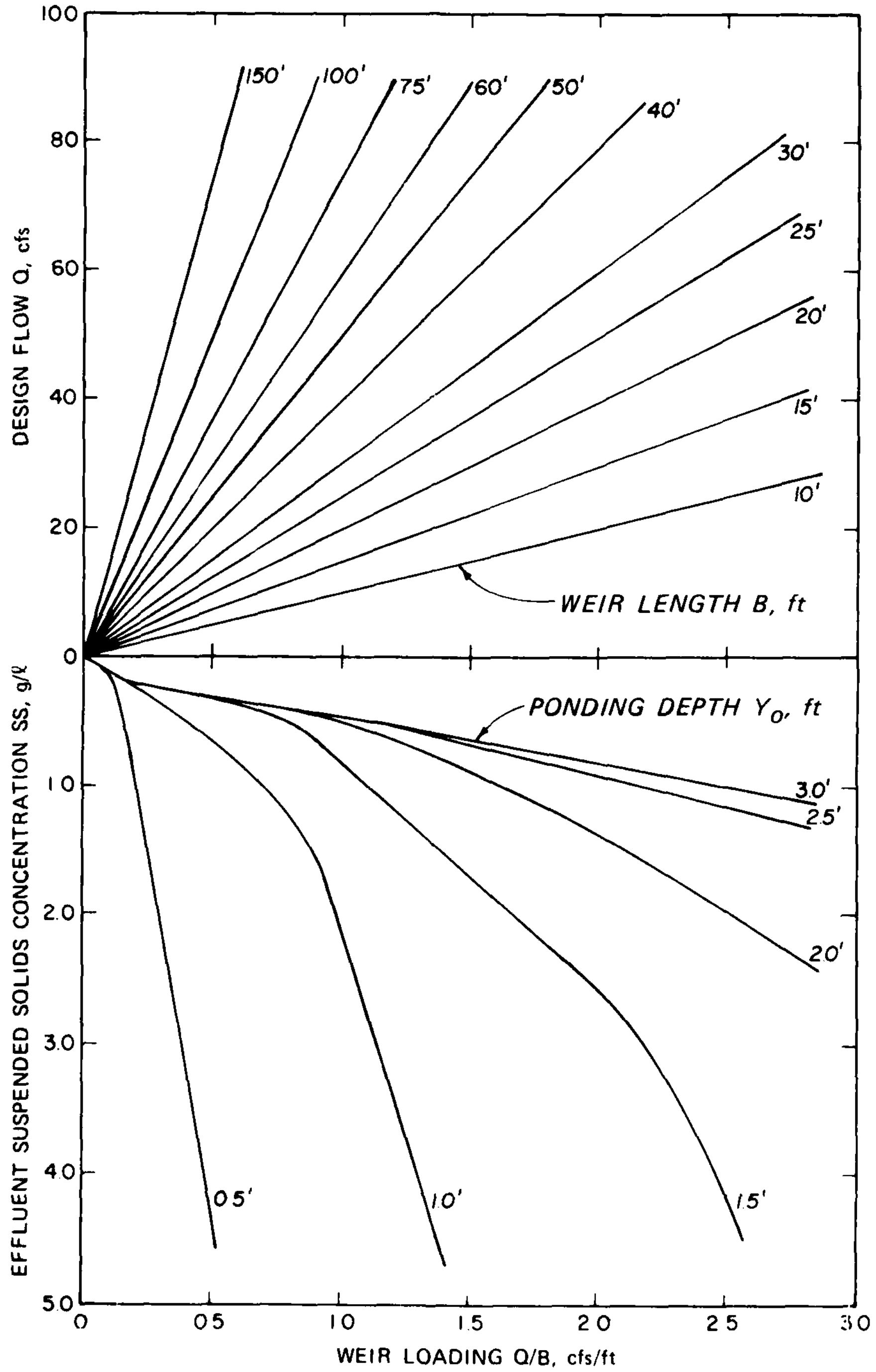


Figure 28. Nomograph relating design flow, weir length, effluent suspended solids concentration, ponding depth, and weir loading for silts and saltwater clays

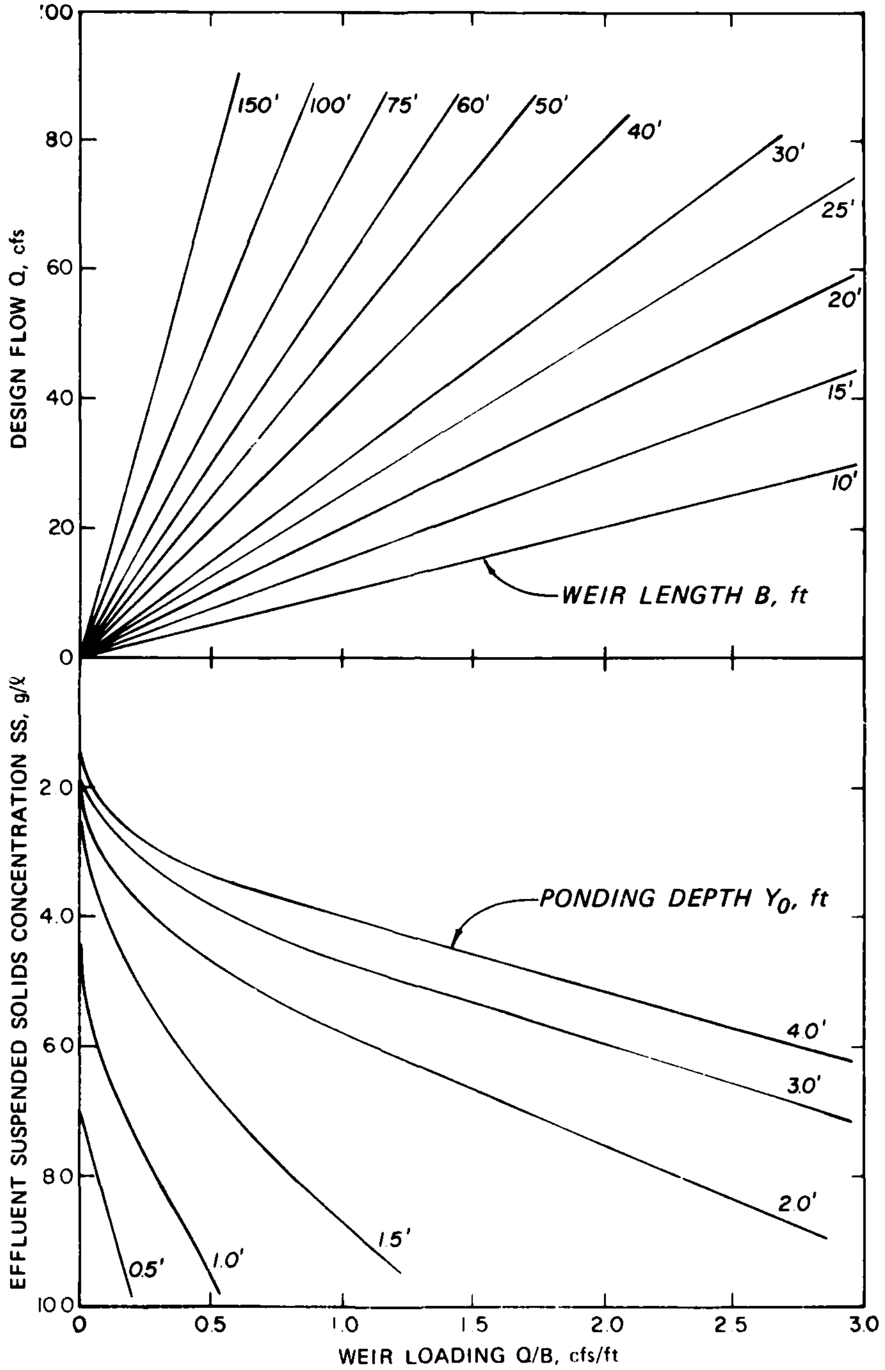


Figure 29. Nomograph relating design flow, weir length, effluent suspended solids concentration, ponding depth, and weir loading for freshwater clays

1978). The required ponding depth for good settling is about 2 to 3 ft; therefore, a minimum of 10 min is needed for settling. Also, due to basin inefficiencies, some of the water will reach the secondary weir in 10 to 20 percent of the theoretical detention time. For secondary containment areas, this may be as short as 10 to 20 min, though the mean detention time may be about 50 min. Based on this information, the settling time in the jar test should be set at 10 min. The effect of settling time on suspended solids removal can be evaluated in the jar test procedures.

157. Selection of polymers for testing. The final consideration before starting the jar tests is the selection of polymers to be tested. To simplify the operation of feeding and dispersing the polymer at the project, a low viscosity liquid polymer should be used. Some polymers effective on dredged material are given in Part III. Polymer manufacturers may be able to suggest others. The manufacturers can also recommend maximum polymer feed concentrations.

158. Polymers selected for testing should be nontoxic, nonhazardous, and unreactive. Polymer manufacturers can provide detailed information on the environmental properties of their products. Also, the U.S. Environmental Protection Agency has approved many polymers for use on potable water at the desired dosages. Very little of an applied dosage is expected to be discharged from the containment area since the polymer adsorbs on the solids and settles in the containment area. Therefore, polymers should not be detrimental to the quality of the receiving waters. Furthermore, Wang and Chen (1977) showed that polymers did not increase the long-term release of contaminants or nutrients from treated dredged material. Consequently, there appears to be no reason to consider polymer-treated, uncontaminated dredged material as a hazardous substance requiring special considerations.

Suspension preparation

159. Dredged material that is discharged over the weir is composed of only the finest fraction of the sediment. In many cases, this material has been suspended and mixed in the primary containment area for several days while the coarser material settled. Therefore, to

obtain representative suspensions for testing, the following procedure is recommended:

- a. Thoroughly mix sediment sample to ensure homogeneity. Then, blend together equal portions of each sample to form a representative composite of the sediment. Grain-size analysis and soil classification may be performed on this material to characterize the mixture and to compare it with previous characterizations of the sediment.
- b. If the sediment mixture contains more than 10 percent (dry weight basis) coarse grained (>No. 200 sieve) material, the material should be sieved through a standard U. S. series No. 200 sieve. The fines can be washed through the sieve using water from the bottom of the water column at the dredging site. If this water is unavailable, tap water may be used in its place, but the salinity of the suspension of fines (<No. 200 sieve) must be adjusted to naturally occurring salinity of the bottom waters at the project site.
- c. Prepare a supply of 2.0-g/ℓ suspensions by diluting a well-mixed portion of the slurry of fines with water from the dredging site or with tap water adjusted with salt to the same salinity. Suspensions at other concentrations would be prepared in the same manner.

Jar test procedures

160. Having established the test variables, the designer is ready to start the laboratory jar test procedures. Care must be exercised in the tests to ensure that each sample is handled uniformly. The tests must be performed in a standard manner to evaluate the results. The following variables must be controlled:

- a. Identical test equipment and setup.
- b. Suspension preparation.
- c. Sample temperature.
- d. Polymer feed concentration and age.
- e. Polymer dosage.
- f. Sample premix time and intensity.
- g. Polymer addition method.
- h. Duration and intensity of rapid mixing.
- i. Duration and intensity of slow mixing.
- j. Settling time.

k. Sampling method.

l. Laboratory analyses of samples.

161. All of the following procedures described in this section are not necessary for every project. The required tests are dependent on the purpose of the study, and some tests can be eliminated based on past experience of treating dredged material under similar circumstances.

162. Selection of polymer. The laboratory jar test procedures are as follows:

a. Fill a 1- or 2-ℓ beaker with a 2.0-g/ℓ suspension of fine-grained dredged material.

b. Mix at 100 rpm and incrementally add polymer at a dosing of 2 mg/ℓ until flocs appear. Note total dosage applied. (Use a polymer feed concentration of 2 g/ℓ or 2 mg/ml.)

c. Fill six 1- or 2-ℓ beakers with a 2.0-g/ℓ suspension of dredged material and measure the suspended solids concentration and turbidity of the suspension.

d. Mix at 100 rpm for 1 min and then rapidly add the desired polymer dosage to each beaker. Use a range of polymer dosages from 0 mg/ℓ to about twice the dosage determined in step b.

e. Immediately adjust the mixing to the desired G for rapid mixing as determined earlier. Mix for the desired duration t also determined earlier.

f. Reduce the mixer speed to a G of 10 sec^{-1} and slow mix for 300 sec.

g. Turn off mixer and let settle for 10 min.

h. Withdraw samples from the 700-ml level of 1-ℓ beakers and from the 1400-ml level of 2-ℓ beakers.

i. Measure the suspended solids concentration and turbidity of the samples. The test data should be recorded on a report form similar to the one shown in Figure 30. Also record any significant observations such as nature, size, and settling characteristics of the flocs; time of floc formation; and any peculiarities.

j. Repeat steps c through i as needed to adequately define the effects of dosage on clarification.

k. Repeat steps a through j for the other polymers. A dosage of 10 mg/ℓ should reduce the solids concentrations by 95 percent if the polymer is effective. Examine enough polymers to find at least two effective polymers.

JAR TEST REPORT FORM

TEST NO. ____________ DATE ____________ SAMPLE SOURCE ____________

COAGULANT ____________ DOSING METHOD ____________ TURBIDITY ____________ pH ______

CONC. ____________ SALINITY ____________ SS ____________ TEMP ______

JAR NO.		1	2	3	4	5	6
RAPID MIX	RPM						
	TIME, SEC						
SLOW MIX	RPM						
	TIME, SEC						
POLYMER DOSE	mg/l						
	ml						
SAMPLE VOLUME	ml						
SETTLING TIME	MIN						
SUSPENDED SOLIDS AFTER SETTLING	mg/l						
TURBIDITY AFTER SETTLING	NTU'S						

WES FORM 1 DEC 81 2243

Figure 30. Jar test report form

l. Select the most cost-effective polymer that can be easily fed and dispersed.

163. Selection of polymer feed concentration. After selecting the best polymer, the effects of polymer feed concentration and polymer solution age on the removals can be evaluated. Some polymers require large dilution factors and aging following dilution to maximize their effectiveness. This test is not required if adequate dilution water and solution aging are provided in the design to meet the manufacturer's recommendations. Often, to simplify the treatment system design, these recommendations are not met. The test is performed as follows:

a. Prepare six fresh solutions of the selected polymer ranging in concentration from about 1 to 40 g/ℓ.

b. Fill six beakers as in step c of paragraph 162.

c. Mix at 100 rpm for 1 min and then rapidly add the polymer solutions at the effective dosage established earlier and in the same manner.

d. Continue to follow the procedures outlined in steps e through i of paragraph 162.

e. Allow two solutions to age as desired (between 1 hr and 1 day) and repeat steps b through d.

164. Determination of required dosage. The dosage requirements of the selected polymer for the anticipated average solids concentration of the primary effluent suspension to be treated at the primary weir should be evaluated. This concentration was determined previously from past records or from the nomographs in Figures 28 and 29. The procedure is as follows:

a. Fill six beakers with suspensions at the desired concentration of the fine-grained fraction of dredged material. Measure the suspended solids concentration and turbidity of the suspension.

b. Mix at 100 rpm for 1 min and then rapidly add the desired polymer dosage to each beaker. The range of dosages should be proportional to the solids concentration.

c. Continue to follow the procedures outlined in steps e through j of paragraph 162.

Other suspensions with different solids concentrations may be examined in the same manner to determine the possible range of dosages required for the project and the possible range of effluent quality obtainable under conditions of variable primary effluent solids concentration to be treated.

165. Effects of mixing. Other mixing conditions can be examined to determine the impact of low flow conditions and to evaluate whether the mixing is adequate. The effects of increasing the mixing by a Gt of 5,000 and 10,000 and of decreasing the flow rate by 50, 75, and 90 percent on the polymer dosage requirements can be evaluated as follows:

a. Calculate the new mixing intensity and duration.

b. Fill six beakers with a suspension at the anticipated average solids concentration.

c. Mix at 100 rpm for 1 min and then rapidly add the desired polymer dosage to each beaker. Select a range of dosages surrounding the optimum dosage determined in the last set of experiments on the same suspension.

d. Immediately adjust the mixing to the G value calculated in step a for rapid mixing and mix for the calculated duration t.

e. Follow the procedures outlined in steps f through i of paragraph 162.

166. Effects of settling time. The effects of settling time on effluent quality can be examined as follows:

a. Determine the range of settling time of interest bearing in mind that the secondary basin will be hydraulically inefficient and the settling conditions are not quiescent.

b. Follow procedures outlined in steps c through i of paragraph 162 but adjust the settling time and sampling schedule to cover the range determined above.

Design of Chemical Treatment Systems

167. This section presents the design procedures for chemical clarification of primary containment area effluents. The design is composed of three subsystems: (a) the polymer feed system including storage, dilution, and injection; (b) the weir and discharge culvert for

mixing; and (c) the secondary basin for settling and storage. The treatment system should be designed to minimize equipment needs and to simplify operation.

Polymer feed system

168. This design assumes that a liquid, low to medium viscosity polymer is being used to minimize handling, pumping, and dilution problems. In most cases, the simplest system (shown in Figure 31) is adequate. Polymer manufacturers should be able to inform the designer if this system is adequate. The experiments on polymer feed concentrations and aging should also indicate its adequacy. If the viscosity of the polymer is high or if low polymer feed concentrations are needed, systems like those shown in Figures 32 and 33 should be used. If the polymer requires aging prior to being fed, the two-tank system should be used. These systems are suitable for all but the smallest projects. Polymers requiring predilution in systems like those in Figures 32 and 33 should be avoided because they increase the equipment and operating labor requirements.

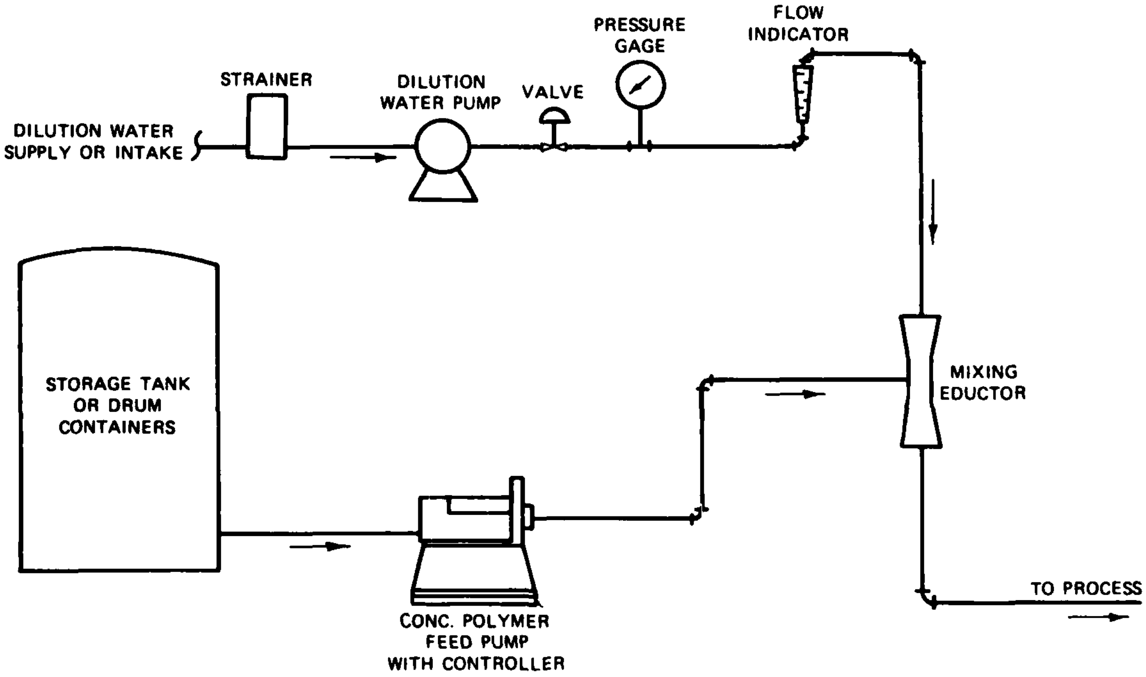


Figure 31. Schematic of a simple liquid polymer feed system

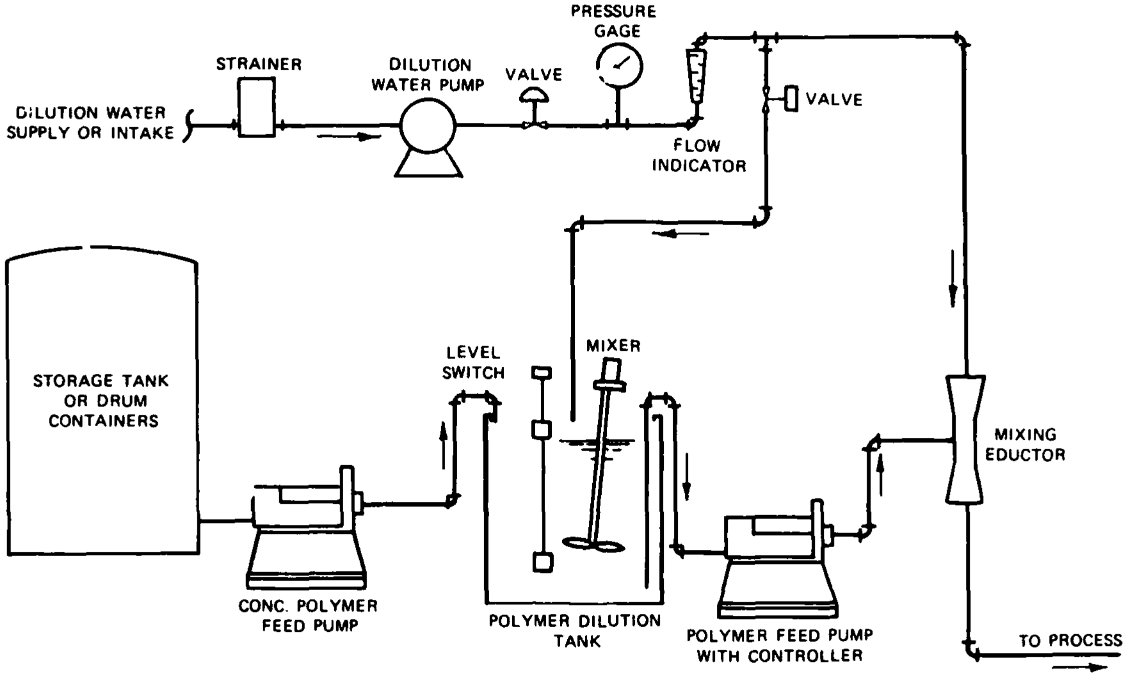


Figure 32. Schematic of a single tank liquid polymer feed system

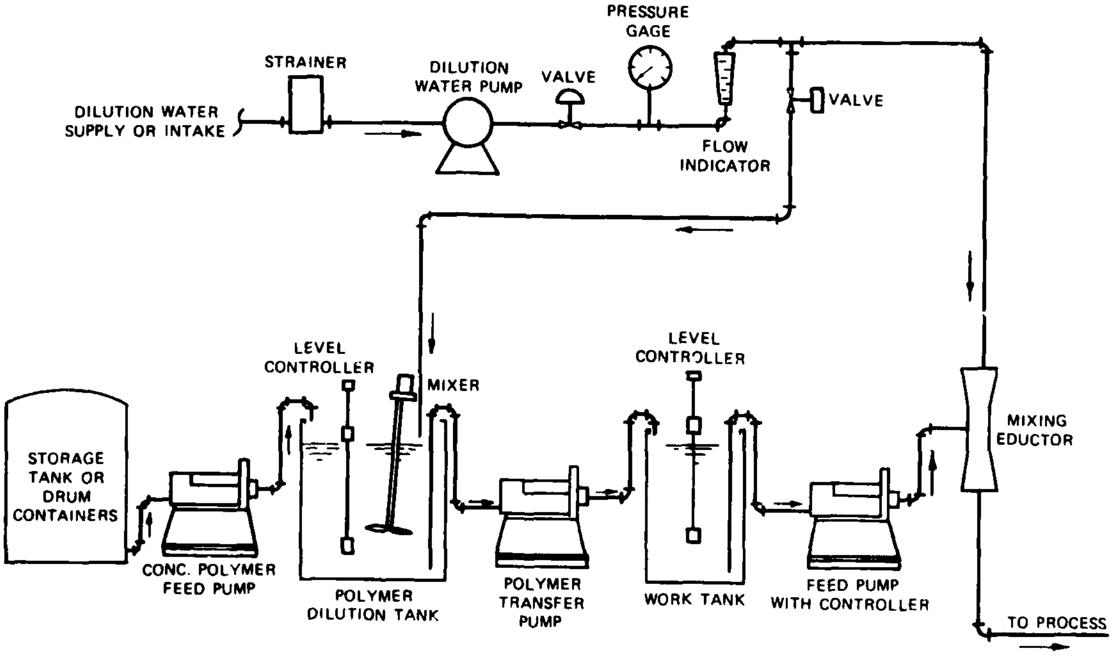


Figure 33. Schematic of a two-tank liquid polymer feed system

169. Storage. The polymer can be stored at the site in the delivery containers, either 55-gal drums or bulk shipping tanks. The polymer can be fed directly from these containers or transferred to a polymer feed tank. Provisions should be made to guard against freezing. The feed tank may need to be heated or stored in a heated shelter to lower the viscosity and facilitate pumping on cold days. The size of the feed tank and storage facilities is dependent on the project.

170. The volume of polymer required for the project may be calculated as follows:

$$\begin{aligned}&\text{Total Volume of Inflow, } \ell \\ &\quad = (\text{Volume to be dredged, yd}^3) \times (\text{In situ Sediment Conc., g}/\ell) \\ &\qquad \times 764.4\ \ell/\text{yd}^3 \div (\text{Dredged Material Slurry Conc., g}/\ell) \qquad (7)\end{aligned}$$

$$\begin{aligned}&\text{Total Volume of Settled Material, } \ell \\ &\quad = (\text{Total Volume of Inflow, } \ell) \times (\text{Influent Slurry Conc., g}/\ell) \\ &\qquad \div (\text{Conc. of Settled Material, g}/\ell) \qquad (8)\end{aligned}$$

If the concentration of settled material is unknown, it is generally conservative to let

$$\begin{aligned}&\text{Total Volume of Settled Material, } \ell \\ &\quad = 2 \times (\text{Volume to be dredged, yd}^3) \times 764.4\ \ell/\text{yd}^3 \qquad (9)\end{aligned}$$

Then,

$$\begin{aligned}&\text{Total Volume to be Treated, } \ell = (\text{Total Volume of Inflow, } \ell) \\ &\qquad - (\text{Total Volume of Settled Material, } \ell) \qquad (10)\end{aligned}$$

$$\begin{aligned}&\text{Total Volume of Polymer Required, gal} \\ &\quad = (\text{Required Dosage, mg}/\ell) \times (\text{Total Volume to be Treated, } \ell) \\ &\qquad \div (\text{Specific Weight of Polymer, kg}/\ell) \\ &\qquad \div 10^6\ \text{mg/kg} \div 3.785\ \ell/\text{gal} \qquad (11)\end{aligned}$$

$$\begin{aligned}&\text{Total Poundage of Polymer, lb} \\ &\quad = (\text{Total Volume of Polymer, gal}) \times 3.785\ \ell/\text{gal} \\ &\qquad \times (\text{Specific Weight of Polymer, kg}/\ell) \times 2.205\ \text{lb/kg} \qquad (12)\end{aligned}$$

171. Polymer pumping. Concentrated polymer solutions should be fed using a positive displacement pump. The pump speed should be regulated by either a manual or automatic controller. The pump should be capable of discharging a wide range of flows to handle the possible range of required polymer dosages and flow rates of water to be treated. The pump capacity should be at least twice the maximum anticipated polymer feed rate or four times the average feed rate. The minimum pumping rate must be less than 10 percent of the average anticipated polymer feed rate to handle low flow conditions.

172. The average polymer feed rate is

$$\begin{aligned}&\text{Avg. Feed Rate, ml/sec}\\&\quad = (\text{Avg. Flow Rate, cfs}) \times (\text{Avg. Required Dosage, mg}/\ell)\\&\qquad \times 28.31\ \ell/\text{ft}^3 \div (\text{Specific Weight of Polymer, g/ml})\\&\qquad\qquad \div 1000\ \text{mg/g}\end{aligned} \tag{13}$$

173. The polymer pump flow capabilities should range from about

$$\text{Pump Range, ml/sec} = (0.1 \text{ to } 4) \times (\text{Avg. Feed Rate, ml/sec}) \tag{14}$$

Two polymer pumps operated in parallel may be required to provide the desired range of feed rates.

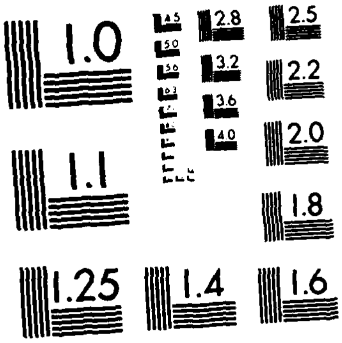
174. If the polymer requires a tank for predilution as in Figures 32 and 33, the polymer should be diluted by a factor of 10 or 20 in the tank. The polymer feed rate would then increase by this same factor.

175. Polymer tanks. The polymer feed tanks and dilution tanks should be large enough to feed polymer for 1 to 2 days under average conditions. The average daily concentrated polymer feed volume is

$$\begin{aligned}\text{Daily Volume, gal/day} &= (\text{Avg. Feed Rate, ml/sec})\\&\qquad \times 86{,}400\ \text{sec/day} \div 3{,}785\ \text{ml/gal}\end{aligned} \tag{15}$$

176. Polymer dilution. The polymer must be diluted to aid feeding

AD-A134 731 CHEMICAL CLARIFICATION METHODS FOR CONFINED DREDGED 2/2
MATERIAL DISPOSAL(U) ARMY ENGINEER WATERWAYS EXPERIMENT
STATION VICKSBURG MS P R SCHROEDER JUL 83
UNCLASSIFIED WES-TR-D-83-2 F/G 13/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

and dispersion. The amount of dilution required can be determined from the manufacturer or experimentally. As a practical limitation, the dilution factor should not exceed 200 under average conditions due to excessive requirements for water at higher dilutions.

177. Supernatant from the containment area, preferably treated supernatant from the secondary cell, can be used for dilution water. However, if the polymer is to be prediluted in a tank, water of good quality should be used to minimize deposition of material in the tank and to maintain the effectiveness of the polymer. The dilution water can be collected from a screened intake suspended near the surface at a place free of debris, resuspended material, and settled material.

178. The dilution water may be pumped by any water pump. The pump capacity should be about 200 times the average polymer feed rate of concentrated polymer. A controller is not needed to regulate the dilution water flow rate since maximizing the dilution aids in dispersion. The polymer and dilution water may be mixed in-line using a mixing eductor.

179. Injector and feed lines. Any injection system can be used so long as it distributes the polymer uniformly throughout the water to be treated. It may consist of a single nozzle or a perforated diffuser pipe running along the weir crest. The system should be as maintenance-free as possible. Fine spray nozzles should be avoided because suspended material from the dilution water may clog them.

180. The feed lines may be constructed of rubber hoses or PVC pipe. They must be designed to carry the design flows of the viscous polymer solution at low temperature. Provisions must be made to prevent freezing, particularly when the system is not operating.

181. Polymer feed system design example. Given the following project information and laboratory results, the design would proceed as follows:

Project Information:

Sediment volume	200,000 yd^3
In situ sediment conc.	900 g/ℓ
Specific gravity of sediment	2.68

Dredged material slurry conc.	150 g/ℓ
Dredge pipeline size	14 in.
Sediment	freshwater clay (CH)
Production time	100 hr/wk
Avg. conc. of settled material	400 g/ℓ
Mean daily temperature	50°F

Laboratory Results:

Selected polymer	low viscosity liquid
Specific weight of polymer	1.10 kg/ℓ
Required dosage at average flow and turbidity	10 mg/ℓ
Polymer feed concentration	20 g/ℓ

a. Polymer requirements.

$$\text{Volume of Inflow, } \ell = 200{,}000 \text{ yd}^3 \times 900 \text{ g}/\ell \times 764.4\ \ell/\text{yd}^3 \div 150 \text{ g}/\ell = 9.17 \times 10^8\ \ell \qquad \text{(7 bis)}$$

$$\text{Volume of Settled Material, } \ell = 9.17 \times 10^8\ \ell \times 150 \text{ g}/\ell \div 400 \text{ g}/\ell = 3.44 \times 10^8\ \ell \qquad \text{(8 bis)}$$

$$\text{Volume to be Treated, } \ell = 9.17 \times 10^8\ \ell - 3.44 \times 10^8\ \ell = 5.733 \times 10^8\ \ell \qquad \text{(10 bis)}$$

$$\text{Volume of Polymer Required, gal} = 10 \text{ mg}/\ell \times 5.733 \times 10^8\ \ell \div 1.10 \text{ kg}/\ell \div 10^6 \text{ mg/kg} \div 3.785\ \ell/\text{gal} = 1{,}380 \text{ gal} \qquad \text{(11 bis)}$$

$$\text{Pounds of Polymer Required, lb} = 1{,}380 \text{ gal} \times 3.785\ \ell/\text{gal} \times 1.10 \text{ kg}/\ell \times 2.205 \text{ lb/kg} = 12{,}640 \text{ lb} \qquad \text{(12 bis)}$$

b. Storage. Since less than 2000 gal of polymer is required, drums should be used for storage instead of a bulk tank. The drums may be stored outside since they are not expected to freeze during the project. However, barrel warmers should be used to aid in transferring the polymer to the feed tank due to the cool temperature. A hand pump or a small electrical positive displacement pump should be used for the transfer from storage.

c. Polymer pump. The feed system shown in Figure 31 should be used since the selected polymer is a liquid of low viscosity requiring a fiftyfold dilution. The average polymer flow rate is

$$\text{Avg. Flow Rate} = 15 \text{ fps} \times \pi/4 \times (14 \text{ in.} \div 12 \text{ in./ft})^2 = 16.04 \text{ cfs} \quad (16)$$

$$\text{Avg. Polymer Flow Rate} = 16.04 \text{ fps} \times 10 \text{ mg}/\ell \times 28.31\ \ell/\text{ft}^3 \div 1.10 \text{ g/ml} \div 1000 \text{ mg/g} = 4.13 \text{ ml/sec} = 0.065 \text{ gpm or } 94.2 \text{ gpd} \quad (13\ \text{bis})$$

The polymer pump capacity should be about four times the average rate or 0.25 gpm. The pump should be able to pump as low a flow as 0.4 ml/sec or 0.0065 gpm.

d. Polymer feed tank. The polymer feed tank should be sized to hold a 2-day supply of polymer. The tank should be kept in a heated shelter with the pumping equipment.

$$\text{Tank Volume} = 94.2 \text{ gpd} \times 2 \text{ days} \times (0.8, \text{ the production efficiency}) = 150 \text{ gal} \quad (17)$$

e. Dilution water pump. To reduce the polymer feed concentration below 20 g/ℓ, the dilution factor must be fifty-five. At average polymer flow rate, the required dilution water flow rate would be 3.6 gpm. The dilution water pump capacity should be twice this rate to dilute higher polymer flows adequately. Therefore, the dilution water flow rate should be

$$\text{Dilution Water Pump Rate} = [(1.1 \times 1000 \text{ g}/\ell) \div 20 \text{ g}/\ell] \times 2 \times 0.0654 \text{ gpm} = 7.20 \text{ gpm} \quad (18)$$

The pump must deliver this flow rate and produce high pressure (60 psi) to force the viscous polymer solution through the eductor, feed lines, and injector.

f. Feed lines. The size of the feed lines should be determined by head loss analysis for pipe flow. This subject is discussed in any fluid mechanics textbook or hydraulics handbook. The pipe diameter is dependent on the viscosity, flow rate, length of line, minor losses, and losses through the eductor and injector. One-inch inside diameter (ID) rubber hose or PVC pipe should be used for this example. The head loss would be less than 30 psi.

Mixing system

182. The weir box and discharge culvert(s) should, if possible, be designed to provide adequate mixing. A 2-ft drop between the water surfaces of the first basin and the second basin is sufficient energy for mixing if efficiently used. Mechanical mixers should be considered if sufficient energy is unavailable. The design of mechanical mixing systems has been presented by Jones, Williams, and Moore (1978) and will not be duplicated here.

183. Weir. The weir should be designed to collect supernatant from the primary containment area and to disperse the polymer thoroughly. The weir box does not provide efficient mixing and, therefore, it is undesirable to lose all the energy of the water by a free fall into the weir box. The system should provide a small drop into the weir box and high head loss through the discharge culvert(s) between the primary and secondary containment areas.

184. The weir box should be designed to prevent leakage; the bottom of the box should be sealed. Only one section of the box needs to be adjustable to the bottom of the box; this would minimize leakage. Weir boards with tongue and groove joints would also decrease leakage. The weir box should be submergible without the weir boards floating from their positions. All sections of the weir should be level and at the same elevation. An example is shown in Figure 34.

185. The height of the weir crest should be adjustable to stop the flow when the flow is too low to treat or to maintain the flow in order to keep treating when the dredge has stopped. The depth of flow

over the weir must be controlled by increments of 1 to 2 in. to maintain a fairly constant flow rate. The weir must also be able to stop the flow when the treatment system is down for maintenance or repair. The simplest mode of operation would be to stop the flow over the weir by adding weir boards when the flow rate is low, and then to remove the added weir boards and resume operation after the elevation of the water surface returns to its height at average flow.

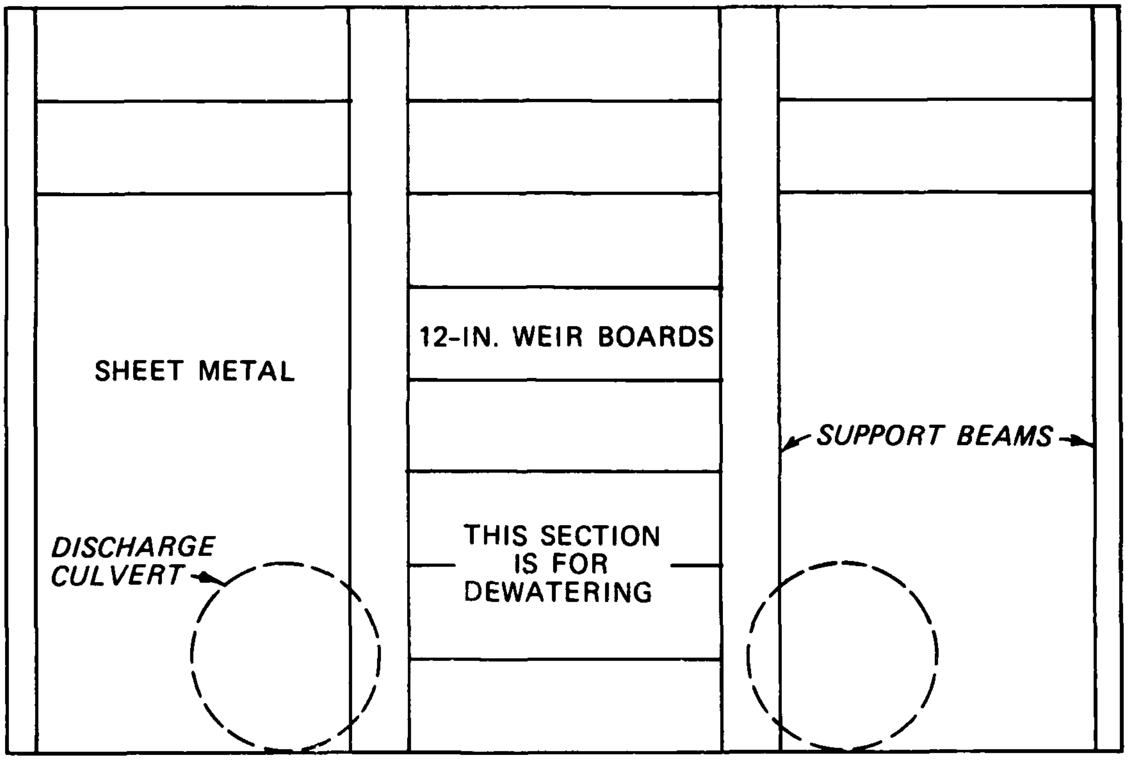


Figure 34. Frontal view of a weir

186. Discharge culvert. The discharge culvert(s) must be designed to provide the required mixing and to discharge the design flow rate safely. The design procedure presented here determines the length, diameter, and number of culverts which maximize mixing within the constraints of most projects. The frictional head loss provides the mixing and increases with increasing culvert length and decreasing diameter. Multiple culverts increase the duration of mixing but decrease the intensity of the mixing. Static mixers may be used in-line to

increase the head loss of a culvert without increasing its length or decreasing its diameter. The use and design of static mixers will not be discussed herein, but information on their use is available from their manufacturers.

187. The design approach is to size the culvert for the maximum flow rate and the minimum available head and then to calculate the available mixing under average flow conditions. The maximum flow rate is assumed to be the average dredge flow rate with continuous, 24-hr/day production. The designer should also consider other possible sources of inflow. The average flow at the weir is assumed to be the product of average dredge flow rate and fractional production time ratio (generally about 0.75 or 18 hr/day). In this manner the culvert will be able to safely discharge the design flow. It is important to estimate the flow rates fairly accurately in order to properly size the culvert. Undersizing can result in overtopping the dikes or in forcing the dredge to operate intermittently. Oversizing can result in inadequate mixing. The amount of mixing can be compared with the mixing requirements determined experimentally to evaluate the design. If inadequate, the designer may wish to change the containment area design to provide a greater head for mixing. The required head can be determined using the design equations.

188. The design procedure is as follows (see Figure 26 for an example weir mixing system):

a. Assume that the maximum flow rate is the average dredge flow rate with continuous production, 24 hr/day.

b. Assume a 0.5-ft drop into the weir box under maximum flow.

c. Determine the difference in elevation Δh , in feet, between the water surface of the basins at their highest operating levels from the design.

d. Let H , in feet, $= \Delta h - 0.5$ where H is the maximum permissible head loss through the culvert at maximum flow.

e. Assuming a submerged inlet and outlet, and a corrugated metal culvert (though less head loss and better mixing for low flows would be realized if the outlet were not submerged), then

$$H = \left(1.5 + \frac{Lf}{D}\right) \frac{\bar{v}^2}{2g} \qquad (4\ \text{bis})$$

f. Select range of culvert lengths from containment area layouts.

g. Let Q = maximum flow rate, cfs
N = number of parallel culverts
then

$$H = \left[1.5 + \frac{185(0.025)^2 L}{D^{4/3}}\right] \left(\frac{8Q^2}{g\pi^2 N^2 D^4}\right) \qquad (19)$$

h. Rearranging the above equation

$$D = \left\{\frac{8Q^2 \left[1.5D^{4/3} + 185(0.025)^2 L\right]}{g\pi^2 H N^2}\right\}^{3/16} \qquad (20)$$

This equation converges to the minimum diameter in three or four iterations by using 2 ft for the initial D and then substituting the calculated D for the next iteration.

i. Solve the above equation using the minimum and maximum culvert length based on the containment area layout for up to five culverts.

j. For each number of culverts, choose the largest commercially available diameter between the calculated diameters for the minimum and maximum culvert lengths. If there are not any commercial sizes between these diameters, select the next larger commercial size and the maximum length.

k. Calculate the culvert length for the selected commercial sizes.

$$L = \left(\frac{g\pi^2 H N^2 D^4}{8Q^2} - 1.5\right) \left[\frac{D^{4/3}}{185(0.025)^2}\right] \qquad (21)$$

l. Calculate $\bar{v}$ and f for the selected sizes at average flow.

$$\bar{v} = 4\ \bar{Q}/\pi D^2 \tag{22}$$

where

$\bar{v}$ = mean velocity at average flow, fps

$\bar{Q}$ = average flow rate, cfs

m. Calculate the mixing Gt of each design at average flow.

$$Gt = \sqrt{\frac{\gamma_s f \bar{v} L^2}{2g\mu_s D}} \tag{23}$$

where

γ_s = specific weight, 62.4 lb/ft^3

μ_s = absolute viscosity, 2.36×10^{-5} lb-sec/ft^2 at 60°F

n. Calculate the head loss at average flow and the maximum carrying capacity of the culvert at a head of Δh to determine limits of the design.

o. Select the best overall design based on mixing, cost, operating flexibility, etc.

189. Example culvert design. Given an 18-in.-diam dredge pipeline, a minimum head difference of 3 ft between the primary and secondary cells, and a range of culvert lengths between 50 and 100 ft based on the containment area design, the culvert design would proceed as follows:

a. $$\begin{aligned} Q_{max} &= 15 \text{ fps} \times \pi(18 \text{ in./12 in./ft})^2 \div 4 \\ &= 26.5 \text{ cfs} \end{aligned} \tag{24}$$

$$\begin{aligned} Q_{ave} &= 26.5 \text{ cfs} \times (\text{Production ratio, } 0.75) \\ &= 19.9 \text{ cfs} \end{aligned} \tag{25}$$

b. $\Delta h = 3$ ft

$$H = 3 \text{ ft} - 0.5 \text{ ft} = 2.5 \text{ ft} \tag{26}$$

c. The calculated minimum diameters for the following lengths and numbers of culverts are:

N	L, ft	D, ft	D, in.
1	50	2.23	26.8
1	100	2.44	29.3
2	50	1.67	20.0
2	100	1.85	22.2
3	50	1.42	17.0
3	100	1.57	18.8
4	50	1.26	15.1
4	100	1.41	16.9
5	50	1.15	13.8
5	100	1.29	15.5

d. The selected commercial sizes and calculated lengths are:

N	D, in.	L, ft
1	27	54.1
2	21	69.3
3	18	73.3
4	18	100.0
5	15	83.0

e. The friction factor and velocity at average flow are:

N	D, in.	$\bar{v}$, fps	f
1	27	5.00	0.0882
2	21	4.14	0.0959
3	18	3.75	0.1010
4	18	2.82	0.1010
5	15	3.24	0.1073

f. Mixing at average flow:

N	D, in.	L, ft	G(sec^{-1})	t(sec)	Gt
1	27	54.1	449	10.8	4855
2	21	69.3	400	16.7	6690
3	18	73.3	382	19.5	7470
4	18	100.0	249	35.5	8830
5	15	83.0	346	25.6	8870

g. Head loss at average flow:

$$H = 1.41 \text{ ft}$$

h. Flow through a completely submerged weir:

$$Q = 29.0 \text{ cfs}$$

i. Generally, a Gt of about 8000 provides adequate mixing for chemical treatment. In this example, either three 18-in.-diam, 73-ft-long culverts, four 18-in.-diam, 100-ft-long culverts or five 15-in.-diam, 83-ft-long culverts could be used. However, four 18-in.-diam culverts would be the best design since it would provide considerably more mixing than three culverts and about the same mixing as five culverts. Also, this design would provide better mixing at lower flow rates.

Secondary containment area

190. Design approach. The secondary area must be designed to provide adequate detention time for good settling and sufficient volume for storage of settled material. The total volume of the cell is the sum of the ponded volume and the storage volume. The required ponded volume is a function of the hydraulic efficiency of the cell and the flow rate. The storage volume is dependent on the solids concentration entering the basin, the depth of the cell, the total volume to be treated, the flow rate, and the mud pumping schedule.

191. Ponded volume. Effective settling requires a ponded depth of 2 to 3 ft and a minimum of 20 min of detention. Due to short-circuiting, the mean detention time should be at least 60 min and the theoretical detention time of the ponded volume should be at least 150 min. The shape of the cell should have a length-to-width ratio of at least 3:1 to reduce short-circuiting.

192. Storage volume. The settling properties of flocculated dredged material resulting from chemical clarification have not been well defined. Solids concentration or density profiles have been measured at only one field site as presented earlier in this report. The settled material was very fluid and, as such, did not clog the inlet culvert though settled material accumulated near the inlet to a depth 1 ft higher than the top of the culvert. The momentum of the inflow was capable of keeping the inlet clear of material. Resuspended material settled rapidly in the basin. The concentration of settled material at the interface between the supernatant and settled layer was 50 g/ℓ, and the concentration increased with increasing depth at a rate of 25 g/ℓ/ft. Therefore, deeper basins stored more material in a given volume due to

compaction. The concentration of the material increased rapidly upon dewatering.

193. Knowing the average available depth of the secondary basin, the total storage requirements can be estimated as follows:

a. The total mass of material to be stored M or pumped from the secondary area is

$$M, \text{g} = (\text{Primary effluent conc.} - \text{Secondary effluent conc., g}/\ell) \times (\text{Volume to be treated, } \ell) \quad (2$$

b. The average concentration of settled material C_s is

$$C_s, \text{g}/\ell = [2 \times 50 \text{ g}/\ell + 25 \text{ g}/\ell/\text{ft} \times (\text{Average depth of storage, ft})] \div 2 \quad (28)$$

c. Total volume of settled treated material V_s is

$$V_s, \ell = (M, \text{g}) \div (C_s, \text{g}/\ell)$$

$$V_s, \text{ft}^3 = (V_s, \ell) \div 28.31 \ \ell/\text{ft}^3 \quad (29)$$

d. The maximum area required A_s is

$$A_s, \text{acre} = (V_s, \text{ft}^3) \div (\text{Average depth of storage, ft}) \div 43{,}560 \text{ ft}^2/\text{acre} \quad (30)$$

194. Ponded area. The required volume V_p and area A_p for ponding are

$$V_p = (\text{Average flow rate, cfs}) \times 9000 \text{ sec} \quad (31)$$

$$A_p = V_p \div (\text{Average depth of ponding, ft}) \quad (32)$$

195. Design area. The containment area should be designed to have a total depth of the sum of the ponded depth and the depth of

storage. The area of the cell should be the larger of the areas required for ponding and for storage. If the area required for storage is greater than the area required for ponding, the depth of ponding can be reduced but not below a depth of 2 to 3 ft, thereby increasing the available depth of storage. If the area for storage is still greater, the only way to reduce the area requirements further would be to remove settled treated material from the basin into the primary containment area to decrease the required storage volume. In the overall basin design, it is important to use the greatest practical depth and to optimize its use to provide good mixing through the discharge culvert, ponding for good settling, and storage for treated material. To minimize the size of the secondary area and to maximize the energy available for mixing, the secondary area should be used only for temporary storage except for small one-time projects. Therefore, the settled treated material should be regularly removed from the basin. This approach would also facilitate dewatering and recurring use of the area for chemical treatment.

196. Mud pumping. If the settled material is to be pumped, the required pumping rate would be

$$\begin{aligned}\text{Mass Pumping Rate, g/day} &= (\text{Influent conc., g}/\ell \\ &\quad - \text{Effluent conc., g}/\ell) \times (\text{Average flow rate, cfs}) \\ &\quad \times 28.31\ \ell/\text{ft}^3 \times (\text{Seconds of production per day})\end{aligned} \tag{33}$$

$$\begin{aligned}&\text{Volumetric Pumping Rate, ft}^3\text{/day} \\ &\quad = (\text{Mass Pumping Rate, g/day}) \div [2 \times 50\ \text{g}/\ell + 25\ \text{g}/\ell/\text{ft} \\ &\qquad \times (\text{Average depth of storage, ft})] \times 2\end{aligned} \tag{34}$$

197. Inlet baffles. The inlet hydraulics of the secondary area can have a significant effect on settling performance. Inlet baffles as shown in Figure 26 can reduce the effects of short-circuiting and turbulent flow and assist in distributing the flow laterally. The baffles should be placed about one diameter directly in front of the inlet.

The baffle should be at least two diameters wide and may be either slotted or solid. Slotted baffles are better and may be made of 4- by 4-in. wooden posts spaced several inches apart. The main purpose of the inlet baffles is to dissipate the kinetic energy of the incoming water and the velocity of the flow toward the weir.

198. Effect on dewatering. Design of the secondary area must consider dewatering of the primary area. If the primary area is to be dewatered using the primary weir box to drain the water, the elevation of the surface of the water or stored material in the secondary area must be lower than the final elevation of the stored material to be attained during dewatering. The elevation difference should be at least 2 ft if the drainage is to be treated. This point is demonstrated in Figure 35.

199. There are several alternatives that can be used to provide for dewatering:

a. The secondary area can be constructed at a lower elevation.

b. The settled, treated material stored in the secondary area can be dewatered and thereby consolidated first.

c. The material can be pumped out of the secondary area.

d. The water can be pumped out of the primary area.

e. A special drainage structure can be constructed to drain the primary cell.

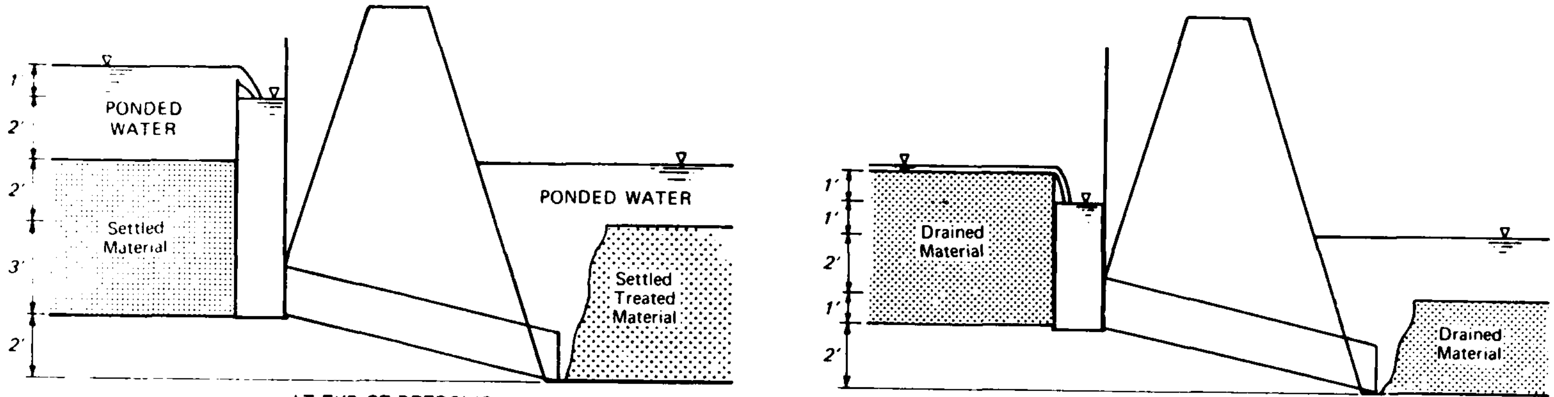
f. A channel can be cut through the settled material in the secondary area to permit drainage through the basin.

The best approach is dependent on site- and project-specific considerations. The effect of treatment on dewatering of the primary area is just one example showing that the designer should consider the entire disposal operation when designing the treatment system. Treatment should not be tacked on a disposal operation as an afterthought.

200. Design example. Given the following project information, the settling basin size would be determined as follows:

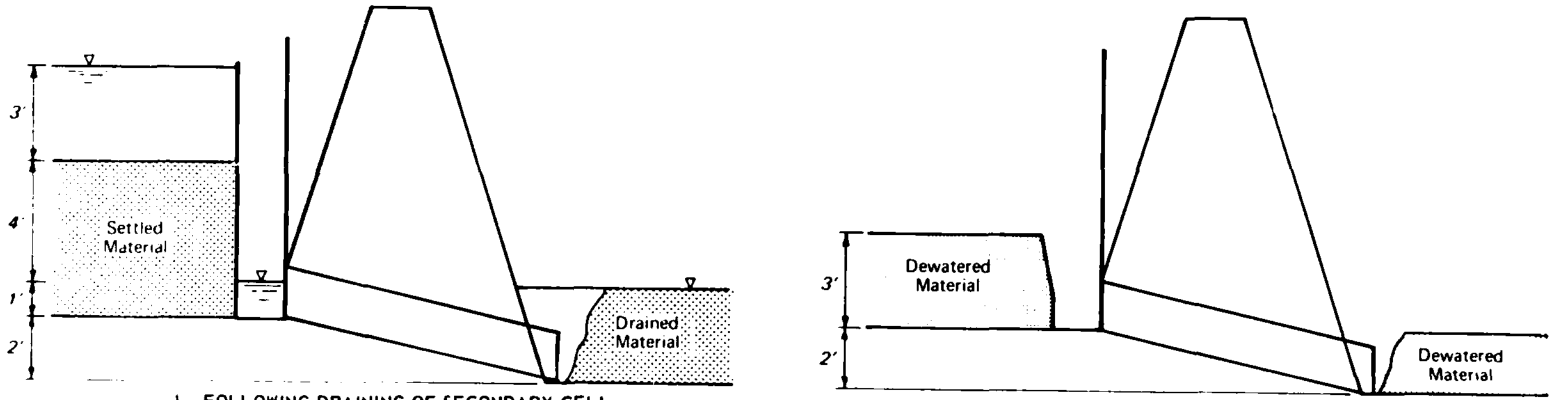
a. Project information.

Primary effluent solids conc.	2 g/ℓ
Secondary effluent solids conc.	50 mg/ℓ



a. AT END OF DREDGING

c. AT END OF TREATING DRAINAGE FROM PRIMARY CELL



b. FOLLOWING DRAINING OF SECONDARY CELL

d. FOLLOWING DEWATERING

Figure 35. Example elevations in containment areas during dewatering sequence

Volume to be treated (as determined in the polymer feed system design)	$5 \times 10^8 \ell$
Depth of basin	6 ft
Average flow rate	16 cfs

b. Volume of settled treated material. Assuming a ponded depth of 3 ft,

$$\text{Mass of settled material} = (2 - 0.05)\ \text{g}/\ell \times 5 \times 10^8\ \ell = 9.75 \times 10^8\ \text{g} \qquad (27\ \text{bis})$$

$$\text{Avg. conc. of settled material} = [(2 \times 50\ \text{g}/\ell) + (25\ \text{g}/\ell/\text{ft} \times 3\ \text{ft})] \div 2 = 88\ \text{g}/\ell \qquad (28\ \text{bis})$$

$$\begin{aligned}\text{Volume of settled material} &= 9.75 \times 10^8\ \text{g} \div 88\ \text{g}/\ell \\ &= 1.11 \times 10^7\ \ell \\ &= 3.91 \times 10^5\ \text{ft}^3 \text{ or } 9.0\ \text{acre-ft}\end{aligned} \qquad (29\ \text{bis})$$

c. Required area based on storage.

$$\text{Area} = 9.0\ \text{acre-ft} \div 3\ \text{ft} = 3.0\ \text{acres} \qquad (30\ \text{bis})$$

d. Volume of ponding.

$$\text{Ponded volume} = 16\ \text{cfs} \times 9000\ \text{sec} = 1.44 \times 10^5\ \text{ft}^3 \text{ or } 3.3\ \text{acre-ft} \qquad (31\ \text{bis})$$

e. Required area based on ponding.

$$\text{Area} = 3.3\ \text{acre-ft} \div 3\ \text{ft} = 1.1\ \text{acres} \qquad (32\ \text{bis})$$

f. Second trial. The areas based on storage and ponding are quite different. Therefore, the ponded depth should be decreased to reduce the area required for storage.

Using a ponded depth of 2 ft and, therefore, a storage depth of 4 ft,

$$\text{Avg. conc. of settled material} = [(2 \times 50\ \text{g}/\ell) + (25\ \text{g}/\ell/\text{ft} \times 4\ \text{ft})] \div 2 = 100\ \text{g}/\ell \qquad (28\ \text{bis})$$

$$\begin{aligned}\text{Volume of settled material} &= 9.75 \times 10^8\ \text{g} \div 100\ \text{g}/\ell \\ &= 9.75 \times 10^6\ \ell \\ &= 3.45 \times 10^5\ \text{ft}^3 \\ &= 7.9\ \text{acre-ft} \qquad (29\ \text{bis})\end{aligned}$$

$$\begin{aligned}\text{Area for storage} &= 7.9\ \text{acre-ft} \div 4\ \text{ft} \\ &= 1.98\ \text{acres} \qquad (30\ \text{bis})\end{aligned}$$

$$\begin{aligned}\text{Ponded volume} &= 16\ \text{cfs} \times 9000\ \text{sec} \\ &= 1.44 \times 10^5\ \text{ft}^3 \\ &= 3.3\ \text{acre-ft} \qquad (31\ \text{bis})\end{aligned}$$

$$\begin{aligned}\text{Area for ponding} &= 3.3\ \text{acre-ft} \div 2\ \text{ft} \\ &= 1.65\ \text{acres} \qquad (32\ \text{bis})\end{aligned}$$

g. Final design. The two areas in the second trial are similar indicating a better design. Therefore, the secondary cell should have the following characteristics:

Volume	12 acre-ft or 5.2×10^5 ft^3
Area	2 acres
Depth	6 ft
Storage depth	4 ft
Ponded depth	2 ft

201. The area and depth of the basin can be reduced further if the basin is not used for storage, that is, if the settled material is pumped out regularly. The size could be reduced to about an area of 1.0 acre and a depth of 5 ft. With a shallow storage depth, the solids concentration of the settled material would be about 60 g/ℓ.

202. The mud pumping rate, assuming 16 hr of production per day, would be:

$$\begin{aligned}\text{Solids Pumping Rate} &= (2.0 - 0.05)\ \text{g}/\ell \\ &\quad \times 28.31\ \ell/\text{ft}^3 \times 16\ \text{cfs} \\ &\quad \times 16\ \text{hr/day} \times 3600\ \text{sec/hr} \\ &= 5.09 \times 10^7\ \text{g/day} \qquad (33\ \text{bis})\end{aligned}$$

$$\begin{aligned}\text{Volumetric Pumping Rate} &= 5.09 \times 10^7\ \text{g/day} \div 60\ \text{g}/\ell \\ &= 8.5 \times 10^5\ \ell/\text{day} \\ &= 0.347\ \text{cfs or } 156\ \text{gpm} \qquad (34\ \text{bis})\end{aligned}$$

General design considerations

203. Shelter. A building should be provided to house the equipment and to furnish shelter for the operators. An 8- by 12-ft portable building is sufficient unless the polymer storage tank and dilution tanks must be housed.

204. Equipment. The equipment should be simple, rugged, heavy-duty, continuous-duty, low-maintenance equipment. Backup equipment must be provided for all essential components.

205. Safety. Good lighting must be provided for the entire work area. The weir must be furnished with a walkway and railings. Provisions should be made for safe, simple adjustments of the weir boarding.

206. Costs. These cost estimates are based on the field demonstrations described in Part IV of this report. The principal costs are construction, labor, and polymer. The costs are presented in 1981 dollars.

207. The one-time, project-independent engineering and design costs are

Flocculant screening	$2,000
Design and equipment selection	$3,000

208. The major nonexpendable equipment costs are given below, but these costs can be much larger if the polymer must be housed or if the polymer must be prediluted prior to feeding.

Two polymer feed pumps with motors and controllers	$ 3,400
Two dilution water pumps with motors	$ 1,200

Two generators	\$ 5,000
One mud pump	\$10,000
One portable building	\$ 5,000
Polymer and dilution water feed lines, intake, and injection rig	\$ 1,000
One mixing eductor	\$ 150
Other miscellaneous equipment	\$ 1,000
Vehicle	\$ 8,000
Portable turbidimeter	\$ 800
Total	\$35,550

Based on a 2-year design life, the prorated monthly cost would be about \$1,500/month. These costs are slightly dependent on the size of the project.

209. The cost of expendable supplies is dependent on the project size.

Fuel	\$400/month
Polymer	\$0.70/lb

210. The labor requirements are dependent on the required effluent quality. To achieve consistently good removals, an operator should attend the system during all operating hours. The operator requires only minimal training but good mechanical aptitude. For the majority of the time, the operator will be idle and free to do other tasks. Labor costs for full-time operators would be about

Labor costs = \$15/hr × 1.5 × (Number of production hours)

211. The total cost excluding costs of construction (secondary cell and outlet structure, access road, land) would be about $\$0.08/yd^3$ to $\$0.25/yd^3$ of in situ sediment to be dredged or \$35 to \$100 per hour of production. The rate of cost is dependent on the size of the project, the production rate, and the dosage of polymer. The approximate breakdown of variable costs are given below for eight cases.

Dredge Size in.	Polymer Dosage mg/ℓ	Variable Cost, percent Equipment	Labor	Polymer	Fuel
10	4	12	70	15	3
	10	9	57	32	2
14	4	10	60	27	3
	10	7	43	48	2
18	4	9	51	38	2
	10	5	33	61	1
24	4	7	39	52	2
	10	4	22	73	1

Operating Guidelines

Operator's manual

212. Prior to the start of the project, an operator's manual and treatment log book should be prepared to minimize problems during the operation of the treatment system. The operator's manual should contain the maintenance schedule, procedures for operating each piece of equipment and the weir, and procedures for adjusting the polymer dosage. The treatment log book should be used to keep a complete record of the treatment operation. The record should include hours of operation, flow rate, polymer dosage, influent and effluent turbidity, basin depths, depth of settled treated material, maintenance, problems, and significant observations.

213. The maintenance schedule and operating procedures for the equipment are dependent on the equipment selection and should be developed specifically for the selected pieces. To set the polymer dosage, it is first necessary to calibrate the polymer pump. The polymer flow rate should be measured for the range of controller settings. Next, based on the laboratory results, a table should be prepared that gives the required dosage as a function of influent turbidity. Then, a table of controller settings should be prepared for a variety of dosages and flow rates. At low flow rates, there is less mixing and the polymer is less effective. Therefore, higher dosages are often required at low flow. If a relationship between mixing and required dosage was developed in the laboratory, the relationship should be converted to relate

flow rate and dosage so the operator can readily adjust the dosage. The required dosages must be verified during the start of operation and the values in the tables must be adjusted accordingly. After verification the operator would only have to measure the influent turbidity and flow rate to determine the controller setting for the polymer pump.

Field dosage verification

214. During verification of the required dosages, the effectiveness of a particular dosage can be evaluated immediately by grabbing a sample of treated suspension from the end of the discharge culvert connecting the two containment areas and running a column settling test on the sample. If the supernatant is clear after 10 min of settling, the dosage should be decreased until the supernatant is slightly cloudy. Better clarification will be achieved in the settling basin where the material can flocculate. This is especially true when the system has been operating continuously for a long period. After selecting a dosage, the effluent turbidity should be monitored to determine whether the dosage should be adjusted further. The dosage should be minimized to reduce chemical costs, but the effluent quality should not be allowed to deteriorate beyond the effluent requirements.

Flow measurement

215. The flow rate can be estimated by measuring the depth of water flowing over the weir crest and the weir length. Assuming that the entire weir crest is at the same elevation, the flow rate can be computed as follows (Rehbock 1912; Rao 1975; Streeter 1971):

$$H = (h/0.85) \div 12 \text{ in./ft} \tag{35}$$

where

H = static head over weir crest, ft
h = depth of flow over weir, in.

$$Q = 3.33\ B(H)^{3/2} \tag{36}$$

where

Q = flow rate, cfs

B = weir length, ft

The above equations apply for sharp- and narrow-crested rectangular weirs that are not submerged.

216. A table should be generated relating the depth of flow over the weir h and the flow rate Q and included in the operator's manual. The weir length should be measured and not taken from design drawings to ensure accuracy. With this table the operator would easily be able to estimate the flow rate by measuring the depth of flow without performing any difficult computations or requiring additional information. The operator should measure the depths at several locations along the weir crest and average the resulting flow rates to determine the overall flow rate. This method would minimize the estimating errors caused by an unlevel or uneven weir crest.

217. The weir crest may become submerged at flow greater than 20 percent above the average. The actual flow rate that submerges the weir is dependent on the weir length and culvert design. The flow rate over submerged weirs is controlled by discharge capacity of the culvert.

Weir operation

218. The weir must be properly operated to maintain good mixing conditions. The weir crest must be kept sufficiently high to maintain the required difference in elevation between the water surfaces of the two containment areas. The weir should also be used to maintain the required flow rate for good mixing. When the flow decreases below the minimum rate for good mixing, the operator should either lower the weir crest by 1 or 2 in., increasing the flow to its average rate, or raise the weir crest sufficiently to stop the flow.

219. The minimum flow rate is based on the experimentally determined minimum acceptable mixing Gt for effective treatment. The minimum flow can be determined as follows:

$$Q_{min} = Q_{avg}\left(\frac{Gt_{min}}{Gt_{avg}}\right)^2 \qquad (37)$$

An example computation is given below.

Given: Average flow = 25 cfs
Gt of average flow = 9000
Minimum acceptable Gt = 6000

The minimum allowable flow is

$$Q_{min} = 25 \text{ cfs} \left(\frac{6000}{9000}\right)^2$$

$$= 11.1 \text{ cfs}$$

220. In general, the weir crest should be operated at the highest practical elevation and the primary containment area should be allowed to fill before any water is discharged over the weir and treatment is started. This would maximize the depth and provide the best conditions for mixing, settling, and storage. Maintaining the maximum ponded depth in the primary area also minimizes the turbidity to be treated and therefore reduces the required polymer dosage.

Other considerations

221. General operation. During the project, the primary and secondary effluent turbidity, and flow rate should be measured at least six times per day and the polymer flow rate should be adjusted as needed. Each piece of equipment should be inspected regularly, particularly the water intake, injection rig, and pumps. The fuel and chemical levels should also be checked as required. Regular maintenance must be performed throughout the project. The buildup of settled treated material should be followed and the material should be pumped out of the basin as the storage volume is depleted.

222. Leakage. The operator should try to eliminate leakage through the weir when the treatment system is turned off. The flow rate of the leakage is too low to treat, but after a couple of days of downtime the leakage can completely exchange the contents of the secondary

area if left unchecked. Since it is untreated, the effluent quality will deteriorate markedly.

223. Dewatering. At the end of the project, the treatment system can be used to treat the drainage from the primary containment area during dewatering. The elevation of the interface of the settled material in the primary area must be greater than the elevation of the water surface of the secondary area. Therefore, the secondary area must be dewatered first to compact the settled treated material and to provide the depth required to treat the drainage at the lower weir height. It is possible that treated material may need to be pumped from the secondary area before the primary area can be dewatered through the weir.

PART VII: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

224. Chemical clarification is an effective treatment method to remove suspended solids and turbidity from the effluent of a fine-grained dredged material containment area. Low viscosity, highly cationic liquid polymers were found to be the most effective chemicals and the simplest to use. The treatment method can be adapted to work within the constraints of a normal disposal operation. The treatment system can be simplified to use little equipment, mainly pumps, thereby making operation easy. Mixing can be performed in the weir structure without mechanical equipment. A small secondary containment area can be used for settling and storage, eliminating the need for a clarifier and sludge handling equipment.

225. The operation of the system is simple. The main duties of the operators are maintenance, filling fuel and polymer feed tanks, inspection, adjusting polymer feed rate, and controlling the height of the weir crest to maintain good mixing. Heavy duty, continuous rated, reliable equipment minimizes operating problems.

226. A well-designed treatment system is capable of producing an effluent that averages a suspended solids concentration of less than 50 mg/ℓ and a turbidity of less than 50 NTU during continuous operation. Under adverse conditions, the effluent suspended solids concentration may be as high as 200 mg/ℓ and the turbidity as high as 200 NTU.

227. The jar test procedure described in this report is capable of determining the most effective flocculant, required dosage, mixing requirements, acceptable polymer feed concentration, and effects of variable primary effluent solids concentration. The required polymer dosage is directly related to the turbidity to be treated and inversely related to the amount of mixing available at the weir.

228. The costs of chemical treatment are highly variable and dependent on the specifics of the dredging project. Excluding the costs of the secondary containment area and weir structure, the costs may

range from about \$0.08/yd^3 to \$0.25/yd^3 of in situ sediment dredged depending on the production rate, dosage, and treatment design. The major costs are labor, polymer, and construction.

229. The dosage required to treat dredged material slurries by injecting polymer into the dredge pipeline is proportional to the nonsettleable turbidity or clay fraction of freshwater sediments. The same loading, milligrams polymer per gram of clays, is required for pipeline injection as for treatment at the weir. The required dosage would be much higher since the concentration of clays in a dredge discharge is much greater than in the effluent from a primary containment area. The variablity of the influent solids concentration would also require that a higher average dosage be used to compensate for periods of high solids concentration. The optimum injection location appears to be about 500 ft from the discharge point. Pipeline injection would greatly increase polymer costs but significantly reduce labor and construction costs. This treatment method may be applicable to small projects at freshwater sites that have a small clay fraction.

230. Finally, a better treatment system design can be achieved if treatment is considered during the planning of the disposal operation. In this manner, the containment area can be laid out to increase the hydraulic efficiency of the basins and to utilize the available depth efficiently for mixing, ponding, and storage.

Recommendations

231. Based on the results of this study, the following recommendations are made:

a. The effects of mixing provided by weir structures designed as recommended in this report on the effectiveness of polymer dosages should be examined and correlated with the effects from laboratory tests. This work is needed to verify the mixing design and to scale-up procedures based on the calculation of Gt values.

b. Column settling tests should be performed on treated material from the effluent of a primary containment area to examine the effects of treatment on the concentration of settled material.

c. The effects of treatment on the dewatering of settled material in the secondary basin should be examined.

d. The pipeline injection treatment method should be carefully studied in the laboratory before being further applied in the field. Laboratory procedures should be developed to test the method and to develop design parameters. Detailed polymer screening should be performed on several freshwater and saltwater sediment slurries that cover a wide range of clay concentrations.

e. Column settling tests and consolidation tests should be performed on the treated slurries to examine the effects of polymer addition on settleability and storage requirements.

f. After laboratory testing, a full-scale, long-term demonstration of pipeline injection should be performed to determine the effects on the effluent quality and the density profiles of the settled material.

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Table 1

Description of Flocculants

Aggregant	Form	Charge	Molecular Weight	Viscosity	Type
Calgon					
CA-2263	Liquid	Cationic	--	--	--
M-500	↓	↓	--	Very high	PA*
M-503	↓	↓	--	Low	PA*
M-512	↓	↓	--	High	--
M-515	↓	↓	--	--	--
M-540	↓	↓	--	--	--
M-550	Powder	Nonionic	--	Medium	PAM**
M-580	Powder	Anionic	High	Very high	PAM**
Hercofloc					
812	Liquid	Low cationic	--	High	--
815	↓	Medium cationic	--	High	--
834	↓	Cationic	--	--	--
848	↓	High cationic	--	Low	--
849	↓	Medium high cationic	--	Very high	--
860	↓	Very high cationic	--	Low	--
863	↓	Extremely high cationic	--	Low	--
864	↓	Very high cationic	--	Low	--
871	↓	Cationic	--	--	--
Magnifloc	↓				
515C	↓	Cationic	--	Not viscous	--
572C	↓	↓	Very low	Medium	--
573C	↓	↓	Low	Medium	PA*
577C	↓	↓	Moderate	High	PA*
581C	↓	↓	High	Very high	PA*

(Continued)

* Polyamine type.
** Polyacrylamide.

Table 1 (Concluded)

Aggregant	Form	Charge	Molecular Weight	Viscosity	Type
Magnifloc (Cont'd)					
585C	Liquid	Cationic	Low	Low	--
587C	Liquid	Cationic	Moderate	Medium	--
591C	Liquid	Cationic	High	Very high	--
834A	Powder	Anionic	Very high	--	--
Nalco					
7132	Liquid	Cationic	Moderate	High	--
8101	↓	High cationic	Moderate	Medium	--
8102		Cationic	Moderate	Medium	--
8103		--	--	--	--
8105		--	--	--	--

Table 2

Initial Aggregant Screening Results

Aggregant	Slurry Concentration g/ℓ	Dosage Minimum mg	Dosage Optimum mg	Final Turbidity NTU
Calgon				
CA-2263	0.21	20	40	60
M-500	0.21	4	10	6
	0.42	4	10	7.5
	0.84	5	12	11
	1.26	5	20	4
	1.69	5	35	31
	2.11	5	40	11
M-503	0.21	2	3	13
	0.42	2	6	9
M-512	0.21	14	20	21
	0.42	22	30	17.5
	0.84	20	40	155
M-515	0.21	25	50	13
	0.42	11	80	22
M-540	0.21	--	55*	--
M-550	0.21	18	42	78
M-580	0.21	--	25*	--
Hercofloc				
812	0.5	--	40*	--
815	0.5	--	40*	--
834	0.5	35	40	69
848	0.5	10	20	49
849	0.5	--	30*	--
860	0.42	--	30*	--
863	0.21	--	20*	--
	0.42	--	25*	--
864	0.42	--	30*	--

(Continued)

* No flocs, discontinued dosing after recorded optimum.

(Sheet 1 of 3)

Table 2 (Continued)

Aggregant	Slurry Concentration g/ℓ	Dosage Minimum mg	Dosage Optimum mg	Final Turbidity NTU
Hercofloc (Cont'd)				
871	0.5	30	40	83
Magnifloc				
515C	0.21	35	55	10
0.42	--	40*	--	
572C	0.21	3	10	6
	0.42	5	15	6
	0.42	3	7	20
	0.84	4	12	11
	1.26	4	16	33
	1.69	5	30	2
	2.11	7	35	37
573C	0.42	2	4	15
	1.26	2	12	12
577C	0.42	2	6	16
	1.26	4	10	10
	2.11	4	20	9
581C	0.21	5	8	21
	0.42	6	10	23
	0.84	7	20	--
	1.26	7	35	28
	1.69	6	35	20
	2.11	10	40	26
585C	0.42	4	12	12
	1.26	6	12	45
587C	0.42	4	10	11
	1.26	5	20	13
591C	0.21	6	10	16
	0.42	7	15	10

(Continued)

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* No flocs, discontinued dosing after recorded optimum.

(Sheet 2 of 3)

Table 2 (Concluded)

Aggregant	Slurry Concentration g/ℓ	Dosage Minimum mg	Dosage Optimum mg	Final Turbidity NTU
Magnifloc (Cont'd)				
591C (Cont'd)	0.84	7	30	15.5
	1.26	10	35	22
	1.69	10	50	15
	2.11	8	55	8
834A	0.21	--	32*	--
Nalco				
7132	0.42	4	8	22
	1.26	6	14	12
8101	0.42	6	12	8
	1.26	8	18	15
8102	0.42	4	8	30
	1.26	6	12	25
8103	0.42	2	4	21
	1.26	4	12	13
8105	0.42	4	10	15
	1.26	6	14	14
Ferric chloride	0.42	15	30	10
	1.26	40	65	78
Aluminum sulfate	0.42	40	60	13
Ferrous sulfate	0.42	35	60	49
Alum	0.42	--	40*	--

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* No flocs, discontinued dosing after recorded optimum.

(Sheet 3 of 3)

Table 3

Jar Test Results

Aggregant	Slurry Concentration g/ℓ	Turbidity, NTU, at Indicated Polymer Dosage, mg/ℓ 2	4	6	8	10	12	14	16	18	20	22	24
Calgon													
M-500	0.5	>240	190	180	160	140	100	80	60	35	30	15	--
M-503	0.5	>220	180	155	130	100	82	70	55	45	35	20	--
Magnifloc													
572C	0.5	215	205	195	180	160	137	120	100	84	54	38	--
573C	0.5	--	160	--	75	--	35	--	19	--	13	--	16
577C	0.5	--	95	--	35	--	18	--	15	--	15	--	20
581C	0.5	190	180	180	170	145	130	110	78	52	38	11	--
585C	0.5	--	190	--	130	--	97	--	57	--	57	--	16
587C	0.5	>240	210	200	165	130	95	85	70	55	50	40	--
591C	0.42	--	210	200	180	160	130	70	50	25	12	--	--
Nalco													
7132	0.5	--	200	--	125	--	63	--	40	--	18	--	16
8101	0.5	--	>240	--	205	--	170	--	160	--	130	--	110
8102	0.5	--	140	--	180	--	142	--	95	--	34	--	27
8103	0.5	--	175	--	125	--	68	--	34	--	15	--	16

(Continued)

Table 3 (Concluded)

Aggregant	Slurry Concentration g/ℓ	Turbidity, NTU, at Indicated Polymer Dosage, mg/ℓ 2	4	6	8	10	12	14	16	18	20	22	24
Calgon													
M-500	1.0	>247	200	150	70	42	16						
M-503	1.0	>250	195	190	145	105	57						
Magnifloc													
573C	1.0	>240	150	35	22	16	11						
577C	1.0	110	25	18	13	13	13						
591C	1.0	>280	220	190	59	24	15						
Nalco													
7132	1.0	90	27	17	14	15	11						
8103	1.0	120	110	59	18	12	11						
Magnifloc													
573C	2.0	>340	>260	>265	180	52	31						
577C	2.0	>250	>260	>325	180	41	19						
Nalco													
7132	2.0	>280	>315	>300	>335	>280	160						

Table 4

Selected Polymers for Various Dredging Projects

Site	Project Type	Sediment Type	Selected Polymer
Yazoo River, Mississippi	New construction	Freshwater clay (CL)*	Magnifloc 577C
Yellow Creek, Tenn-Tom Waterway, Mississippi	Maintenance	Freshwater silty sand (SM)*	Hercofloc 863
Port Canaveral, Florida	Maintenance	Saltwater clay	Magnifloc 577C
Cooper River Rediversion, South Carolina	New construction	Freshwater clay	Hercofloc 863
Depot Slough, Oregon	Maintenance	Saltwater organic sandy silt	Hercofloc 863
Red Wing Small Boat Harbor, Mississippi River, Minnesota	Maintenance	Freshwater sandy silt	Nalco 7103

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* Unified Soil Classification System (USCS) designation.

Table 5

Turbidity Results at Yellow Creek Demonstration

	Hercofloc 863		Turbidity, NTU	
Hour	Dosage mg/ℓ	Duration hr	Influent	Effluent
0	13	0	--	250
9	10	0	--	--
10.5	10	1.5	1110	56
11	10	2	--	68
11.5	10	2.5	--	58
12	10	3	--	52
12.5	10	3.5	--	51
13	10	4	--	51
13.5	10	4.5	--	48
14	10	5	--	48
15	8	0	1075	49
16	8	1	1050	80
17	8	2	1025	89
18	8	3	1075	82
19	8	4	1150	86
20	8	5	1075	87
21	5	0	975	102
22	5	1	1200	122
23	5	2	1050	151
24	5	3	1150	148
25	5	4	1100	168
26	5	5	1100	200
27	13	0	1200	248
28	13	1	1200	132
29	13	2	1200	164
30	0	0	--	--
90	10	0	1150	504
92	10	2	1175	364
94	10	4	1225	189
96	10	6	1200	161
98	10	8	1225	140
100	10	10	1225	121
102	10	12	1150	107
104	10	14	1100	101
106	13	1	1150	88
108	13	3	1175	104
110	13	5	1175	84
112	13	7	1175	72
115	13	10	1150	63

Table 6

Suspended Solids Results at Yellow Creek Demonstration

Hour	Hercofloc 863 Dosage mg/ℓ	Hercofloc 863 Duration hr	Suspended Solids Concentration, mg/ℓ Influent	Suspended Solids Concentration, mg/ℓ Effluent
0	13	0	--	--
9	10	0	--	--
10.5	10	1.5	1220	56
11	10	2	--	73
11.5	10	2.5	--	45
12	10	3	--	42
12.5	10	3.5	--	39
13	10	4	--	43
13.5	10	4.5	--	39
14	10	5	--	28
15	8	0	1160	42
16	8	1	--	70
17	8	2	1130	71
18	8	3	1220	63
19	8	4	1200	73
20	8	5	1190	69
21	5	0	1200	91
22	5	1	--	108
23	5	2	1230	139
24	5	3	1220	141
25	5	4	1230	172
26	5	5	1300	208
27	13	0	1320	226
28	13	1	1260	170
29	13	2	1280	111
30	0	0	1220	--
90	10	0	1220	440
92	10	2	1180	315
94	10	4	1280	206
96	10	6	1300	154
98	10	8	1280	131
100	10	10	1290	114
102	10	12	1180	96
104	10	14	1200	86
106	13	1	1230	73
108	13	3	1140	80
110	13	5	--	52
112	13	7	1270	44
115	13	10	1280	29

Table 7

Results with Catfloc-T at Yellow Creek Demonstration

Hour	Dosage mg/ℓ	Duration hr	Turbidity, NTU Influent	Turbidity, NTU Effluent	Suspended Solids Concentrations, mg/ℓ Influent	Suspended Solids Concentrations, mg/ℓ Effluent
0	10	0	1150	63	1280	29
1	10	1	1150	62	1280	45
2	10	2	--	58	--	38
3	10	3	1100	56	1170	33
4	10	4	--	62	--	45
5	8	0	1100	78	1160	62
6	8	1	--	92	--	62
7	8	2	1050	95	1040	82
8	0	0.5	--	200	--	162
9	0	1.5	1050	355	1090	288
10	0	2.5	--	555	--	492
11	0	3.5	1050	640	1100	600
12	0	4.5	--	760	--	672
13	0	5.5	1050	870	1180	770
38	13	0	--	32	--	18
39	13	1	--	30	--	17
40	13	2	--	33.5	--	15
41	13	3	--	66	--	54
42	13	4	--	70	--	55

Note: Hour 14, 10 mg/ℓ Hercofloc 863 was used for 24 hr.
Hours 8 to 14, no polymer was fed due to a break in the feed line.

Table 8

Jar Test Verification Results

Hercofloc 863 Dosage, mg/ℓ	Turbidity NTU	Turbidity Removal, percent	Suspended Solids Concentration, mg/ℓ	Suspended Solids Removal, percent
		Following 10 min of Settling		
0	825	2.9	1120	22.8
4	240	71.8	300	79.3
6	157	81.5	164	88.7
8	97	88.6	92	93.7
10	63	92.6	54	96.3
12	59	93.1	50	96.6
		Following 75 min of Settling		
0	685	19.4	830	42.8
4	215	74.7	276	81.0
6	130	84.7	126	91.3
8	77	90.9	82	94.3
10	53	93.8	48	96.7
12	39	95.4	32	97.8

Table 9

Suspended Solids Concentration Profiles of Treated Material

Location A*		Location B		Location C		Location D		Location E	
Depth, ft	Solids Concentration g/ℓ	Depth, ft	Solids Concentration g/ℓ	Depth, ft	Solids Concentration g/ℓ	Depth, ft	Solids Concentration g/ℓ	Depth, ft	Solids Concentration g/ℓ
0.5	59.1	1.0	5.56	1.5	1.11	2.5	0.70	2.5	0.64
1.0	70.0	1.5	35.1	2.0	89.8	3.0	0.54	4.0	0.65
1.5	78.3	2.0	14.7	2.5	8.24	3.5	1.79	4.5	1.90
2.0	108.9	2.5	52.9	3.0	77.6	4.0	1.15	5.0	85.8
2.5	113.6	3.0	56.6	3.5	47.6	4.5	78.5	5.5	69.6
3.0	100.9	3.5	84.0	4.0	93.8	5.0	60.7	6.0	80.7
3.5	110.1	4.0	172.4	4.5	129.2	5.5	75.2	Bottom 6.5	124.4
4.0	98.3	Bottom 4.8	193.4	5.0	116.3	6.0	102.7		
4.5	163.3			Bottom 6.0	170.8	Bottom 6.6	161.9		
Bottom 5.3	196.4								

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* Locations shown in Figure 20.

Table 10

Costs for Yazoo River Demonstrations

		1979 Dollars
Engineering and Design		
Screening of chemicals		\$750
Design and fabrication of spray rig		200
Miscellaneous items		100
Engineering and equipment selection		Unknown
Nonexpendable Equipment		No charge
Construction		
Secondary cell, spillway, and outlet structure		Unknown
Expendable supplies		
Polymer (per mg/ℓ of dosage)		\$ 4/hr
Gas and oil		2/hr
Miscellaneous		1/hr
Equipment rentals		
Generator		\$ 7/day
Vehicles		54/day
Operating labor		\$25/hr
Average cost		
6 mg/ℓ dosage		$\$0.14/\text{yd}^3$
	or	\$55/hr
12 mg/ℓ dosage		$\$0.25/\text{yd}^3$
	or	\$80/hr

Table 11

Yellow Creek Demonstration Costs

	1981 Dollars
Engineering and design	
Laboratory tests	$2,000
Design and equipment selection	3,000
Nonexpendable equipment	
2 polymer feed pumps with motors and controllers	$3,400
2 dilution water pumps with motors and controllers	3,700
2 generators	5,000
Flowmeter	2,300
Pump pulleys	100
Spray nozzles	100
Water jet eductor	150
Trailer	5,000
Polymer feed lines, dilution water lines and intake, and injection rig	1,000
Mud pump	10,000
Project equipment cost is 5% of total per month.	
Construction	
Secondary cell and outlet structure	Unknown
Land cost	Unknown
Access road	Unknown
Expendable supplies	
Polymer	$30,000
Gas and oil	1,200
Miscellaneous	400
Operating labor	30,000
Repair	800
Average cost	$0.20/yd^3 or $55/hr

Table 12

Breakdown of Yellow Creek Demonstration Costs

Category	Percent of Total Cost*
Engineering and design	7
Nonexpendable equipment	7
Expendable supplies	44
Operating labor	41
Repair	1

---

* Excluding construction costs.

Table 13

Settling Results for 120-g/ℓ Slurry

Time	Relative Interface Height at Indicated Polymer dosage, mg/ℓ					
hr	0	2	4	8	16	32
			100% Fine-Grained Material			
0	1.000	1.000	1.000	1.000	1.000	1.000
19	-	0.990	0.990	0.728	0.711	0.675
22	-	0.988	0.989	0.716	0.701	0.617
23	-	0.985	0.989	0.710	0.698	0.665
24	-	0.981	0.989	0.708	0.694	0.661
25.5	-	0.963	0.988	0.700	0.688	0.657
29.5	-	0.747	0.984	0.690	0.682	0.647
43	-	0.687	0.800	0.658	0.654	0.624
45	-	0.680	0.800	0.652	0.650	0.619
			75% Fine-Grained, 25% Coarse-Grained Material			
0	1.000	1.000	1.000	1.000	1.000	1.000
0.5	0.980	0.978	0.978	0.976	0.953	0.965
1.0	0.936	0.931	0.931	0.929	0.908	0.916
2.0	0.756	0.755	0.747	0.763	0.743	0.775
3.5	0.608	0.604	0.605	0.607	0.596	0.612
5.0	0.586	0.585	0.582	0.584	0.573	0.584
6.0	0.579	0.578	0.573	0.577	0.564	0.572
9.0	0.553	0.552	0.548	0.552	0.537	0.542
			50% Fine-Grained, 50% Coarse-Grained Material			
0	1.000	1.000	1.000	1.000	1.000	1.000
0.4	0.978	0.974	0.980	0.973	0.970	0.959
0.6	0.963	0.960	0.958	0.958	0.954	0.939
1.0	0.888	0.887	0.989	0.892	0.887	0.873
1.4	0.800	0.799	0.815	0.801	0.804	0.792
1.9	0.697	0.695	0.717	0.711	0.702	0.711
3.0	0.585	0.526	0.543	0.540	0.544	0.549
3.9	0.503	0.500	0.502	0.509	0.512	0.511
5.3	0.482	0.479	0.482	0.489	0.494	0.493

Table 14

Suspended Solids Results for 120-g/ℓ Slurry

50% Fine-Grained, 50% Coarse-Grained Material

Time	Solids Concentration, g/ℓ, at Midpoint of Supernatant at Indicated Polymer Dosages, mg/ℓ					
hr	0	2	4	8	16	32
0.1	4.98	5.04	5.03	4.58	4.60	3.25
1.0	2.90	2.76	2.78	2.68	2.65	--
1.9	2.68	2.61	2.52	2.46	2.34	2.01
3.0	1.53	1.66	1.53	1.41	1.53	1.26
3.9	1.37	1.38	1.32	1.29	1.21	1.17
5.4	0.28	0.36	0.28	0.28	0.04	0.04

Table 15

Settling Results for 100-g/ℓ Slurry

Time	Relative Interface Height at Indicated Polymer Dosage, mg/ℓ				
hr	0	4	8	16	32
	100% Fine-Grained Material				
0	1.00	1.00	1.00	1.00	1.00
0.7	0.99	0.99	0.99	0.99	0.98
1.0	0.98	0.98	0.98	0.97	0.97
1.3	0.97	0.97	0.97	0.96	0.96
1.8	0.94	0.92	0.92	0.90	0.94
2.0	0.92	0.90	0.90	0.88	0.93
2.3	0.89	0.86	0.86	0.84	0.93
3.1	0.77	0.74	0.74	0.73	0.91
3.4	0.74	0.71	0.72	0.72	0.91
4.5	0.69	0.67	0.68	0.69	0.90
6.1	0.67	0.66	0.66	0.68	0.75
24.2	0.59	0.57	0.58	0.59	0.61
	75% Fine-Grained, 25% Coarse-Grained Material				
0	1.00	1.00	1.00	1.00	1.00
0.9	0.94	0.93	0.92	0.91	0.87
1.0	0.92	0.92	0.91	0.90	0.84
1.3	0.88	0.88	0.87	0.85	0.78
1.6	0.85	0.84	0.83	0.81	0.75
1.9	0.80	0.79	0.78	0.76	0.70
2.7	0.64	0.64	0.63	0.62	0.60
4.0	0.57	0.57	0.56	0.55	0.60
5.7	0.55	0.54	0.53	0.52	0.58
23.8	0.45	0.44	0.43	0.43	0.42

(Continued)

Table 15 (Concluded)

Time hr	Relative Interface Height at Indicated Polymer Dosage, mg/ℓ 0	4	8	16	32
	50% Fine-Grained, 50% Coarse-Grained Material				
0	1.00	1.00	1.00	1.00	1.00
0.3	1.00	1.00	1.00	0.89	0.89
0.5	0.99	0.99	0.99	0.84	0.82
0.7	0.89	0.88	0.87	0.79	0.75
0.9	0.84	0.82	0.81	0.71	0.68
1.3	0.77	0.74	0.73	0.63	0.59
3.4	0.49	0.48	0.47	0.46	0.47
5.4	0.46	0.44	0.44	0.42	0.43

Table 16

Suspended Solids Results for 100-g/ℓ Slurry

Time hr	Solids Concentration, g/ℓ, at Midpoint of Supernatant at Indicated Polymer Dosage, mg/ℓ 0	4	8	16	32
			100% Fine-Grained Material		
1.8	6.82	7.04	6.53	6.26	2.30
3.4	6.45	5.97	6.27	4.77	--
4.5	5.95	4.99	4.78	3.90	--
24.2	1.08	1.12	0.92	0.88	0.76
			75% Fine-Grained, 25% Coarse-Grained Material		
0.9	27.24	18.14	17.08	13.66	17.57
1.3	7.94	7.36	7.00	7.01	5.69
1.9	6.73	6.30	5.82	5.36	4.25
2.7	5.65	5.39	4.83	--	3.52
4.0	4.31	3.90	3.41	2.78	2.92
5.7	3.16	3.14	2.79	2.44	2.02
23.8	0.88	0.76	0.88	0.64	0.68
			50% Fine-Grained, 50% Coarse-Grained Material		
1.3	6.00	4.93	4.76	3.41	1.96
3.4	1.94	1.70	1.65	1.49	1.25
5.4	1.25	1.09	1.17	0.93	0.72

Table 17

Pipeline Injection Treatment Efficiency, 100-g/ℓ Slurry

Slurry	Polymer Dosage, mg/ℓ	Average Suspended Solids Reduction Relative to Control, percent
100 percent fine grained	4	4
	8	10
	16	22
	32	30
75 percent fine grained	4	7
	8	12
	16	23
	32	33
50 percent fine grained	4	13
	8	15
	16	26
	32	42

Table 18

Results of Pipeline Injection Field Test

Injection Location	Polymer Dosage mg/ℓ	Turbidity, NTU		Percent Removal	Suspended Solids Concentration, g/ℓ		Percent Removal
		Initial	Supernatant*		Initial	Supernatant*	
No addition		3,040	2,060	32.2	11.54	2.77	76.0
		4,900	3,360	31.4	17.70	4.50	74.6
		6,580	3,920	40.4	20.94	5.21	75.1
6000 ft	13	320	60	81.2	0.96	0.08	91.3
		730	115	84.2	7.06	0.10	98.5
		2,320	340	85.3	7.42	0.36	95.1
		2,400	435	81.9	8.30	0.54	93.5
	26	1,000	96	90.0	5.0	0.10	98.0
		2,000	99	95.0	8.0	0.09	98.8
		3,600	1,080	70.0	12.0	1.10	90.8
	39	2,480	107	95.7	7.75	0.10	98.7
		2,520	91	96.4	7.55	0.08	98.9
		2,940	208	92.9	10.16	0.23	97.7
		6,240	2,520	59.6	23.02	2.92	87.3
4000 ft	13	15,360	4,080	73.4	38.44	5.44	85.8
		17,640	5,440	69.2	50.44	6.70	86.7
		18,240	6,080	66.7	49.34	7.41	85.0

(Continued)

* Supernatant following 10 min of settling.

Table 18 (Concluded)

Injection Location	Polymer Dosage mg/ℓ	Turbidity, NTU		Percent Removal	Suspended Solids Concentration, g/ℓ		Percent Removal
		Initial	Supernatant		Initial	Supernatant	
4000 ft (Cont'd)	26	2,550	114	95.5	8.92	0.16	98.2
		5,040	368	92.7	18.72	0.46	97.5
		12,075	2,555	78.8	27.76	2.96	89.3
	39	4,270	156	96.3	14.32	0.20	98.6

Table 19

Removal of Nonsettleable Suspended Solids by Pipeline Injection

Injection Location	Polymer Dosage mg/ℓ	Polymer Loading mg/g*	Suspended Solids Concentration, g/ℓ		Percent Removal
			Nonsettleable**	Supernatant†	
No addition	0	0	2.89	2.77	4.0
		0	4.43	4.50	-1.7
		0	5.24	5.21	0.5
6000 ft	13	54.2	0.24	0.08	65.0
		7.3	1.77	1.77	94.1
		7.0	1.86	0.36	80.6
		6.3	2.08	0.54	74.0
	26	20.8	1.25	0.10	92.0
		13.0	2.00	0.09	95.3
		8.7	3.00	1.10	63.3
	39	20.1	1.94	0.10	94.8
		20.6	1.89	0.08	95.8
		15.4	2.54	0.23	90.9
		6.8	5.76	2.92	49.3
4000 ft	13	1.4	9.61	5.44	43.4
		1.0	12.61	6.70	46.9
		1.1	12.34	7.41	39.9
	26	11.7	2.23	0.16	92.8
		5.6	4.68	0.46	90.2
		3.7	6.94	2.96	57.3
	39	10.9	3.58	0.20	94.4

---

* Milligrams of polymer per gram of nonsettleable suspended solids.

** The suspended solids concentration which would not settle within 10 min in a 1-ℓ graduated cylinder without polymer addition and set to equal 25 percent of the initial suspended solids concentration of the sample.

† Supernatant following 10 min of settling.

Table 20

Removal of Nonsettleable Turbidity by Pipeline Injection

Injection Location	Polymer Dosage mg/ℓ	Polymer Loading mg/1000 NTU*	Turbidity, NTU Nonsettleable**	Turbidity, NTU Supernatant†	Percent Removal
No addition	0	0	1,980	2060	-4.7
		0	3,190	3360	-5.5
		0	4,280	3920	8.3
6000 ft	13	61.9	210	60	71.2
		27.7	470	115	75.8
		8.6	1,510	340	77.5
		8.3	1,560	435	72.1
	26	40.0	650	96	87.2
		20.0	1,300	99	92.9
		11.1	2,340	1080	56.3
	39	24.2	1,610	107	93.4
		23.8	1,640	91	94.4
		20.4	1,910	208	89.1
		9.6	4,060	2520	37.9
4000 ft	13	1.3	9,980	4080	59.1
		1.1	11,470	5440	52.6
		1.1	11,870	6080	48.7
	26	15.7	1,660	114	93.1
		7.9	3,280	368	88.8
		3.3	7,850	2555	67.4
	39	14.0	2,780	156	94.4

* Milligrams of polymer per 1000 NTU of nonsettleable turbidity.

** The turbidity which would not settle within 10 min in a 1-ℓ graduated cylinder without polymer addition and set equal to 65 percent of the initial turbidity.

† Supernatant following 10 min of settling.

Table 21

Design Mixing Values (Gt)

Flow cfs	Available Head, ft 2	3	4	5	6
5	8,200	9,800	11,300	12,200	12,900
8	7,800	9,300	10,800	11,600	12,300
12	7,500	9,000	10,400	11,200	11,900
16	7,200	8,700	10,000	10,800	11,500
21	7,000	8,400	9,700	10,500	11,100
27	6,800	8,200	9,500	10,200	10,800
36	6,600	7,900	9,100	9,800	10,400
47	6,400	7,600	8,800	9,500	10,100
60	6,200	7,400	8,500	9,200	9,800
74	6,000	7,200	8,300	8,900	9,500
106	5,700	6,800	7,900	8,500	9,000

END

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