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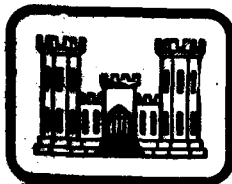
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LABORATORY AND PILOT SCALE EVALUATION OF COAGULATION, CLARIFICATION, AND FILTRATION FOR UPGRADING SEWAGE LAGOON EFFLUENTS.

by

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20. ABSTRACT (Continued)

convert complete retention lagoons to controlled discharge systems, thus increasing design capacities.

A truck-mounted chemical-physical treatment facility was designed and constructed for this study. Unit processes constituting the treatment facility included: coagulation, flocculation, sedimentation, and filtration. Analyses were performed to determine treatment efficiencies for biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), suspended solids, and orthophosphate. The algal genera present within the lagoon system being studied were also identified.

The efficiency of several coagulants alone and in combination with coagulant aids was investigated. Optimum dosages of coagulant and/or coagulant aid were determined. Alum, lime, and ferrous sulfate were tested as coagulants, and cationic polyelectrolytes WT 2820, WT 2076, WT 2830, and Aqua-Floc 420 were studied as coagulant aids.

The coagulation-flocculation-sedimentation system produced effluents with total suspended solids less than 15 mg/l and orthophosphate concentrations less than 1.0 mg/l. Mean COD and BOD₅ concentrations of 37 and 6 mg/l, respectively, were obtained. Addition of a granular media filtration system further reduced COD, BOD₅, total suspended solids, and orthophosphate concentrations to mean values of 30, 5, 7, and 0.42 mg/l, respectively.

Highest quality effluents were obtained at a pH ranging from 5.9 to 6.2, alum dosages between 200 and 300 mg/l, and addition of 1 to 2 mg/l of a cationic polyelectrolyte.

Similar results were also obtained using a fill and draw rather than a continuous flow system. Removals of orthophosphate and suspended solids ranged from 90 to 95 percent for the coagulation-flocculation-sedimentation system operated in the fill and draw mode of operation.

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PREFACE

The investigation reported herein was funded by the Office, Chief of Engineers, U. S. Army, from Civil Works Appropriation 96X3121, General Investigation--Research and Development.

This investigation was conducted during the period 1978-1979 by personnel of the Environmental Engineering Division (EED) of the Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), and the School of Civil Engineering and Environmental Science, Oklahoma University, Norman, Oklahoma.

The study was conducted with the permission and cooperation of the U. S. Army Engineer District, Tulsa, COL Anthony C. Smith, District Engineer. Appreciation is extended to Mr. Clyde Pigg, Reservoir Manager, and his men for their invaluable assistance provided on the portion of the study conducted at the Highway 9 recreation area.

The portion of the study at Arrowhead State Park was conducted with the permission and cooperation of Mr. Robert A. Pike, Director of Division of State Parks. Appreciation is extended to Mr. Gene Thompson, Superintendent of Arrowhead State Park, and his men for their assistance in setting up and dismantling the equipment.

The study was conducted by Dr. Leale E. Streebin, Mr. Jim Gopal, and Ms. Mary Waldron, Oklahoma University, and Messrs. Douglas Thompson and Mark Corey, EED. The work effort was accomplished under the direct supervision of Mr. Norman R. Francingues, Chief, Water Supply and Wastewater Treatment Group, and the general supervision of Mr. Andrew J. Green, Chief, EED, and Dr. John Harrison, Chief, EL. This report was prepared by Messrs. M. John Cullinane, Jr., and Richard A. Shafer, EED.

Directors of WES during the investigation and preparation of this report were COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

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

Units of measurement used in this report can be converted as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
acres	4046.856	square metres
cubic feet	0.02831685	cubic metres
Fahrenheit degrees*	5/9	Celsius degrees or Kelvins
feet	0.3048	metres
gallons (U. S. liquid)	0.003785	cubic metres
gallons (U. S. liquid) per day	0.003785	cubic metres per day
gallons (U. S. liquid) per minute	0.003785	cubic metres per minute
horsepower (550 foot- pounds per second)	745.6999	watts
inches	2.54	centimetres
pounds (force) per square inch	6894.757	pascals
square feet	0.09290304	square metres

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

LABORATORY AND PILOT SCALE EVALUATION OF COAGULATION,
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PART I: INTRODUCTION

Background

1. The U. S. Army Corps of Engineers (CE) is responsible for designing, constructing, maintaining, and operating wastewater treatment systems for its recreational areas at more than 50 CE projects located nationwide. The use of these areas for over 438 million visitor days in 1978 emphasizes the magnitude of this responsibility. The Corps of Engineers operates more than 2000 wastewater treatment facilities. A 1976 survey conducted by the U. S. Army Engineer Waterways Experiment Station (WES) revealed that of this number more than 200 are classified as wastewater stabilization lagoons.¹

2. The value of lagoons for treating wastewaters from small facilities has long been recognized. Lagoons for the treatment of municipal, industrial, recreational, and agricultural wastes have gained popularity in the last three decades. This popularity is attributable to low capital (where land costs are not excessive) and operation costs, low maintenance and repair costs, and the relative lack of technical skills required to successfully operate and maintain a lagoon system.

3. Recently, however, lagoons have fallen into disfavor due to the production of an algae-laden effluent with its attendant high concentrations of suspended solids. The removal of algae through chemical-physical means utilizing mechanical treatment has been technically demonstrated for large flow-through lagoon systems. The technical feasibility and cost-effectiveness of such systems for upgrading lagoons having an intermittent or seasonal discharge have not been proven.

Purpose

4. The purpose of this research was to investigate the technical feasibility of utilizing end-of-pipe chemical-physical methods for increasing the capacity of complete retention and/or intermittently discharging wastewater stabilization lagoons located at CE recreational sites.

Technical Approach

5. A three-phase study was designed to define technically sound and cost-effective chemical-physical treatment processes and to investigate the performance of a selected process or series of processes under field loading conditions:

- a. Phase I. Conduct a literature review to determine viable processes successfully utilized for upgrading flow-through lagoon systems. Develop pilot system design and operating criteria for a selected chemical-physical process for application to seasonally discharging lagoons. Investigate site requirements and select location for field tests.
- b. Phase II. Conduct laboratory studies to characterize wastewaters to be subjected to chemical-physical treatment for upgrading and determining optimum chemical dosages.
- c. Phase III. Evaluate pilot scale treatment process performance and determine operational procedures necessary to maintain efficient operation of the chemical-physical treatment process under field conditions utilizing both fill and draw and continuous flow-through modes of operation.

Data collected and conclusions drawn from the continuous-flow studies constitute the main body of this report, whereas the results of the batch flow studies are presented in Appendix A.

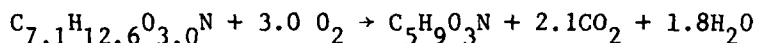
PART II: LITERATURE REVIEW

Lagoon Kinetics

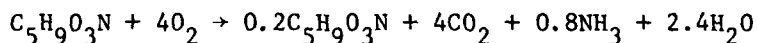
6. It is generally recognized that stabilization lagoons, when properly designed and operated, will eventually develop a population of algae and bacteria which, working in a symbiotic relationship, will partially stabilize the organic materials found in domestic wastewaters. The simplistic view of lagoon kinetics formerly held by the engineering community was one in which the bacteria oxidize the organic matter while algae, using the process of photosynthesis, supply the oxygen necessary for aerobic bacterial action. The lagoon process has, therefore, been described as a cyclic process in which unstable organic matter is converted to a stable cell mass.²

7. Unfortunately, the symbiotic relationship between the algae and bacterial species is several orders of magnitude more complex than this somewhat oversimplified view of stabilization lagoon kinetics. Figure 1 presents a suitable schematic representation of the activity occurring in a facultative lagoon.³ The transformation of organics and nutrients is characterized by the simultaneous synthesis and endogenous respiration of both the bacterial and algal species found in the lagoon. McKinney² presents the basic synthesis and respiration reactions as follows:

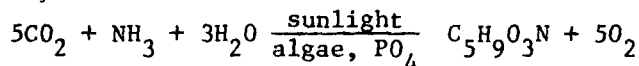
Bacterial Synthesis:



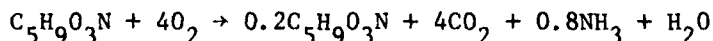
Bacterial Respiration:

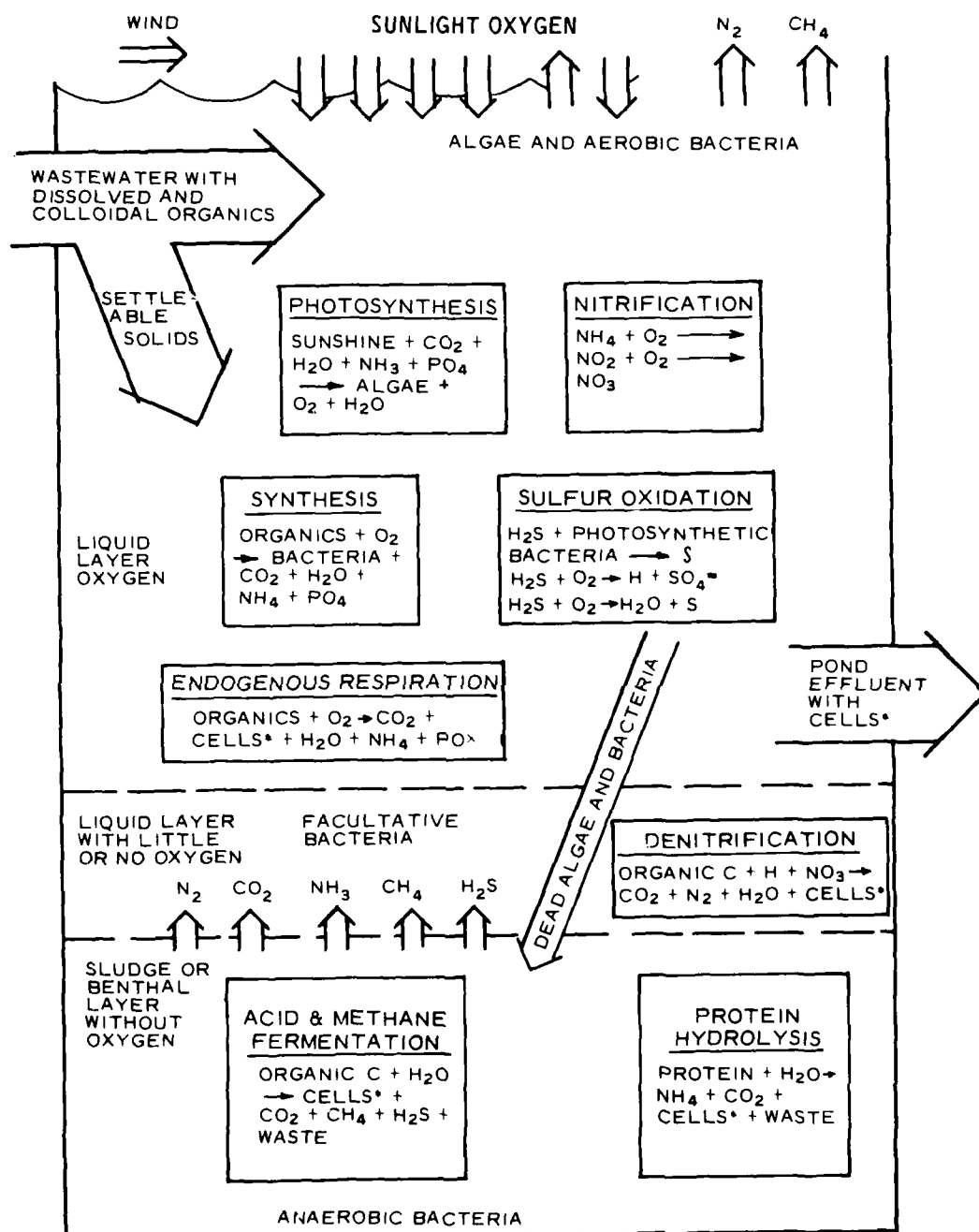


Algal Synthesis:



Algal Respiration:





NOTE: * REPRESENTS ALGAL AND BACTERIAL CELLS.

Figure 1. Schematic of activity in facultative ponds

8. The McKinney reactions described above are not sufficiently descriptive of the pollutant removal mechanisms actually taking place within the lagoon system. While the reaction equations presented in Figure 1 are somewhat of an oversimplification, the biochemical reactions and physical removal mechanisms taking place within the system are qualitatively portrayed.

9. The lagoon may be thought of as a three-layer system consisting of anaerobic, facultative, and aerobic zones. Incoming settleable solids plus dead bacterial and algal cells settle to the bottom of the lagoon into an anaerobic zone. These settled solids undergo acid and methane fermentation producing new bacterial cells, providing energy for the cells, and releasing CH_4 , CO_2 , H_2S , NH_3 , organic acids, and residues. These materials along with incoming suspended or dissolved organic materials in the raw wastewater are commingled through intrapond mixing resulting from wind or thermally induced currents and undergo aerobic decomposition in the aerobic zone.

10. Although Figure 1 is an oversimplification of the total process, the carbon and nutrient recycling effect taking place within the lagoon is illustrated. The effects of carbon recycling are: (a) decomposition of the solids originally in the raw wastewater, (b) some loss of the carbon load of the raw wastewater and bottom sludge to the atmosphere, and (c) conversion of most of the soluble and organic material into bacterial and algal cell mass. Thus, a significant portion of the original organic constituents of the wastewater exhibit an oxygen demand long after the initial synthesis process. McKinney² reports a theoretical hydraulic detention time of 160 days for satisfactory lagoon performance. A value of 120 to 180 days is given as an appropriate design hydraulic detention time for multiple-cell lagoons in order to produce an acceptable effluent.

11. The production of a high-quality effluent with a reasonable hydraulic detention time is a direct function of successful solids removal, primarily removal of the algal solids. This may be accomplished through use of long detention times allowing time for cell lysing and

more complete oxidation or by some solids removal process after lagoon treatment.

12. Various algae species may inhabit a sewage lagoon, but there is a characteristic dominance by only a very few; *Chlorella* and *Scenedesmus* are the two predominant green algae. They are small in size, less than 20 μ . The most common blue-green algae is the filamentous *Oscillatoria* species which often forms mats upon the surface of a lagoon. Diatoms have been found in lagoons and *Euglena* and *Chlamydomonas* have been reported as the most frequently occurring of the pigmented flagellates.⁴ Allen⁵ reported that *Chlorella* and *Scenedesmus* are the principal algae in ponds where active oxidation is taking place. The studies of Allen indicate that *Chlorella* developed as the predominant species and was eventually replaced by *Scenedesmus* and *Chlamydomonas* as the detention time increased.

13. The characteristics of the algae species present in the lagoon will determine the effectiveness of the available algae removal processes. The small size of *Chlorella* and *Scenedesmus* prevents them from being effectively removed solely by settling or filtration. The filamentous blue-greens and diatoms tend to clog filters. The flagellated algae tend to render the sedimentation process ineffective due to their mobility.

Algae Removal Techniques

14. Numerous and varied processes have been proposed for removal of algae from lagoon effluents. Middlebrooks et al.⁶ identify seven such processes including:

- a. Coagulation-flocculation.
- b. Granular media filtration.
- c. Dissolved air flotation.
- d. Centrifugation.
- e. Microstraining.
- f. Land application systems.
- g. In-pond removal.

These seven processes have been evaluated in many laboratory, pilot, or full-scale studies. A brief discussion of each process follows.

Coagulation-flocculation

15. The negative charge associated with algal cells prevents natural flocculation and settling. Ives⁷ demonstrated experimentally that algal cells carry a negative electric charge. It was found that the charge density was a function of the viscosity and dielectric constant of the dispersing liquid, temperature, concentration, and valence of the ionic species in the medium. The charge density was found to be lowest at a pH of 2. The algae, however, remained electro-negative at all pH values. Ives postulated that the coagulation of algae with chemicals resulted from charge neutralization of the negatively charged algae by the positively charged metal and hydroxy-metal ions with subsequent agglomeration and sedimentation of the cell mass.

16. Golueke and Oswald⁸ conducted a series of experiments to investigate the relation of hydrogen ion (H^+) concentrations to algal flocculation. A pH value of 3 caused the most extensive flocculation. They postulated that the free hydrogen ion (H^+) concentration not only served to neutralize the surface charge of the algal cells, but it also acted as a bonding agent. The greater the density of the surface charge, the more pronounced was the bonding.

17. Separation of algal cells by simple sedimentation processes without coagulation is not a viable option due to the tendency of the algal cells to remain in suspension. A number of chemical coagulants can be used to destroy the electrical stability of the colloidal algal cells and increase their susceptibility to flocculation and subsequent sedimentation. Lime, alum, and ferric salts are the most commonly used coagulants primarily due to their availability and comparatively low cost.⁴ Polyelectrolytes have also been investigated as coagulant aids.⁹ Each coagulant is generally most effective in a limited pH range.¹⁰

18. The use of alum as the coagulant of choice is perhaps the most widely investigated and reported. Shindala and Stewart¹¹ investigated chemical treatment of stabilization lagoon effluents using alum as a

coagulant. The optimum dosage was found to range between 75 and 100 mg/l with removal of 90 percent of the phosphate and 70 percent of the chemical oxygen demand (COD). Stone, Parker, and Cotteral¹² reported that a lagoon effluent containing 80 to 158 mg/l suspended solids required an alum dose of 175 mg/l to produce an effluent suspended solids less than 30 mg/l. The pH was found to be an extremely important variable with optimum flocculation and settling occurring at a pH between 6.0 and 6.3.

19. Golueke and Oswald⁸ performed studies to determine dosages for maximum algae yield using alum, lime, and polyelectrolytes as coagulants. A summary of these results is shown in Table 1.

Table 1
Coagulant Dosage for Maximum Algae Removal⁸

<u>Coagulant</u>	<u>pH</u>	<u>Dosage mg/l</u>	<u>Algae Removal percent</u>
Alum	6.7	60-120	85-100
Lime	10.6-11.0	100-200	75
Purifloc	5.0-10.4	3.0-10	95-99
Sandellite	6.5-10.0	2.5-4	80-100

20. McGarry¹³ studied the coagulation of algae using alum and polyelectrolytes. The optimum cost for removal of algae was obtained with an alum dose ranging between 75 and 100 mg/l. Polyelectrolyte addition was found not to be cost-effective. Folkman and Wachs¹⁴ determined that the concentration of coagulant required for optimum flocculation was primarily a function of algal species rather than algal concentration. Graham and Hunsinger¹⁵ reported on direct addition of chemicals to seasonally discharging lagoons. Addition of 500 to 700 mg/l lime produced maximum removal of *Chlorella* at pH 10.8 and *Scenedesmus* at pH 10.5. This phenomenon was attributed to the zeta potential of the individual species.

21. The Lancaster Tertiary Treatment Plant in California⁴ uses alum precipitation, settling, and filtration for algae and phosphorus

removal. The effluent from this treatment plant is used in recreational lakes by the county of Los Angeles. Typical operating data are shown in Table 2. The high alum dosages are determined by phosphorus removal rather than algae removal requirements.

Table 2
Typical Operating Data, Lancaster, California,
Tertiary Treatment Plant⁴

Parameter	Date	
	Feb 1973	Sep 1973
Influent flow rate, mgd*	0.089	0.563
Aluminum sulfate dose, mg/l	243 $\pm$ 44	337 $\pm$ 31
Flocculation pH range	6.2 to 6.6	6.3 to 6.8
Mean time between filter backwash, hr	112	14
Influent quality		
Suspended solids, mg/l	156 $\pm$ 19	129 $\pm$ 10
Total phosphate, mg/l	30.2 $\pm$ 5.9	25.6 $\pm$ 5.0
pH range	9.3 to 9.8	9.3 to 9.5
Temperature, °F	48 $\pm$ 3	65 $\pm$ 3
Effluent quality		
Turbidity, JTU	1.0 $\pm$ 0.3	0.8 $\pm$ 0.3
Total phosphate, mg/l	0.19 $\pm$ 0.05	0.15 $\pm$ 0.05

* A table of factors for converting U. S. customary units of measurement to metric (SI) is presented on page 3.

Filtration

22. Filtration of algal matter can be accomplished by passing the waste through a filter media of fine particles. A variety of media have been investigated including sand, diatomaceous earth, fly ash, and synthetic media. Removal by filtration is accomplished by a combination of processes with interstitial straining being the primary removal process. Velocity gradients within pores aid in flocculation and also increase the probability of small particles striking and sticking to the surface of the media. Gravitational sedimentation may also occur within the pore spaces.

23. Effluent from an oxidation lagoon serving Linwood, Kansas, was treated using an upflow filter system with fly ash as the filter medium.¹⁰ The filter was constructed using 24.5 in. of fly ash supported by 6 in. of graded gravel. Optimum COD removal was reported at a hydraulic loading rate of 0.06 gpm/ft². Removal efficiencies at this rate are presented in Table 3. Replacement of the fly ash was required at 6- to 12-week intervals.

Table 3
Algae Removal Efficiencies for Upflow
Flyash Filter¹⁰

<u>Parameter</u>	<u>Percent Removal</u>
COD	63
Suspended solids	85
Volatile suspended solids	90
Turbidity	64
Orthophosphate	41

24. Gloyna, Hermann, and Drynan¹⁶ studied separation of algae from oxidation lagoon effluents using pressure filters operated at a rate of 2 gpm/ft² and a pressure loss of 12 psi. Higher pressures were found to be undesirable since algae and the filter medium tended to penetrate the screen. Diatomaceous earth was found to have excellent algae removal characteristics and moderately high filtering rates. Using crushed graphite as a filter media resulted in algae reductions between 88 and 97 percent.

25. Borchardt and O'Melia¹⁷ conducted a study to determine the effectiveness of sand filtration for algal suspensions. No difference in algae removal was recorded for flow rates of 2.0, 1.0, and 0.2 gpm/ft². Removal efficiencies were found to vary with sand size with the smaller sands having higher removals. Minimum removals for each sand size used in the study are shown in Table 4.

Table 4
Algae Removal Efficiencies as a
Function of Sand Size¹⁷

<u>Sand Size</u> <u>mm</u>	<u>Minimum Algae Removal</u> <u>percent</u>
0.524	10
0.397	22
0.316	33

Average removals of 50 percent were obtained with the 0.397 mm sand. In an associated study, Foess and Borchardt¹⁸ found that lowering the pH of the liquid increased removal efficiencies. McGhee and Patterson¹⁹ used an upflow sand filter with a loading rate of 1.0 gpm/ft² and 0.25 mm sand size. Typical results for this study are found in Table 5.

Table 5
Algae Removal Efficiencies for Upflow
Sand Filtration¹⁹

<u>Parameter</u>	<u>Influent</u> <u>mg/l</u>	<u>Effluent</u> <u>mg/l</u>	<u>Removal</u> <u>percent</u>
Biochemical oxygen demand (BOD ₅)	6	5	17
Chemical oxygen demand (COD)	57	47	17
Suspended solids	19	8	58

26. Intermittent sand filtration has been investigated in several studies. Middlebrooks and Marshall²⁰ reported BOD₅ reduction for a 0.17 mm sand of 70.4 and 88.4 percent for respective hydraulic loading rates of 0.8 and 0.4 mgad. Mean BOD₅ reduction for a 0.72 mm sand was found to be essentially constant for hydraulic loading rates of 0.4 mgad and 0.6 mgad, 59.9 and 63.2 percent, respectively.

27. Reynolds et al.²¹ also investigated intermittent sand filtration. The sand media utilized in these studies had an effective size

of 0.17 mm and a uniformity coefficient of 9.74. The average influent suspended solids concentration was 26 mg/l while effluent suspended solids concentrations ranged between 3.7 mg/l at a hydraulic loading rate of 0.4 mgad and 7.2 mg/l at a loading rate of 0.8 mgad. A maximum influent suspended solids concentration of 72.1 mg/l resulted in effluent suspended solids concentrations of less than 40 mg/l for loading rates of up to 0.4 mgad. The average influent BOD₅ was 8.1 mg/l while average effluent BOD₅ ranged from 1.7 mg/l for a hydraulic loading rate of 0.4 mgad to 4.3 mg/l for a rate of 1.2 mgad. The length of the filter run ranged from 14 to 42 days for hydraulic loading rates of 1.2 and 0.4 mgad, respectively.

28. Various other filtration techniques have been attempted. Complete removal of algae was obtained when diatomaceous earth, corn starch, and calcined rice hulls were used separately as filtering media.⁵ Tests were also run on different types of filter paper, nylon, and cotton and woolen screens. These filtration methods, however, were found to be economically infeasible.⁸

29. Filtration as a singular treatment process appears to have limited value for removal of algal cells. Reported suspended solids removals range from 40 to 100 percent depending on the filter medium used. High algae concentrations either blind the filter or require frequent backwashing resulting in uneconomical operational characteristics. In addition, the motile algae have been reported to be capable of moving through the filter media.

Flotation

30. Flotation can be viewed as settling in reverse. Whereas flocculation and settling depend on an agglomeration and increase in specific gravity to promote settling, flotation depends on the entrapment of gas bubbles during the flocculation process thus reducing the specific gravity which causes the algae to rise to the surface for physical removal. Chemical addition may be used to enhance removal efficiencies by creating an algae-bubble-chemical matrix. The required gas has been introduced by a variety of methods including dissolving, dispersing, and electrochemical production.

31. Floating algae blankets have been reported in some cases in the presence of chemical coagulants.^{11,22} This phenomenon may be caused by the entrapment of gas bubbles produced during photosynthesis. Autoflotation, the production of the required gas bubbles by the algae, was investigated at Stockton, California, where some propensity for algae removal was exhibited; however, performance was found to be erratic. Autoflotation depends on the algal system to produce the necessary fine bubbles. The process of autoflotation is not continuous; therefore, autoflotation cannot be relied upon as the only means of algae removal. It can be used to assist other flotation methods. Van Vuuren and Van Duuren²² reported 70 percent suspended solids removal using 200 mg/l alum addition and a vertical flow flotation tank. Flotation of the algal mass resulted from physical air entrainment from aeration and photosynthesis. The algal float was stable enough for mechanical removal via skimming.

32. Sandbank et al.²³ used electrolysis to produce the required gas bubbles. An addition of 200 mg/l alum at pH 6.0 resulted in 79 to 88 percent volatile solids removal.

33. Funk et al.²⁴ investigated dissolved air flotation in bench scale studies for removal of *Chlorella vulgaris*. A removal efficiency of 95 percent using ferric chloride as the coagulant and pH values less than 7.0 was reported.

34. Bare et al.²⁵ used a bench scale flotation unit and laboratory-grown algal cultures to study the effects of algae concentration, amount of coagulant, type of coagulant, and method of operation, i.e. direct pressurization or recycle. Bare et al. also conducted pilot scale studies on removal of algal solids from operating lagoon effluents. The conclusions from this study included:

- a. The use of pressurized recycle on both naturally flocculated and chemically flocculated samples greatly improved removal efficiencies.
- b. Ninety percent removals were obtained with 18 percent recycle.
- c. A dosage of 175 mg/l of alum resulted in 90 percent removal of a 125-mg/l suspension of algae while 85 mg/l

of ferric sulfate was required for 90 percent removal of 100 mg/l algal suspension.

- d. The maximum allowable hydraulic loading rate was found to be 2.35 gpm/ft² including 18 percent recycle.
- e. The solids content of the skimmings was approximately 1 percent at the maximum hydraulic loading.

35. Dissolved air flotation was studied at the Stockton Plant and proved to be successful. Low suspended solids concentrations required an alum dosage between 75 and 150 mg/l for 60 to 70 percent suspended solids removal. When suspended solids concentrations were high, alum dosages were increased to a range of 150 to 250 mg/l for comparable results. Flotation also demonstrated a capability for concentrating the algal float. Float concentrations as high as 3.6 percent were recorded.

Centrifugation

36. Pilot scale studies using centrifugation as the algae removal process have proven the technical effectiveness of such systems. In experiments with centrifugation, Golueke and Oswald⁸ reported that algae removal rates decreased linearly as throughput rates increased from 100 to 385 gpm using a Model B-30 Dor Oliver centrifuge. Beginning with algal concentrations of 200 mg/l in the influent, the removal rates varied from 80 to 90 percent at 385 gpm.

37. The California Department of Water Resources²⁶ reported the results of the evaluation of a DeLaval self-cleaning centrifuge both as a primary concentrator and as a dewatering device. Used as a primary concentrator, the unit removed up to 95 percent of the influent algae (influent concentration of 800 mg/l).

38. The high initial cost and subsequent high operating and maintenance costs generally limit the practicability of using centrifuges for upgrading lagoons. In addition to the cost factors, centrifuges require skilled operators, which are in limited supply.

Microstraining

39. Microstrainers are low speed rotating drum screens operating under gravity conditions. Wastewater enters the open end of the drum and flows outward through the fabric. In the past, the fabric was generally constructed of stainless steel with a mesh opening ranging from

23 to 60 μ . Recently 1- μ polyester fabric has been evaluated with apparent success.²⁷ The solids that are removed from the liquid form a mat on the inside of the drum and function as a filter. Decreasing the rotational speed of the drum results in higher effluent quality. High pressure jets above the drum backwash the sludge mat into a trough from which the algae are disposed of or returned to the lagoon.

40. Golueke and Oswald⁸ conducted pilot scale studies with wastewater algae using microstrainers at flow rates of 50 to 100 gpm. Only a small amount of algae was removed even though a filter aid was used. Other sources, however, have reported successfully removing algae and other suspended material. Berry²⁸ reported 89 percent average removal of plankton using four 7.5-ft-diam, 5-ft-wide drums with a 35- μ fabric at a maximum flow of 8 mgd. Tume²⁹ reported 90 to 95 percent removal of suspended solids using a 7.5-ft-diam by 5-ft-wide drum approximately three fifths submerged with a 23- μ fabric. Diaper³⁰ reports 70 to 80 percent removal with a 23- μ fabric and 50 to 60 percent removal with a 35- μ fabric. Berry²⁸ reported on the operation of 15 microstrainer plants in Canada and concluded that they are effective and economical for algae removal. In a series of nine investigations over a period of years, an average reduction of 89 percent was reported.

41. The reported removal efficiencies for microstraining vary considerably which may be attributed to different algal species, operational procedures, or primarily fabric mesh openings. The California Department of Water Resources²⁶ reported that strainers with pore sizes of 25 to 35 μ were ineffective for algae removal. Removals of up to 30 percent were reported.

42. In recent years, additional investigations into fabric design have resulted in vastly improved performance characteristics. Kormanik and Cravens²⁷ have investigated use of a 1- μ polyester fabric for the past 3 years. Excellent removal characteristics have been demonstrated with average removal rates of 80 to 90 percent reported.

43. Microstrainers require relatively little maintenance beyond inspection and lubrication. Because of the ease of operation, microstraining should be considered in any alternative evaluation process.

Land application systems

44. Land application techniques have been used extensively to upgrade lagoon effluents.^{31,32} Land treatment systems for small facilities are relatively uncomplicated and relatively inexpensive to maintain and operate. The wastewater does need to be sampled periodically to determine if the system is operating properly. The feasibility of land application generally depends on effluent requirements, the availability of land, climatology, and the hydrogeology of the proposed site. The cost of any available land may be an economic disincentive to land application techniques.

45. Three basic types of land application techniques are in use including slow infiltration, rapid infiltration, and overland flow.^{31,33} In land treatment, the hydraulic and nutrient loading rates must be adjusted to the treatment capacity of a particular crop-soil system. The crop irrigation systems are normally capable of treating one to several inches of wastewater per week with the actual rate of application based on the renovative capacity of the particular soil and crop system used. Renovated water may be collected in a drainage system and returned to a specific stream, reused in industry, or allowed to infiltrate into the groundwater system.

46. The soil required for the irrigation systems is preferably well-drained loamy to sandy clay. The soil depth requirement is generally from 5 to 6 ft to ensure aerobic bacterial action. The direction and velocity of groundwater flow must be studied to determine if the groundwater will carry contaminants to surrounding water supplies. Distribution methods have included the use of sprays, ridges and furrows, and flooding. Pollutant removals have been satisfactory with BOD, suspended solids, and fecal coliform removals in the 95 to 99 percent range.^{31,33}

47. Overland flow³² is the most feasible land application method for the treatment of wastewater on soils of low permeability. The treatment is primarily a soil surface phenomenon with soil microorganisms being active in the treatment process. The slope of the site must be great enough to prevent ponding but not so great as to allow the water

to rush from the treatment site. Two to six percent slopes with lengths between 150 to 300 ft are recommended. A cover crop is also an integral part of the process since substantial amounts of phosphorus and nitrogen are removed by the plants. The system oscillates between aerobic and anaerobic conditions by alternate flooding and drying. Reported BOD and suspended solids removals for overland flow have been in the 95 to 99 percent range.³¹⁻³³

48. Rapid infiltration systems³⁴ will accommodate several acre-feet of water per week depending on the permeability of the soil. Sandy loams or loamy sands are most suitable for these high rate systems. These soils are permeable enough to permit high infiltration rates and fine enough to provide sufficient purification of the wastewater as it infiltrates into the soil. High original water tables are not objectionable if the water table can be controlled by artificial drainage systems. Periods of infiltration should be rotated with periods of resting or drying of the soil. This permits infiltration rates, which usually decrease during application, to recover. Reported removals of BOD, suspended solids, and fecal coliform have been in the 95 to 99 percent range.

In-pond removal

49. In-pond removal techniques are generally characterized by mixing, chemical addition, sedimentation, lagoon design modification, or biological techniques for enhancing the removal of algae. The common characteristic of each is that the chemical, physical, or biological interaction with the algae takes place within the confines of the lagoon system.

50. Complete containment of wastewater in retention lagoons is required in some states.³⁵ The lagoon is designed such that the evaporation from the surface is equal to the waste flow into the pond. The method may be feasible in applications involving low waste flows where land is economically available and net evaporation rates are high. Complete containment is impractical for many small systems due to climatological characteristics and the resultant large land area requirements. This method has been successfully utilized for industries where high BOD and low waste flows are encountered.³⁶

51. Biological discs and baffles have been installed in lagoons under the theory that fixed growth systems surpass suspended growth systems in suspended solids removal capacity.³⁶ The baffles also tend to reduce hydraulic short-circuiting and promote hydraulic turbulence resulting in more desirable mixing of the influent wastewater with the contents of the lagoon. The organisms associated with a fixed growth system form a dense slime which sloughs periodically; however, unlike the buoyant suspended organisms, the slime is usually dense enough to settle out of the liquid under the influence of gravity.

52. Nielson³⁷ conducted a study to determine if baffles could improve the performance of waste stabilization lagoons. Nielson concluded that:

- a. Biological degradation rates were significantly higher in baffled ponds.
- b. Suspended solids concentrations generally decreased or were constant in ponds where scum baffles were used.
- c. If the kinetic constants determined for the lagoon models are applicable to full-scale systems, a conventional lagoon without baffles would require almost twice the land area of a longitudinally baffled lagoon in order to produce a similar effluent.
- d. The pond with over and under baffles reduced effluent suspended solids concentrations.

53. Algal precipitation by adding chemicals directly to the lagoon system has been attempted in several studies.^{15,26,36} This practice however may cause a sludge buildup which may require periodic dredging to maintain design depths.³⁶ The California Department of Water Resources²⁶ evaluated the use of lime, alum, ferric sulfate, and ferric chloride. These experiments indicated that the concentration of these chemicals required to remove specific amounts of algae varied according to the operating conditions and were relatively independent of the initial algal concentration. Ninety percent suspended solids removals were attained with chemical dosages ranging from 20 to 200 mg/l.

54. A study conducted in the Province of Ontario, Canada, indicated suspended solids reductions from 65 to 10 mg/l with alum treatment.¹⁵ Sludge accumulations of less than 0.1 in./application were

reported. Additional studies will be necessary to determine optimum dosage for various coagulants and the effects of such in-pond chemical addition on the removal kinetics in the lagoon system.

Summary

55. Based on the literature review cited above, a summary table was prepared presenting the characteristics associated with each algae removal technique identified during the course of the review. Table 6 presents the collated data.

Table 6
Process Selection Considerations

<u>Algae Removal Technique</u>	<u>Percent Removal</u>	<u>Comments</u>
Complete containment	100	Large land area required
Baffles	40-68	Model studies only
In-pond chemical precipitation	40-70	Long-term effects unknown
Autoflotation	30-60	Can be used to aid chemical coagulation
Centrifugation	80-98	High cost of operation and maintenance
Microstraining	0-90	High initial cost. Data inconclusive
Coagulation- flocculation	85-95	Efficient
Flotation	70-90	Efficient in combination with chemical treatment
Filtration, sand miscellaneous	30-60 70-95	Major problem removing algae from the filter media
Land application	90-99	Feasibility depends on land cost and type of terrain

56. From the results of the literature survey, two broad categories of end-of-pipe treatment appear to offer the most promise for

application to the needs of the CE. These include land application and chemical-physical treatment. Land application techniques are being investigated by the U. S. Army Engineer Cold Regions Research Laboratory under the CE Wastewater Management Research Program. In-pond chemical precipitation of algae is being investigated by WES under a separate work unit.

57. For this study, a chemical-physical treatment train consisting of coagulation, flocculation, sedimentation, and filtration processes (CFSF) arranged in series was selected for investigation. One of the major advantages of the CFSF process is the concurrent removal of phosphates with the algal mass. Should effluent requirements include strict phosphate limitations, the CFSF system is capable of producing effluents with phosphorus concentrations less than 1 mg/l.

PART III: EXPERIMENTAL PROCEDURE

Test Site

58. The selection of field test sites for this study was primarily a function of the availability of site support and the applicability of the expected results to Corps needs. As previously indicated, the WES has identified over 200 Corps-operated lagoons, most of which discharge either seasonally or intermittently. Based upon a survey of several possible sites, Lake Eufaula, Oklahoma, was selected as the area best suited to the needs of the proposed study. The initial survey of the Lake Eufaula area indicated that the loadings on the Arrowhead State Park lagoon system were substantial enough to maintain continuous operation of the proposed unit process to be utilized in upgrading the lagoon effluent.

59. Arrowhead State Park at Lake Eufaula is one of Oklahoma's seven state parks, offering year-round recreation to vacationers. Figure 2 shows the location of Arrowhead State Park in Pittsburg County just east of Canadian, Oklahoma, off U. S. Highway 69. The lagoons selected for study are located approximately 500 ft north of the primary treatment facility. Figure 3 indicates the size and relative location of the various existing treatment processes.

60. Treatment plant loadings are primarily due to domestic sewage from park cottages and lodge facilities. Peak loadings occur during the summer months due to the increase in use of park facilities during this period. Figure 4 is a graphical presentation of occupancy data for the period April 1977 through July 1978. Peak occupancy generally occurs during the months of July and August. Minimum occupancy occurs during the months of December, January, and February, with the lodge being closed for repairs during the month of December.

61. Waste from the lodge and cottage facilities is initially treated in a primary clarifier. Clarifier effluent was originally treated by a trickling filter before being discharged to Lake Eufaula while sludge was treated in an anaerobic digester. Increased demands on

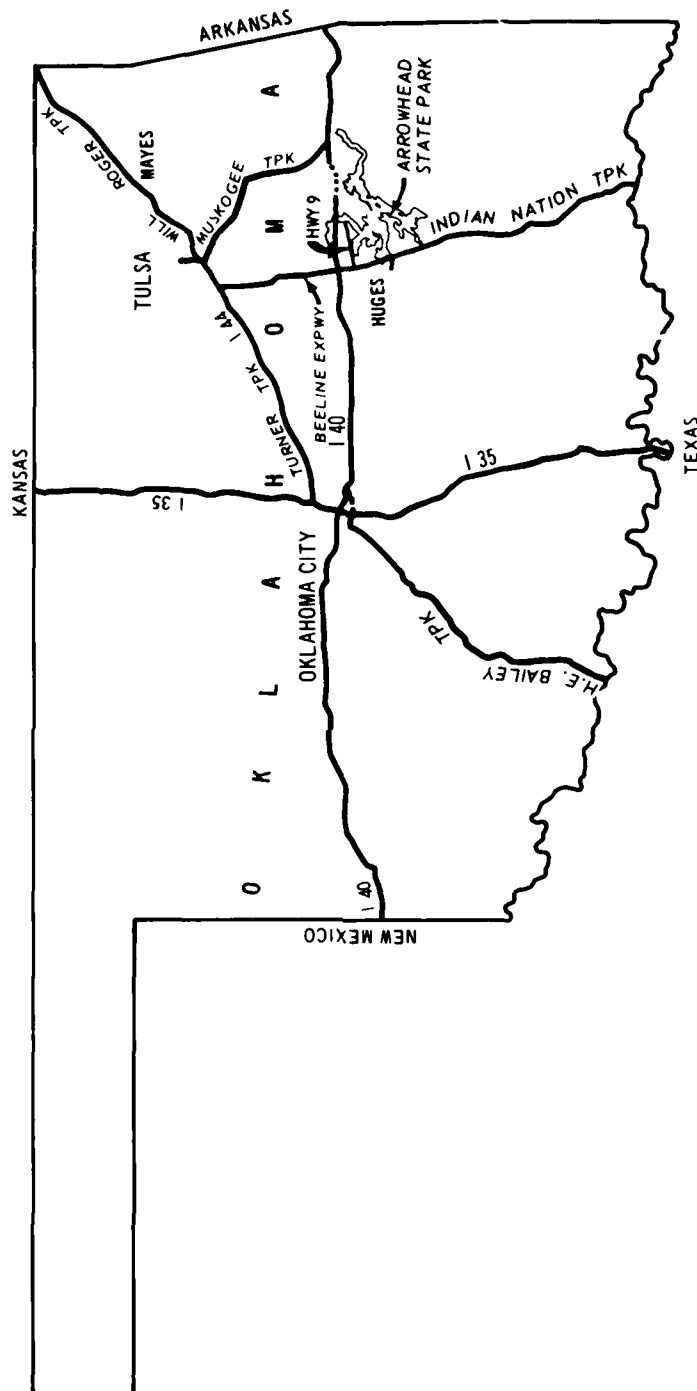


Figure 2. Location of Arrowhead State Park on Lake Eufaula

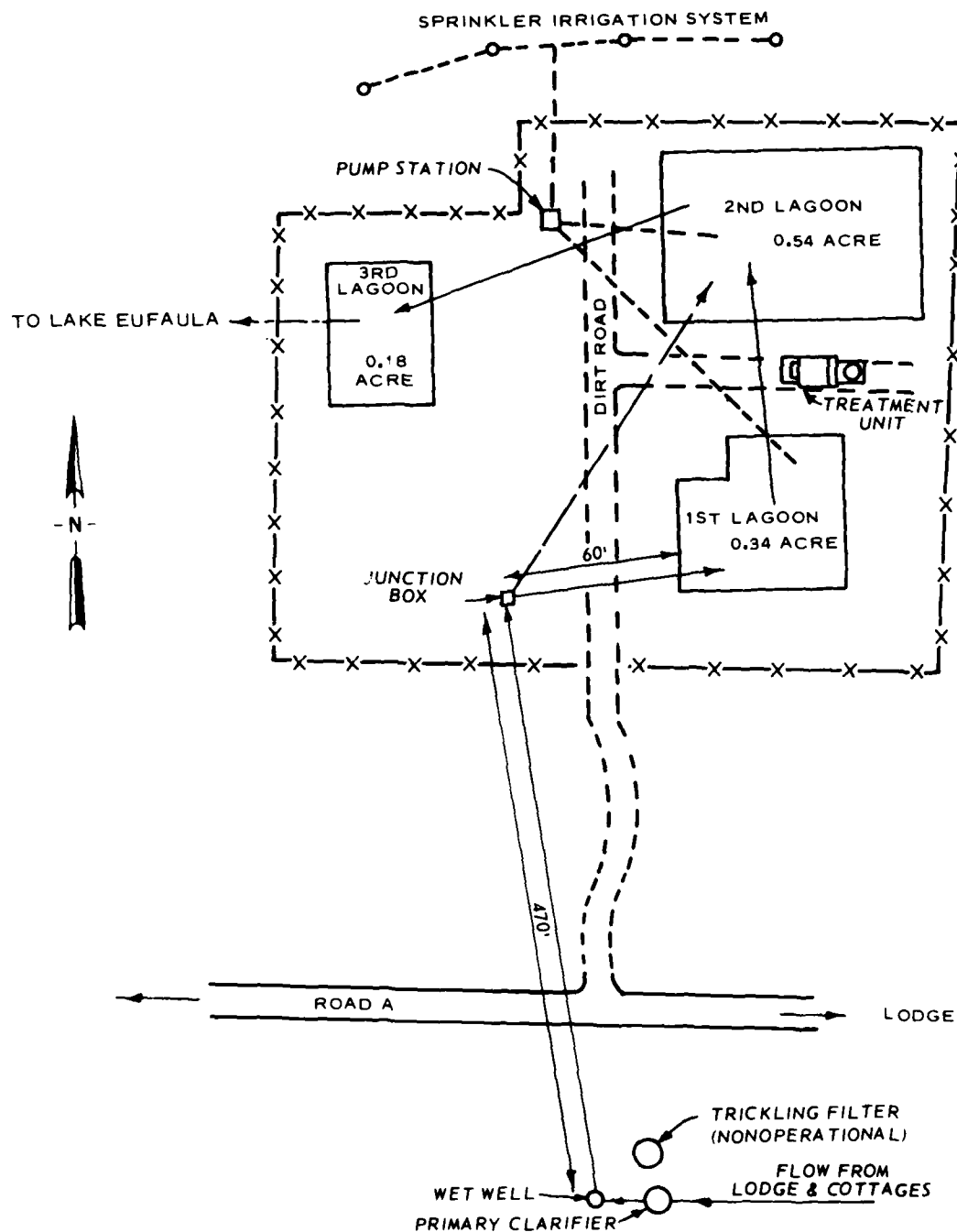


Figure 3. Diagram of existing treatment facility

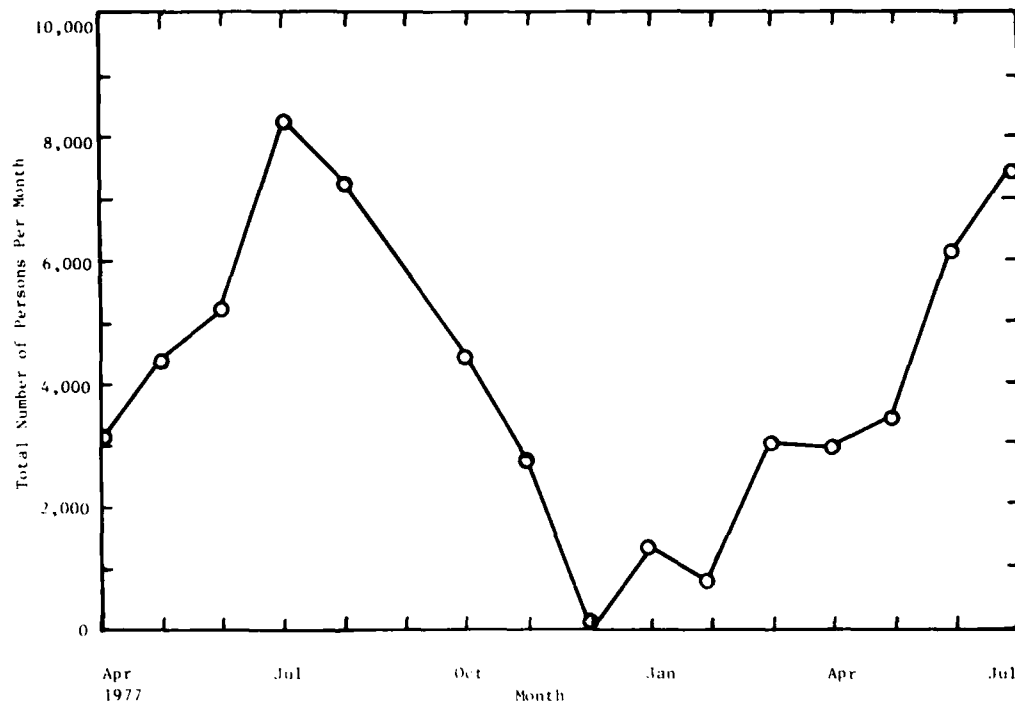


Figure 4. Occupancy data, April 1977-July 1978

the treatment system, however, necessitated upgrading of the facility. A facultative lagoon system consisting of three sewage lagoons in series was constructed to provide the additional treatment capacity required for the park. The lagoons in series differ in size with the surface area of the first, second, and third lagoon being approximately 0.34, 0.54, and 0.18 acres, respectively. At present, the trickling filter is being bypassed and the anaerobic digester has been converted into a wet well. Sludge collected in the primary clarifier is handled separately.

62. The facultative lagoon system was originally designed as a total retention system. However, increases in occupancy and water use created the need for more treatment capacity. The need for additional treatment capacity was satisfied through installation of a sprinkler irrigation system. As the need arises, the level of the second lagoon is lowered periodically by using the spray irrigation system. The third lagoon is used for storage during the winter months when land application is not feasible.

Pilot Plant

Design

63. The pilot treatment plant selected for use during the study allowed consideration of four unit processes including: coagulation, flocculation, sedimentation, and filtration. The unit consisted of a mixing chamber, a rectangular upflow clarifier, two filters, a clear well for storing effluent from the filters, and a backwash waste tank.

64. The mixing chamber is divided into two sections, a rapid mix tank (1.9 ft by 1.5 ft by 2 ft side water depth (SWD)) and a slow mix tank (6.4 ft by 1.9 ft by 2 ft SWD). The hydraulic retention time in the rapid mix and slow mix tanks is 3 and 13 min, respectively, at the design flow of 10,000 gpd. A flash mixer is provided in the rapid mix tank to enable mixing of the coagulant with the incoming wastewater. Flocculation in the slow mix tank is provided by two variable-speed, paddle-type mixers. Flocculated wastewaters are discharged to the upflow clarifier.

65. The clarifier was originally designed as a rectangular horizontal (cross-flow) system. A 3-in.-diam downcomer was added to carry the wastes from the flocculation tank to the bottom of the clarifier thus effectively converting the clarifier from a cross-flow to an upflow mode of operation. Clarifier surface dimensions are 7 ft 3 in. by 4 ft, truncated after 4 ft SWD. The truncated pyramidal bottom section of the clarifier allows adequate sludge blanket maintenance. Hydraulic retention time for the design flow of 10,000 gpd is 3.8 hr with an overflow rate of 347 gpd/ft². Settled solids are periodically removed from the bottom of the clarifier via an air lift pump. The clarified effluent flows across the effluent weir into a splitting box where the flow may be distributed between two filters.

66. The pilot treatment facility contains two downflow gravity filters. Filter No. 1 utilizes sand as the filter media whereas filter No. 2 utilizes a dual media consisting of sand and anthracite. Each filter has a surface area of 3.75 ft² (2.5 ft by 1.5 ft) and a depth of 8 ft. A pipe lateral underdrain/backwash system is located just below

the filter bed. The filtration rate at the design flow of 10,000 gpd is 0.93 gpm/ft².

67. Filter No. 1 (sand media) was initially composed of 18 in. of sand media and 4 in. of support gravel. The mean effective size of the sand media was determined to be 0.32 mm with a uniformity coefficient of 1.76. Particle sizes of the sand media range from 0.15 to 0.85 mm.

68. The dual media filter consists of 18 in. of sand (2.65 specific gravity) topped with an 8-in. bed on anthracite coal media (1.4 to 1.6 specific gravity). This 26-in. bed of dual media is supported on a 4-in. layer of gravel. The effective size of coal was determined to be 0.86 mm with a uniformity coefficient of 1.7. The size of coal ranges from 0.1 to 2.0 mm. The ratio of 90 percent coal size to 10 percent sand size is 6.0, indicating substantial media intermixing after backwashing.

69. A 275-gal clear well is provided for storage of filtered water for use in backwashing the filters. Two submersible backwash pumps are housed in the clear well, one pump for each filter cell. Wastewater from backwashing is collected in a 250-gal waste storage tank and eventually pumped to an appropriate discharge point.

70. The hydraulic capacities, retention times, and loading rates were calculated for each unit process in the pilot treatment system. These values are reported for flow rates of 10,000, 15,000, and 20,000 gpd (Appendix B).

Operation

71. The pilot treatment plant was operated on a continuous flow basis. Data were taken periodically to determine BOD₅, suspended solids, and orthophosphate removal efficiencies. Various parameters such as flow rate, chemical dosage, and mode of operation were varied to determine optimum operating conditions.

72. Wastewater was pumped from the first lagoon to the pilot plant. Appropriate dosages of chemicals were added based upon preliminary jar tests. Coagulant was added to the rapid mix basin whereas polyelectrolyte and acid were independently added to the slow mix basin via metering pumps.

73. Clarified and filtered water was collected in the clear well

and either discharged to the third lagoon or used for backwashing the filters. The backwash wastewater was collected in the backwash waste tank and subsequently pumped to the third lagoon.

74. Sludge accumulating in the bottom of the clarifier was discharged into the second or third lagoon. Sludge wasting was accomplished as necessary, but at least weekly.

Sampling and Analysis

75. A sampling and analysis program was established for the study. Essentially, the objectives of this sampling and analysis program were as follows:

- a. Preliminary sampling of lagoon influent and effluent to characterize the quantity and quality of wastewaters in the system under existing conditions.
- b. Performance of jar tests to determine optimum coagulants and associated dosages.
- c. Collection of samples from the lagoon, clarifier, and filter effluents.
- d. Analysis of collected samples for COD, suspended solids, orthophosphate, and pH.
- e. Measurement of influent and effluent flows.

76. The chemical dosages required for algae coagulation and flocculation were determined using standard jar test optimization techniques using a Phipps & Bird stirring apparatus. Samples of 750 ml in 1-l beakers were placed on the stirrer. Varying amounts of coagulant were added to each beaker while the sample was rapidly mixed for 1 min at 120 rpm. The paddle speed was then decreased to 30 rpm for a period of 30 min. Precipitation of floc of varying degrees of density was noted in all beakers during the slow mix period. Following the slow mixing period, each sample was allowed to settle for 30 min. Supernatant was drawn from each beaker for analysis for COD, suspended solids, and orthophosphate. Visual observations of sludge settling characteristics were also taken.

77. During pilot plant operations, grab samples were periodically

taken from the lagoon, the clarifier, and each filter. Each sample was analyzed for COD, suspended solids, and orthophosphate. The samples were collected in small plastic bottles (350 ml) and refrigerated at 4°C until the analyses could be performed. Samples were not collected until at least 2 hr had elapsed after pilot unit start-up each morning, thus giving time for the system to stabilize. Additional samples were collected at 2-hr intervals.

78. Lagoon samples were collected a few feet from the pump intake, approximately 6 in. below the water surface. Clarifier effluent samples were collected in the clarifier effluent launderer. Samples of the filtered effluent were taken at the discharge point of each filter.

79. The pH of the lagoon, slow mix chamber, clarifier, and filter contents was taken periodically during operation of the pilot facility. Flow measurements were taken periodically and adjustments made to the flow control valve to maintain proper flow rates.

80. The COD and BOD₅ determinations were performed on all the samples according to procedures outlined in Standard Methods for the Analysis of Water and Wastewater, 14th edition.³⁸ Suspended solids determinations were made using the millipore filter technique. The Environmental Protection Agency (EPA) single reagent method was followed for orthophosphate determinations using a wavelength of 650 nm for absorbance.

81. Algae identification was verified using Smith's³⁹ key to the freshwater algae of the United States. Algal samples were preserved with the addition of Tranceaus algae preservative (6 percent water, 3 percent ethyl alcohol (95 percent), and 1 percent formaldehyde). Algae enumeration utilized the Sedgwick-Rafter counting cell, field counting method described in Standard Methods.³⁸

PART IV: RESULTS AND DISCUSSION

Wastewater Characterization

82. Influent and effluent characteristics for the lagoon system were determined periodically during the onsite portion of the study. In addition, the algal species present in the lagoon system were identified.

83. Loading rates for the first lagoon were estimated by installing a timer to record the total operating time of the pumps in the wet well. Pumping rates were estimated by noting the rate at which the water level decreased in the wet well during a pumping cycle. After making appropriate correction for inflow during the pumping cycle, the pumping rate was determined to be 85 gpm with an average pumping cycle of 9.6 min. Occupancy rates from the lodge and cottages along with the daily flow into the first lagoon are presented in Figure 5. As can be observed from Figure 5, daily flows correlate well with occupancy data.

84. Organic loading rates to the first lagoon ranged from 25 to 53 lb BOD₅/acre/day (60 to 150 mg/l) with an average loading of 44.3 lb BOD₅/acre/day. The COD in the influent to the first lagoon ranged from 144 to 300 mg/l. Orthophosphate levels in the influent ranged from 8.3 to 38.8 mg/l with most of the phosphate present in the soluble form. Influent suspended solids ranged from 44 to 197 mg/l.

85. The BOD₅, COD, suspended solids (SS), and orthophosphate removal efficiencies of the first lagoon are presented in Table 7. The BOD removal efficiencies ranged from 56 to 74 percent with BOD₅ concentrations in the first lagoon effluent ranging from 18 to 87 mg/l. The COD removal efficiencies ranged from 44 to 69 percent with effluent COD ranging from 74 to 364 mg/l. Orthophosphate levels in the lagoon varied widely ranging from 8.1 to 27.0 mg/l with removal efficiencies ranging from 8 to 45 percent.

86. The concentration of suspended solids in the influent to the first lagoon ranged from 44 to 197 mg/l. Removal efficiencies ranged from 2 to 62 percent with effluent concentrations ranging from 40 to 150 mg/l. Oxidation lagoons, in general, do not have high suspended solids

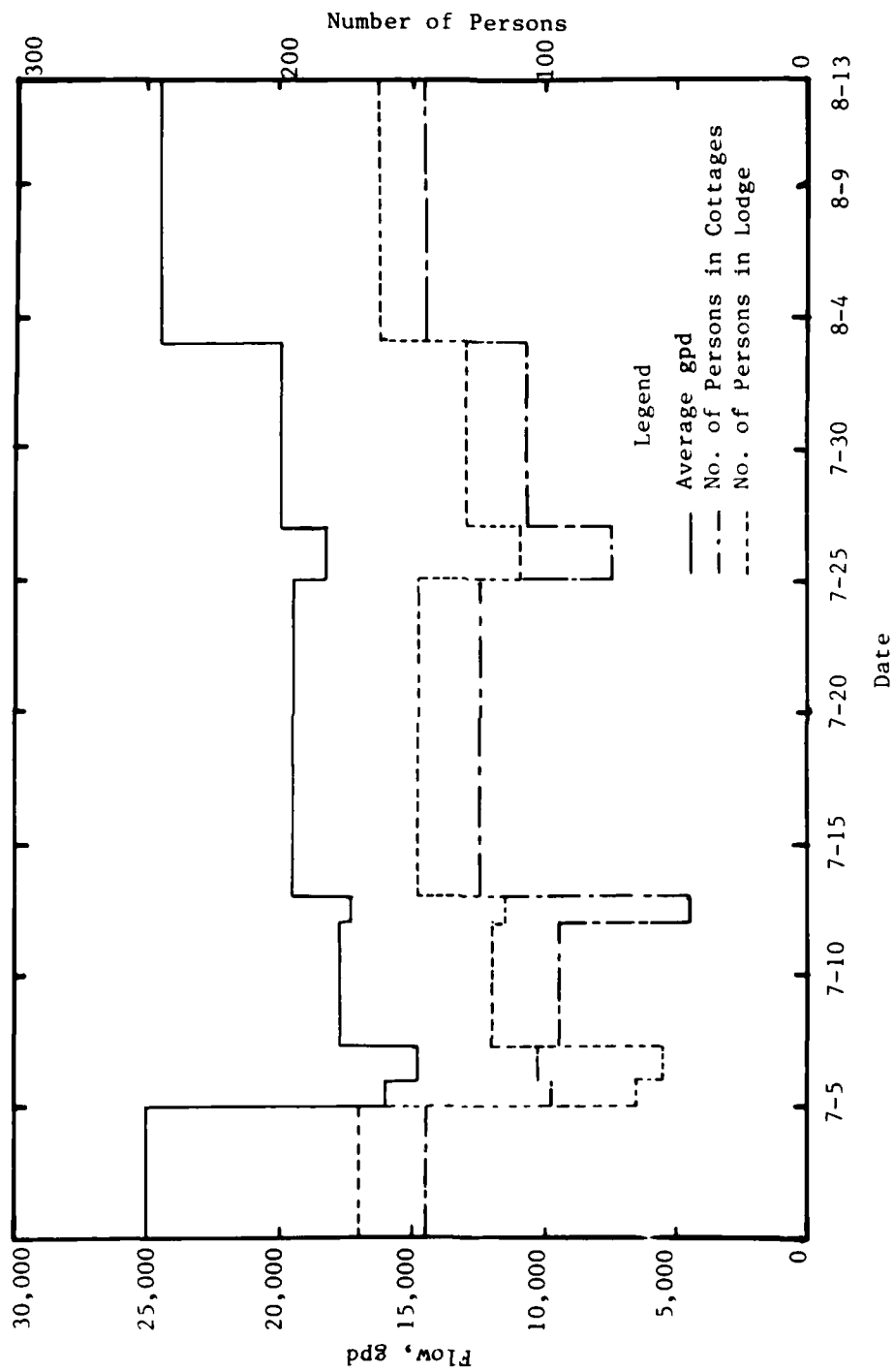


Figure 5. Wastewater flows and occupancy data for July and August 1978

Table 7
Removal Efficiencies of the First Lagoon

Date	Percent Removal			
	BOD	COD	SS	Orthophosphate
6/23/78 (3:30 PM)	64.0	48.6	--	--
6/27/78 (5:00 PM)	67.0	51.7	1.9	34.1
6/28/78 (12:15 PM)	61.1	44.0	37.5	8.3
6/29/78 (3:00 PM)	73.7	61.1	61.9	45.6
7/14/78 (10:00 AM)	--	--	13.0	--
8/1/78 (2:40 PM)	56.2	69.3	--	32.3
8/10/78 (2:30 PM)	68.4	54.0	9.1	45.2

removal efficiencies, and, in many cases, the suspended solids concentration may actually increase due to algal growth.

87. Increases in lagoon loadings coupled with the normal increases in algal activity during the summer months tend to have an accumulative effect on the lagoon system. Algal blooms in all three lagoons were noted throughout the study period. The algae present in the system were identified by visual determination. The algae genera found in the lagoon are listed in Table 8, the first genera listed generally being dominant.

88. At the beginning of the study period in June, all three lagoons had similar algal compositions. A prominent floating mat of *Polycystis* in the second lagoon occurred during the first week of June, followed by another visible mat in the second week in the first lagoon consisting of *Chlamydomonas*, *Chlorogonium*, *Merismopedia*, and diatoms. During the third week of June, the effluent from the pilot plant and filter backwash were being discharged into the third lagoon and at the point of discharge into the lagoon a visible mat of algae consisting of *Polycystis*, *Anabaena*, *Euglena*, and *Chlorella* developed.

Table 8
Algal Genera Present in Facultative Lagoons

Month	First Lagoon	Second Lagoon	Third Lagoon
June	<i>Euglena</i>	<i>Euglena</i>	<i>Euglena</i>
	<i>Chlamydomonas</i>	<i>Chlamydomonas</i>	<i>Chlamydomonas</i>
	<i>Scenedesmus</i>	<i>Scenedesmus</i>	<i>Scenedesmus</i>
	<i>Chlorella</i>	<i>Chlorella</i>	<i>Chlorella</i>
	<i>Phacus</i>	<i>Phacus</i>	<i>Phacus</i>
	<i>Diatoms</i>	<i>Diatoms</i>	<i>Diatoms</i>
	<i>Pandorina</i>	<i>Pandorina</i>	<i>Pandorina</i>
	<i>Eudorina</i>	<i>Eudorina</i>	<i>Eudorina</i>
	<i>Anabaena</i>	<i>Anabaena</i>	<i>Anabaena</i>
	<i>Oscillatoria</i>	<i>Oscillatoria</i>	<i>Oscillatoria</i>
	<i>Aphanizamenon</i>	<i>Aphanizamenon</i>	<i>Aphanizamenon</i>
	<i>Polycystis</i>	<i>Polycystis</i>	<i>Polycystis</i>
July and August	<i>Euglena</i>	<i>Polycystis</i>	<i>Polycystis</i>
	<i>Chlamydomonas</i>	<i>Diatoms</i>	<i>Anabaena</i>
	<i>Scenedesmus</i>	<i>Chlamydomonas</i>	<i>Chlamydomonas</i>
	<i>Diatoms</i>	<i>Merismopedia</i>	<i>Euglena</i>
	<i>Merismopedia</i>	<i>Euglena</i>	<i>Scenedesmus</i>
	<i>Phacus</i>	<i>Anabaena</i>	<i>Chlorella</i>
	<i>Chlorella</i>	<i>Scenedesmus</i>	<i>Merismopedia</i>
	<i>Chlorogonium</i>	<i>Phacus</i>	<i>Oscillatoria</i>
	<i>Oscillatoria</i>	<i>Chlorella</i>	
		<i>Chlorogonium</i>	
		<i>Oscillatoria</i>	
		<i>Pandorina</i>	
		<i>Eudorina</i>	

89. During the latter part of July and the first of August, a definite change in algal composition occurred. *Chlamydomonas* was the dominant genera in the first lagoon with an increase in diatoms and *Merismopedia* also becoming evident. Diatoms were the dominant genera in the second lagoon. *Chlamydomonas* was the dominant genera in the third lagoon; however, copious numbers of *Anabaena* and *Polycystis* were also present. Also during this period, large visible mats of floating algae were present in all three lagoons. Autoflotation occurred in the first and second lagoons with visible gas bubbles present within the algal mats.

90. Bacteriological data for each lagoon were collected several times during the study period. Table 9 presents a summary of typical bacteriological data.

Table 9
Bacteriological Data

<u>Site</u>	<u>Date</u>	<u>Fecal Coliform/100 ml</u>
First lagoon	7/31/78	40,000
	8/2/78	48,000
	8/2/78	61,000
Second lagoon	8/1/78	<20
	8/1/78	1,800
Third lagoon	8/1/78	<20
	8/1/78	<20

Laboratory Investigations

91. Preliminary jar tests were run on samples taken from the first lagoon which served as the influent wastewater to the treatment facility. Jar tests were conducted using lime, alum, and ferrous sulfate as coagulants. Jar tests were also conducted using a combination of lime and alum. Table 10 presents the dosages of each coagulant used and the pH of the supernatant.

Table 10
Preliminary Jar Tests for Coagulant

<u>Sample</u>	<u>Lime mg/l</u>	<u>Alum mg/l</u>	<u>Ferrous Sulfate mg/l</u>	<u>Supernatant pH</u>
Raw	--	--	--	7.8
1	16	--	--	9.2
2	33	--	--	9.2
3	66	--	--	9.2
4	100	--	--	9.3
5	133	--	--	9.8
7	--	--	33	7.3
8	--	--	66	7.0
9	--	--	133	6.6

(Continued)

Table 10 (Concluded)

Sample	Lime mg/l	Alum mg/l	Ferrous Sulfate mg/l	Supernatant pH
10	--	--	200	6.4
11	--	--	266	5.7
12	--	--	333	5.6
13	--	--	33	7.3
14	--	--	66	7.3
15	--	--	133	6.7
16	--	--	200	6.4
17	--	--	266	6.3
18	--	--	333	6.2
19	166	33	--	9.5
20	166	66	--	9.3
21	166	133	--	8.4
22	166	200	--	8.3
23	166	266	--	7.3
24	166	333	--	6.7
25	333	33	--	10.5
26	333	66	--	10.4
27	333	133	--	9.8
28	333	200	--	9.5
29	333	266	--	9.1
30	333	333	--	8.8
Raw	--	--	--	8.6
1	--	133	--	6.8
2	--	166	--	6.7
3	--	200	--	6.2
4	--	233	--	6.1
5	--	266	--	5.7
6	--	300	--	5.5

Visual observation indicated that alum tended to produce the best flocculating and settling characteristics. Thus, alum was selected for further study, including a determination of optimum dosages, and use during the pilot treatment phase.

92. The alum dosage studies were performed utilizing COD, suspended solids, and orthophosphate as the parameters on which the optimum dosage determination would be based. Table 11 presents the results of the alum optimization studies.

Table 11
Alum Dosage Optimization Results

Sample	Alum mg/l	pH	COD mg/l	Orthophosphate mg/l	SS mg/l
Raw	--	7.8	124	13.4	118
1	33	7.3	85	7.5	104
2	66	7.0	72	6.5	87
3	133	6.6	61	2.5	83
4	200	6.4	50	0.75	54
5	266	5.7	56	1.0	48
6	333	5.6	70	1.15	27
Raw	--	9.2	126	21.03	--
1	20	7.5	114	14.86	--
2	40	7.3	106	11.90	--
3	80	6.9	86	5.42	--
4	120	6.3	47	1.18	--
5	160	6.0	36	0.34	--
6	200	5.9	36	0.15	--

93. The jar tests were also conducted to determine the optimum coagulant aid and dosage for use with alum. Table 12 presents the results of these jar tests.

Table 12
Alum-Polymer Coagulation Results

Sample	Alum mg/l	Polymer mg/l	pH	COD mg/l	Orthophos- phate, mg/l	Settling Characteristic
WT 2820						
7	133	5.0	7.0	--	--	
8	166	5.0	6.5	--	--	
9	200	5.0	6.2	--	--	
10	233	5.0	6.1	--	--	Best
11	266	5.0	5.8	--	--	Best
12	300	5.0	4.8	--	--	
WT 2820						
1	233	1.67	--	--	--	
2	233	3.33	--	--	--	
3	233	5.00	--	--	--	
4	233	6.67	--	--	--	Best
5	233	8.33	--	--	--	Best

(Continued)

Table 12 (Concluded)

<u>Sample</u>	<u>Alum mg/l</u>	<u>Polymer mg/l</u>	<u>pH</u>	<u>COD mg/l</u>	<u>Orthophos- phate, mg/l</u>	<u>Settling Characteristic</u>
6	233	10.00	--	--	--	
		WT 2076				
7	200	0.33	6.2	--	--	
8	200	0.66	6.3	--	--	
9	200	1.00	6.3	--	--	
10	200	1.32	6.3	--	--	
11	200	1.65	6.3	--	--	
12	200	2.00	6.3	--	--	
		WT 2820				
13	200	0.33	6.2	--	--	
14	200	0.66	6.4	--	--	
15	200	1.00	6.4	--	--	
16	200	1.32	6.4	--	--	
17	200	1.65	6.4	--	--	
18	200	2.00	6.4	--	--	
		WT 2830				
19	200	0.33	6.3	2.6	0.55	
20	200	0.66	6.5	5.2	0.47	
21	200	1.00	6.5	10.4	0.44	
22	200	1.32	6.5	13.0	1.72	
23	200	1.65	6.5	14.3	0.86	
24	200	2.00	6.5	18.2	0.63	
		Aqua-Floc 420				
25	200	0.33	6.0	7.8	0.19	
26	200	0.66	5.8	5.2	0.11	
27	200	1.00	5.9	2.6	0.17	
28	200	1.32	5.8	2.6	0.04	
29	200	1.65	6.0	1.3	0.05	
30	200	2.00	5.9	1.3	0.04	

Pilot Scale Investigation

94. The major emphasis of the pilot phase of the study was the evaluation of clarifier and filter performance under various hydraulic loading conditions. In addition, an attempt was also made to study the feasibility of direct filtration of the lagoon effluent.

95. Table 13 presents the data collected for clarifier performance during the first phase of the study when operation of the clarifier was conducted with the addition of alum as the sole coagulant. Actual flow rates fluctuated around 10,000 gpd. A flow of 15,000 gpd was attempted twice; however, floc carryover from the clarifier was noted and the effluent from the filter was green in color. Therefore, evaluation at this waste flow rate was discontinued.

96. Jar tests indicated alum dosages between 200 and 300 mg/l gave optimum BOD, suspended solids, and orthophosphate removals. A pH range of 5.9 to 6.2 was also indicated as the optimum for orthophosphate removal. Therefore, a pH of 6 was maintained in the slow mix by varying alum dosages between 200 and 300 mg/l as the influent characteristics varied. These characteristics varied from day to day with the pH varying almost hourly, increasing as the day progressed.

97. The COD in the clarifier influent varied from 74 to 364 mg/l and removal efficiencies varied from 41 to 92 percent with the median removal values in the 60 to 70 percent range. The COD in the effluent ranged from 12 to 110 mg/l.

98. The suspended solids in the influent ranged between 55 and 108 mg/l with removal efficiencies varying from 71 to 96 percent. The suspended solids concentrations in the effluent ranged from 4 to 23 mg/l. On several occasions, floc was found to float to the top of the clarifier. Van Vuuren and Van Duuren²² also reported a floating algae mat occurring with coagulation using alum.

99. Removal of orthophosphate was pH dependent with the highest orthophosphate removal efficiency (99 percent) occurring at a pH range between 5.7 and 6.2 in the slow mix. Fluctuations in pH outside this range precipitated a drop in orthophosphate removal efficiencies. The EPA⁴⁰ reports optimum phosphorus removal occurs between a pH of 5 and 6 when using alum. The phosphate removal efficiencies always exceeded 82 percent, fluctuating between 82 and 99 percent for the pH range of 4.6 to 6.6. The orthophosphate concentration in the influent ranged between 8.1 and 26.5 mg/l and was reduced to between 0.37 and 3.9 mg/l in the clarifier effluent.

Table 13

**** Percent removal.**

100. During the later phases of the study, a cationic polyelectrolyte was added as a coagulant aid to the alum. Polyelectrolytes have been shown to improve clarifier efficiency and allow higher flow rates with no decrease in removal efficiencies.⁹ Preliminary jar tests indicated that a cationic polymer would increase COD, suspended solids, and orthophosphate removals. Clarifier performance data for this phase of the study are presented in Table 14.

101. The concentration of COD in the influent ranged from 184 to 312 mg/l and the effluent concentration varied from 60 to 120 mg/l. Removal efficiencies ranged from 50 to 76 percent. The corresponding concentration of BOD₅ in the effluent was 9 to 18 mg/l.

102. The concentration of the suspended solids in the influent ranged from 40 to 150 mg/l and the effluent concentration varied from 19 to 80 mg/l. Removal efficiencies ranged from 10 to 83 percent.

103. The removal of orthophosphates was again found to be pH dependent with the highest removal efficiencies occurring within a pH range of 5.1 to 6.2. Except for the 77 percent removal which occurred at a pH of 4.5, the removal efficiencies ranged from 80 to 93 percent. Orthophosphate concentrations in the influent ranged from 13.8 to 27 mg/l, whereas effluent concentrations ranged from 1.8 to 5.1 mg/l.

104. Removal efficiencies of the clarifier generally declined during the later stage of the study. This may be attributed to the use of higher hydraulic loading rates during this phase of the study. The use of polyelectrolyte did allow the use of these higher loading rates without the heavy floc carryover that occurred under similar loading rates during the nonpolymer addition phase. It is also hypothesized that the shift in algal genera present during the latter phase of the investigation also contributed to the decline in removal efficiencies. Folkman and Wachs¹⁴ indicate that variations in algal removal efficiencies may be attributed to the differences, in general, of algae which may be dominant in the lagoon system.

105. Filter performance was evaluated under two basic influent conditions: filtration of the clarified lagoon effluent and filtration of the unclarified lagoon effluent. Both the sand filter and dual media

Table 14

Date	Time	Waste Flow Rate gpd	Alum Dosage mg/l	Poly- electro- lyte mg/l	H ₂ SO ₄ ml/min	pH	Slow Mix	COD		SS		Orthophosphate				
								Influent mg/l	Effluent mg/l	R* %	Influent mg/l	Effluent mg/l	R* %	Influent mg/l	Effluent mg/l	R* %
8/1	1440	16,477	317	1.2	--	4.6-6.0		192	96	50.0	72	48	33.3	19.5	2.8	85.6
	1600	13,881	300	1.1	--	5.8-6.0		224	60	73.2	100	19	81.0	21.0	2.0	90.0
8/3	0800	13,536	309	1.0	646	5.6		220	68	69.1	96	59	38.6	20.8	4.2	80.0
	1130	17,121	255	0.8	no acid	7.0		184	76	59.0	76	68	10.5	20.5	2.6	87.3
	1230	16,617	297	1.4	660	5.2-5.6		216	104	51.9	--	--	--	13.8	2.3	83.3
8/10	1520	13,953	340	1.4	480	4.5		292	120	58.9	112	80	28.6	15.0	3.4	77.3
	1700	12,326	740	--	--	--		312	76	75.6	136	58	57.4	17.0	2.0	88.2
	1430	9,737	429	1.5	no acid	6.2		--	--	--	40	25	37.5	26.0	1.9	92.7
1545	9,216	454	1.6	no acid	5.1-6.2		--	--	--	--	150	26	82.7	27.0	1.8	93.3

*** Percent removal.**

filter were evaluated under these influent conditions.

106. Performance data collected during the filtration of clarified lagoon effluent are presented in Table 15. Removal efficiencies of the filter were found to be erratic. Backwashing, influent pollutant concentrations, loading rates, and effective media size and uniformity are all variables which may affect filter performance. Table 15 illustrates an apparent increase in COD concentration between influent and effluent occurring in the latter part of the study. This is attributed to the attempt being made at that time to increase filtration rates. The filters were being bumped, i.e., the backwash pumps were turned on for a few minutes to expand the filter bed and then turned off and filtration continued. Although filtration rates were improved, the subsequent filtration flushed the solids through the filters, thus increasing effluent COD concentrations. During normal operation, i.e., no bumping, the filters reduced COD, suspended solids, and orthophosphate concentrations and ensured a high quality effluent during periods of floc carryover from the clarifier.

107. Data collected on filter cycle time and backwash water volume are presented in Table 16. The sand media filter tended to blind at a much faster rate than the dual media filter. Backwash water volume, as percent of flow for the sand filter, ranged from 8 to 53 percent, whereas for the dual media filter the range was from 3 to 26 percent. Filter run times for the dual media filter were substantially longer than for the sand filter. Hydraulic loading rates for the sand filter ranged from 0.56 to 1.33 gpm/ft², whereas for the dual media filter rates ranged from 0.70 to 1.76 gpm/ft².

108. Direct filtration of lagoon effluent was also investigated to determine the capabilities of the wastewater treatment system to function adequately without chemical addition. Table 17 presents the filter performance data collected during this phase of the study. As can be determined from Table 17, initial results were very promising, but as filtration progressed effluent quality rapidly deteriorated to an unacceptable level. The initial high removal rates for BOD₅, COD, suspended solids, and orthophosphate (79, 72, 82, and 97 percent,

Table 15
Filter Performance Data

Date	Time	COD						Suspended Solids						Orthophosphate					
		Influent mg/l	Effluent mg/l	SM	DM	Removal, %	DM	Influent mg/l	Effluent mg/l	SM	DM	Removal, %	DM	Influent mg/l	Effluent mg/l	SM	DM	Removal, %	DM
6/14	1600	52	52	20	61	61	61	--	--	--	--	--	--	3.9	0.19	0.19	95	95	95
	1715	12	20	20	+	+	+	--	--	--	--	--	--	3.75	1.02	0.94	75	75	75
6/15	1615	48	64	84	+	+	+	--	--	--	--	--	--	1.28	0.43	0.31	66	75	75
6/19	1400	40	80	20	+	50	50	--	--	--	--	--	--	1.56	0.61	0.61	61	60	60
6/20	1600	52	32	40	38	23	23	--	--	--	--	--	--	0.37	0.78	0.78	+	+	+
6/20	1600	52	52	36	0	30	30	--	--	--	--	--	--	--	--	--	--	--	--
6/22	1700	36	24	28	33	22	22	--	--	--	--	--	--	--	--	--	--	--	--
6/23	1530	20	16	8	20	60	60	23	14	8	39	65	65	0.75	0.2	0.1	73	86	86
6/27	1700	31	59	16	+	48	48	4	4	0	0	100	100	0.8	0.2	0.25	75	68	68
6/28	1215	23	55	23	+	0	0	7	3	7	64	0	0	1.1	0.2	0.35	81	68	68
6/29	1500	43	35	35	18	18	18	10	4	5	56	50	50	1.45	0.15	0.25	89	82	82
8/1	1440	96	64	68	33	29	29	48	8	8	83	83	83	2.8	0.25	0.40	91	85	85
8/2	0400	60	64	28	+	53	53	19	11	7	42	63	63	2.0	0.5	0.4	75	80	80
	0800	68	84	68	+	0	0	59	6	12	89	80	80	14.5	0.4	0.65	97	95	95
	1130	76	90	100	+	+	+	68	26	11	61	83	83	2.6	0.5	0.45	80	92	92
8/3	1230	104	116	112	+	+	+	--	--	--	--	--	--	2.3	1.3	1.4	43	39	39
	1520	120	112	124	6	+	+	80	29	36	63	55	55	3.4	0.9	1.4	73	58	58
	1700	76	132	132	+	+	+	58	14	13	75	77	77	2.0	0.2	1.2	90	40	40
8/10	1430	--	--	--	--	--	--	25	12	11	52	56	56	1.9	1.3	1.1	31	42	42
	1545	--	--	--	--	--	--	26	7	2	73	92	92	1.8	1.0	0.8	44	55	55
	1815	--	--	--	--	--	--	115	28	34	75	70	70	5.1	0.7	4.6	86	9	9

Note: SM = sand media filter; DM = dual media filter.

Table 16
Filter Cycle Time and Backwash Data

Date	Filter Run min	Sand Media Filter			Dual Media Filter			Backwash Volume as % Flow	Flow gal	Total Backwash gal	Gal/Backwash	Backwash Volume as % Flow	Flow gal	Total Backwash gal	Gal/Backwash	Backwash Volume as % Flow
		Flow gal	Backwash gal	Total	Filter Run min	Flow gal	Total Backwash gal									
6/19/78	280	622	--	--	45	182	--	--	45	182	200	--	45	182	200	--
6/19/78	60	133	400	400	295	1191	--	53	295	1191	--	15	295	1191	--	15
6/20/78	300	1087	--	--	300	1975	--	--	300	1975	200	--	300	1975	200	--
6/20/78	60	217	400	400	60	395	400	31	60	395	200	17	60	395	200	17
6/22/78*	220	504	--	--	220	916	--	--	220	916	--	--	220	916	--	--
6/23/78	130	354	200	200	135	668	200	--	135	668	200	--	135	668	200	--
6/23/78	230	603	--	--	225	1152	--	21	225	1152	--	11	225	1152	--	11
6/27/78*	185	536	--	--	185	974	--	--	185	974	--	--	185	974	--	--
6/28/78	240	950	--	--	240	950	--	--	240	950	--	--	240	950	--	--
6/29/78	210	1115	200	200	400	1806	--	--	400	1806	--	--	400	1806	--	--
6/29/78	150	691	--	--	--	--	--	11	--	--	--	--	--	--	--	--
7/12/78	195	542	190	190	375	1962	--	35	375	1962	190	--	375	1962	--	--
7/12/78	180	540	--	--	--	--	--	18	--	--	--	--	--	--	--	--
7/13/78*	240	555	200	200	310	780	200	--	310	780	200	26	310	780	200	26
7/13/78	70	225	--	--	--	--	--	26	--	--	--	--	--	--	--	--
7/14/78	110	430	--	--	110	430	--	--	110	430	--	--	110	430	--	--
8/1/78**	240	1206	--	--	1215	7288	--	8	1215	7288	--	3	1215	7288	--	3

* Tertiary unit was empty when waste was introduced into the slow mix chamber. Alum was used as coagulant.

** In addition to alum, cationic polyelectrolyte was used as a coagulant aid.

Table 17
Performance Data for Direct Filtration

Date Time	Sample Location	Hydraulic Loading gpm/ft ²	Suspended Solids			COD			BOD ₅			Orthophosphate		
			Influ- ent mg/l	Efflu- ent mg/l	Removal Percent	Influ- ent mg/l	Efflu- ent mg/l	Removal percent	Influ- ent mg/l	Efflu- ent mg/l	Removal percent	Influ- ent mg/l	Efflu- ent mg/l	Removal percent
7-5-78 1325	Filter 1	2.38	46	7	85	117	31	74	28	6	79	15	0.45	97
	Filter 2	2.38	46	10	78	117	35	70	28	6	79	15	0.56	96
7-5-78 1540	Filter 1	2.38	35	27	23	127	131	--	31	25	19	15	13.0	13
	Filter 2	2.38	35	32	9	127	123	3	21	21	32	15	13.0	13
7-12-78 1100	Filter 1	1.09	74	88	--	184	161	12	44	31	30	18	8.5	53
	Filter 2	1.09	74	94	--	184	161	12	44	27	39	18	16.5	8
7-12-78 1650	Filter 1	1.09	104	63	40	242	161	33	58	31	47	18	14.5	21
	Filter 2	1.09	104	51	51	242	157	35	58	27	53	18	15.3	16

respectively) are attributed to residual alum in the filter media which reacted with lagoon effluent and resulted in a high-quality effluent. As filtration progressed, effluent quality was poor even at relatively low loading rates.

109. The direct filtration study confirmed the results of the literature review, which indicated low algal removals for direct sand filtration.¹⁷ Due to their negative charge, the algae have a low affinity for sand. Larger diatoms are removed but also cause blinding of the filter. Thus, for wastewater with high algae concentrations, filtration alone is ineffective.

Summary

110. The operation of a continuous-flow coagulation-flocculation-sedimentation-filtration system for upgrading of wastewater stabilization lagoons was successfully demonstrated. Operation of the mobile facility produced an effluent quality generally acceptable as meeting advanced wastewater treatment criteria.

111. Efficiencies for removal of COD, BOD₅, suspended solids, and orthophosphate are summarized in Table 18; Table 19 presents a summary of the optimum conditions for coagulation-flocculation and settling of the algae mass.

Table 18
Summary of Effluent Quality*

<u>Parameter</u>	<u>Clarifier</u>		<u>Filter</u>	
	<u>Mean</u>	<u>Range</u>	<u>Mean</u>	<u>Range</u>
COD	37.0	12-52	30.0	8-40
BOD ₅	6.0	2-8	5.0	1-6
TSS**	11.0	4-23	7.0	5-7
Orthophosphate	1.03	0.75-1.45	0.42	0.1-0.94

* All values reported in mg/l.

** TSS = total suspended solids.

Table 19
Summary of Optimum Conditions

<u>Parameter</u>	<u>Value</u>
pH	5.9-6.2
Alum	200-300 mg/l
Aqua-Floc 420	1-2 mg/l

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

112. A coagulation-flocculation-clarification-filtration (CFCF) treatment facility operated in the continuous-flow mode of operation was determined to be effective in removing significant amounts of algae and phosphorus from the effluents of intermittently discharging wastewater treatment lagoons. Evaluation of the pilot studies indicated that lagoons followed by the CFCF treatment system can be operated in such a fashion as to meet what has become known as advanced wastewater treatment standards.

113. Results of the laboratory and pilot scale studies indicated that alum, lime, and ferrous sulfate are effective algal coagulants. Alum was determined to be the coagulant of choice due to the beneficial side effect of phosphorus precipitation. Coagulant aids such as cationic polyelectrolytes were shown to have only a marginally beneficial effect on effluent quality.

114. Direct gravity filtration of lagoon effluents was shown to be ineffective in significantly reducing lagoon effluent suspended solids concentrations. Direct filtration was capable of removing only that phosphorus contained within the algal cell mass.

115. A coagulation-flocculation-clarification (CFC) treatment system applied to lagoon effluents can produce an acceptable colorless and odorless effluent with minimal amounts of suspended solids. Subsequent filtration, although not strictly necessary to produce a high-quality effluent, can be used to ensure production of a high-quality effluent during periods of clarifier upset.

116. The concept of a mobile chemical-physical treatment facility for upgrading intermittently discharging lagoon systems appears to be viable for implementation at Corps recreation facilities. Such system or systems could be rotated between recreation sites during the off season, lowering water levels in the lagoon, thus providing additional holding capacity and ultimately increasing treatment capacity of the

lagoon. This concept would be particularly applicable in those areas where the technical feasibility of complete retention ponds is marginal, i.e. annual precipitation slightly exceeds evaporation.

Recommendations

117. A preliminary design and cost estimate for a mobile chemical-physical treatment facility should be prepared to determine the cost-effectiveness of such a treatment facility.

118. A detailed study of the applicability of such a mobile system to Corps needs should be prepared. This study should identify potential sites for implementation of such a system.

119. The long-term effects of returning the alum-algae sludges to the lagoon system should be investigated.

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APPENDIX A: BATCH TREATMENT STUDIES

1. The major thrust of this investigation was the continuous-flow studies conducted at Arrowhead State Park described in the main text of this report. However, during the conduct of these continuous-flow studies, an additional substudy on fill and draw (batch) coagulation, flocculation, and clarification was performed at two sites, the Arrowhead State Park lagoon site used for the continuous-flow studies and a Corps of Engineer lagoon serving the Highway 9 Landing Recreation Area, Lake Eufaula, Oklahoma.

2. The Highway 9 lagoon system consists of two 1/4-acre lagoons operated in series. The system is designed as a total retention facility; however, periodic discharges are known to occur. The wastewaters treated at the Corps lagoons are primarily trailer dump and washroom-latrine facilities. No data were collected on hydraulic or organic loading of the lagoon system.

3. The batch mix facility consisted of a cylindrical tank of mild steel construction 52 in. in diameter and 5 ft deep. A 1-1/2-in.-diam inlet was located 15 in. from the top of the tank. Supernatant was withdrawn from a 1-1/2-in. outlet located 8 in. from the bottom of the tank. Sludge was drained from the tank through a 1-1/2-in. outlet located at the bottom center of the tank. A 3-hp Lightnin mixer with variable speed control was mounted centrally at the top of the tank. Four vertical baffles were evenly placed on the sides of the tank to prevent vortex formation.

4. The following procedures were established for operation of the batch unit.

- a. Waste from the lagoon was pumped into the batch flow tank until the water surface was approximately 15 in. from the top of the tank (1600 gal).
- b. A measured dose of alum was added manually and the contents rapidly mixed at 100 rpm for 120 sec. Complete alum dispersion was noted.
- c. The contents of the tank were then slow-mixed at 25 rpm for 28 min.

- d. After flocculation, the contents were allowed to settle under quiescent conditions for 30 min.
- e. Samples of the supernatant were collected and analyzed for pH, chemical oxygen demand (COD), suspended solids, and orthophosphate.
- f. The contents of the tank were then drained back to the lagoon systems.

5. Preliminary jar tests were conducted to determine optimum coagulants and their respective dosages. Based on these jar tests, alum was chosen as the coagulant to be used during the subsequent fill and draw studies.

6. The data collected during the batch runs at the Arrowhead lagoon site are tabulated in Table A1. Influent pH varied from 8.0 to 10.6. Average influent concentrations of COD, suspended solids, and orthophosphate were 151, 135, and 8.7 mg/l, respectively. Alum dosage was varied from 160 to 315 mg/l. For all runs, the formation of aluminum hydroxide floc was observed in the tank within 20 to 30 sec after the addition of the alum. During run No. 2, a floating algae mat was observed.

7. The optimum chemical dosages for removal of orthophosphate, COD, and suspended solids may be determined graphically through the use of Figures A1-A3. The optimum pH for the removal of phosphates with alum is in the range of 6.0 to 6.3. Values of pH either above or below this range resulted in decreased removal of phosphates. The alum dosage for optimum removal for phosphate removal was determined to be 230 mg/l (Figure A1). The highest phosphate removal efficiency achieved at the Arrowhead lagoon was 95 percent with a corresponding effluent concentration of 0.41 mg/l. Optimum alum dosage for COD removal was determined to be 240 mg/l (Figure A2). The highest removal efficiency for COD was 68 percent with an effluent COD concentration of 49 mg/l. Alum dosage for optimum suspended solids removal was determined to be 250 mg/l (Figure A3). The highest suspended solids removal efficiency attained was 92 percent with an effluent suspended solids concentration of 11 mg/l. These results confirm jar test results that optimum alum dosage is between 200 and 300 mg/l and optimum pH for phosphorus removal is approximately 6.

Table A1

A3

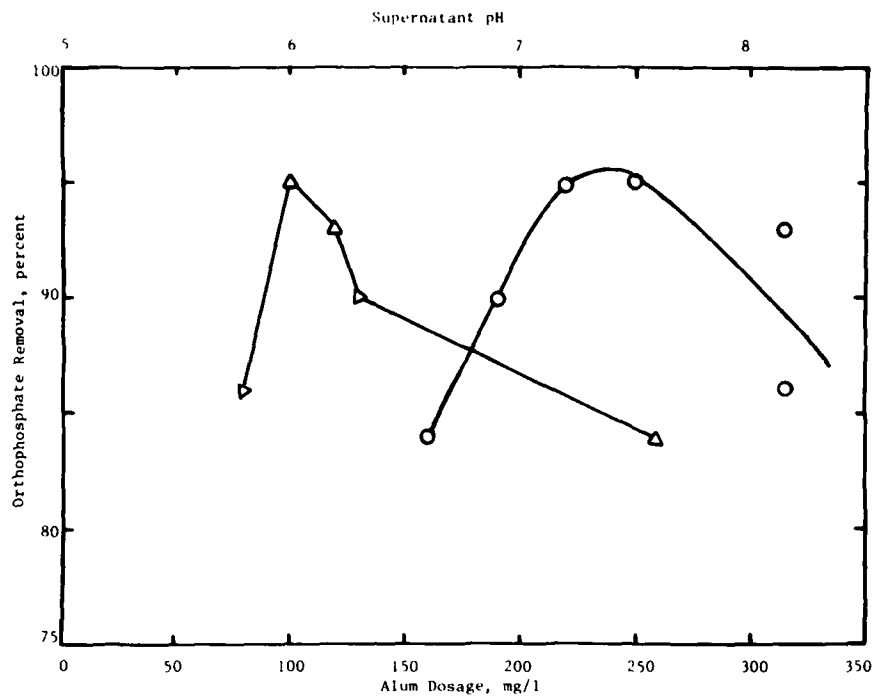


Figure A1. Orthophosphate removal versus alum dosage, Arrowhead

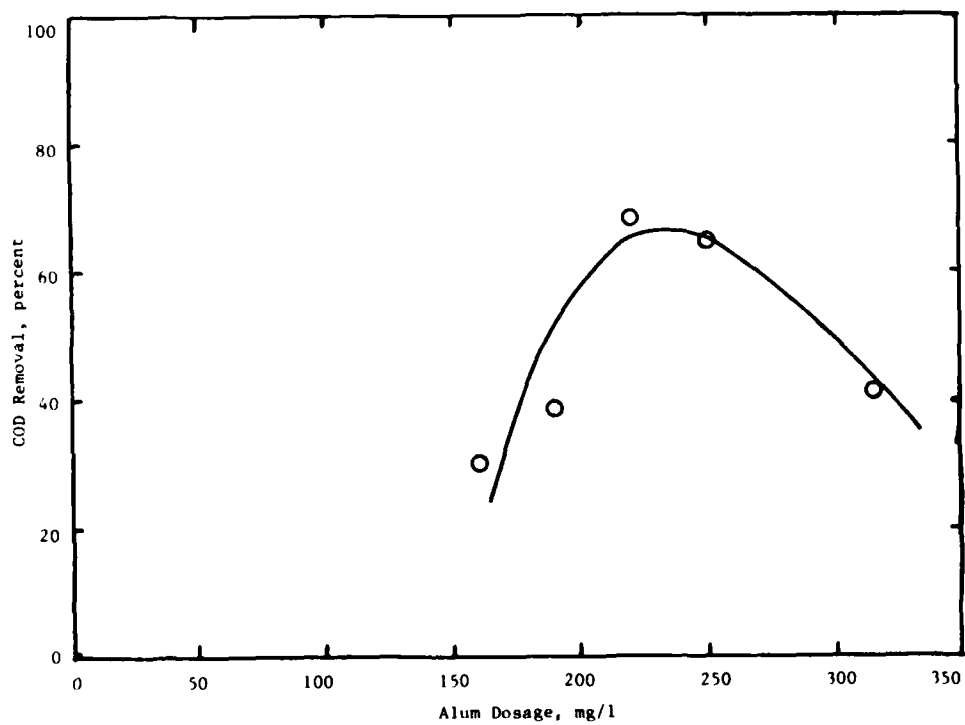


Figure A2. COD removal versus alum dosage, Arrowhead

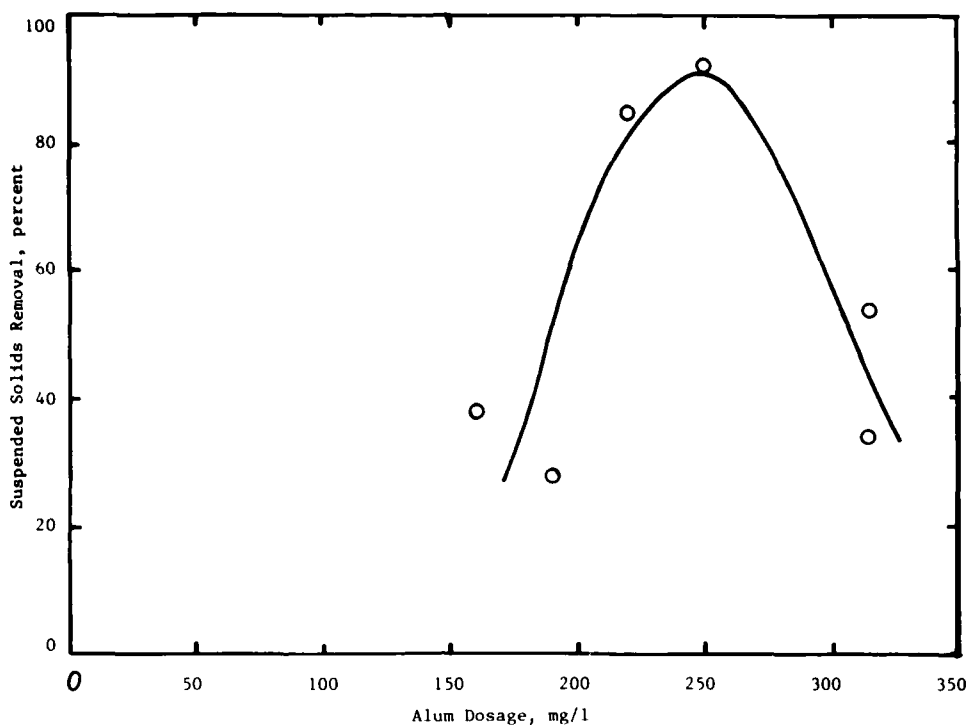


Figure A3. Suspended solids removal versus alum dosage, Arrowhead

8. Results of the batch runs conducted at the sewage lagoons at the Highway 9 landing site are tabulated in Table A2. The effects of alum dosage on orthophosphate, COD, and suspended solids removals are graphically presented in Figures A4-A6, respectively. The influent COD, suspended solids, and orthophosphate concentrations ranged from 124 to 152, 40 to 124, and 2.5 to 5.4 mg/l, respectively. Alum dosages were varied between 235 and 315 mg/l for the Highway 9 studies. The aluminum hydroxide floc formed after coagulation had very good settling characteristics at all alum dosages except 250 mg/l.

9. The chemical dosages for optimum removal of orthophosphate, COD, and suspended solids may be determined graphically through the use of Figures A4-A6. Orthophosphate removal as high as 96 percent was achieved at a coagulant dosage of 265 mg/l with a residual phosphate concentration of 0.2 mg/l. Alum dosages beyond 280 mg/l provided no increase in orthophosphate removal. A suspended solids removal efficiency of 81 percent was achieved with an alum dose of 265 mg/l with resultant effluent

Table A2
Data on Batch Studies at Highway 9 Landing

Run	Alum Dosage mg/l	COD			Suspended Solids			Orthophosphate		
		Influent mg/l	Effluent mg/l	Removal percent	Influent mg/l	Effluent mg/l	Removal percent	Influent mg/l	Effluent mg/l	Removal percent
1	235	124	64	49	40	31	23	2.5	0.75	70
2	250	144	88	39	79	52	30	4.9	2.5	50
3	265	152	32	86	104	20	81	5.0	0.2	96
4	280	152	12	92	98	30	70	5.4	0.35	94
5	315	144	60	58	124	84	33	3.35	1.7	50

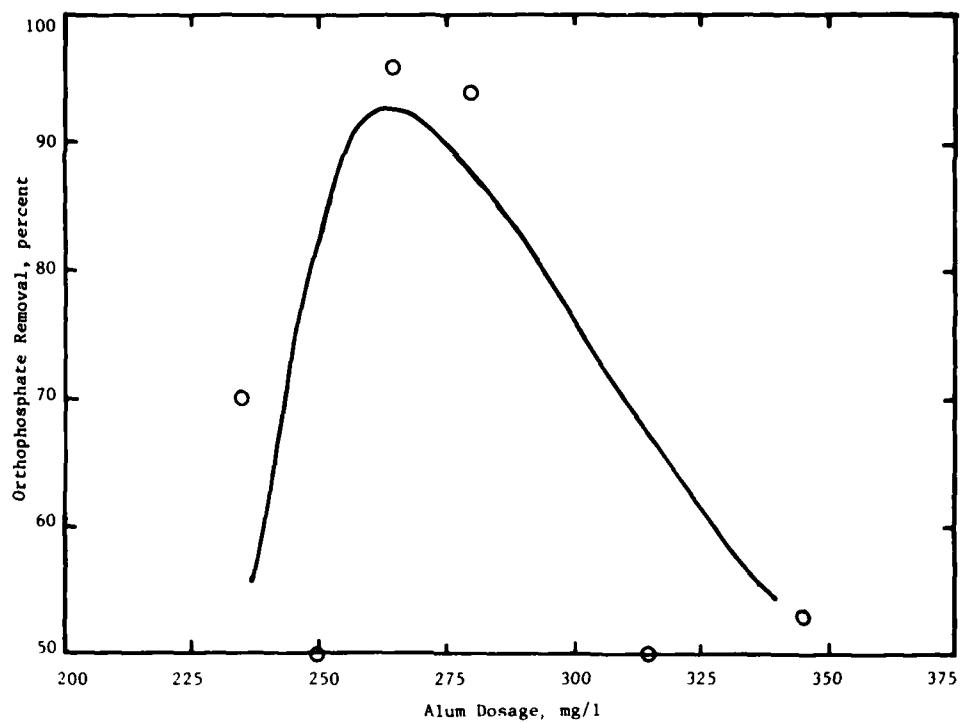


Figure A4. Orthophosphate removal versus alum dosage, Highway 9 landing

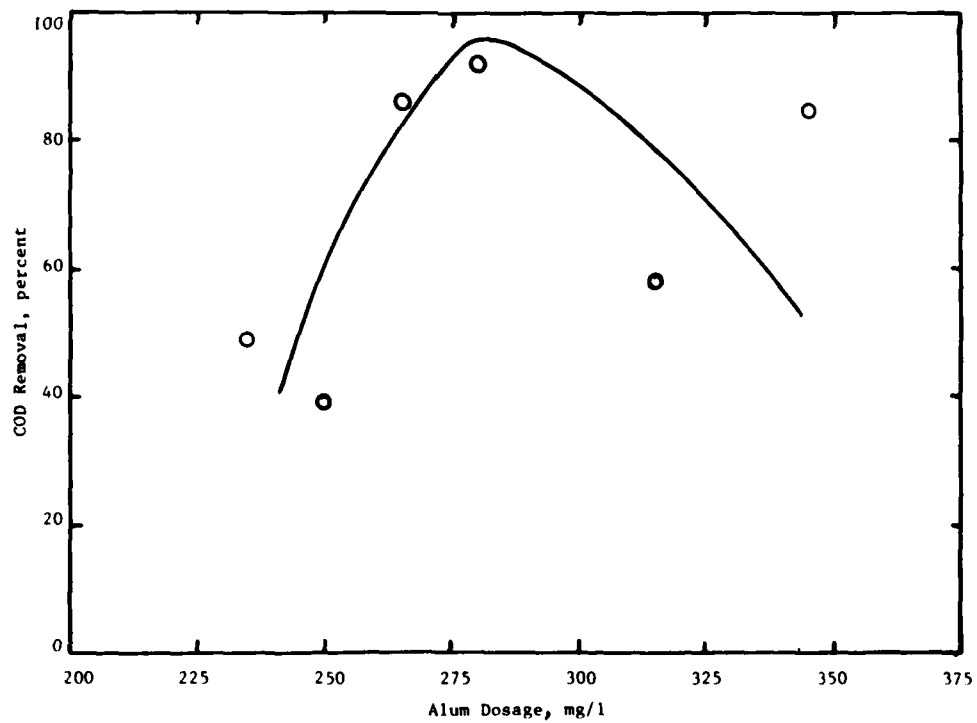


Figure A5. COD removal versus alum dosage, Highway 9 landing

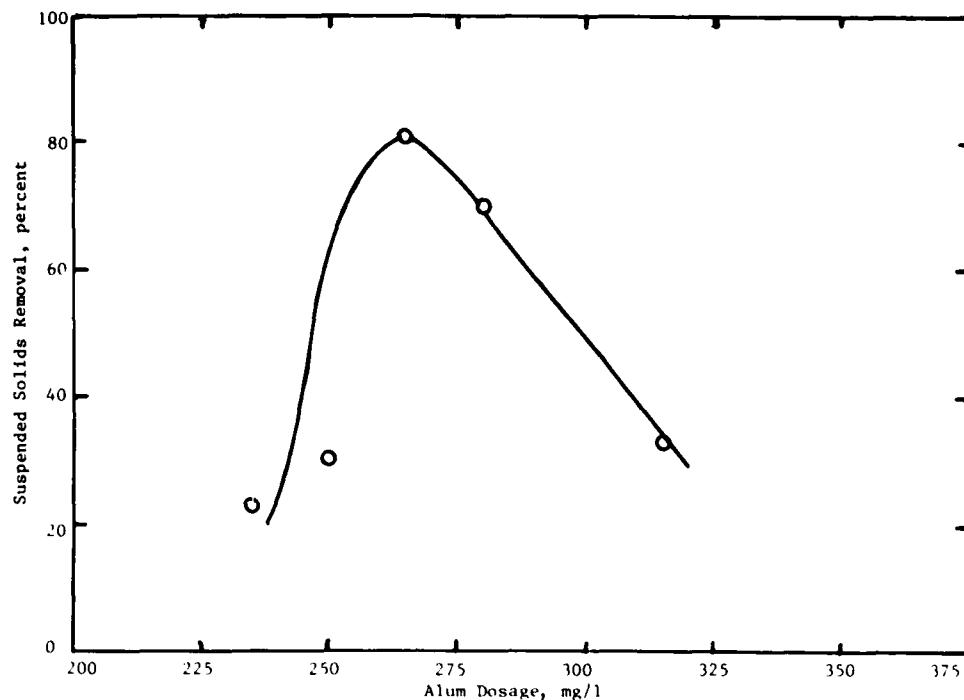


Figure A6. Suspended solids removal versus alum dosage, Highway 9 landing

suspended solids concentration of 20 mg/l. Maximum removal of COD occurred with an alum dosage of 280 mg/l with a resultant effluent COD concentration of 12 mg/l.

10. Based on the results of these fill and draw studies, several conclusions may be drawn. Chemical coagulation of algae-laden sewage lagoon effluent yields an acceptable clear and colorless product water. Aluminum sulfate was found to yield good results when used as a coagulant in the treatment of lagoon effluent to remove algae. Alum dosages in the 200- to 300-mg/l range give good quality effluent in terms of COD, suspended solids, and orthophosphate removals. Orthophosphate removals range between 50 and 96 percent with the lowest attained effluent concentration of 0.2 mg/l. Suspended solids removals range between 23 and 92 percent with the lowest attained effluent suspended solids concentration of 11 mg/l. Finally, COD removal ranges between 49 and 92 percent with the lowest effluent concentration being 12 mg/l.

11. Application of the fill and draw technique can be effectively utilized to upgrade on an emergency basis those Corps complete retention lagoons that periodically discharge to the receiving stream. The feasibility of using the fill and draw technique in such situations will require National Pollutant Discharge Elimination System (NPDES) permitting by State and Federal authorities. Contingent on permit limitations, the fill and draw technique can significantly increase lagoon effluent quality and perhaps meet stringent water quality determined effluent limitations.

12. Fill and draw techniques for Corps lagoons will be a low capital, high labor cost operation. Therefore, consideration should be given to using the fill and draw technique on small systems not consistently discharging.

APPENDIX B: PILOT PLANT DESIGN PARAMETERS

This appendix presents pilot plant design parameters under various hydraulic loading conditions.

Unit	Discharge Rate, gpd		
	10,000	15,000	20,000
Slow mix tank			
Dimensions, 7.9 by 1.9 by 2 ft SWD*			
Volume, gal	220		
Retention time, min	31.7	21.1	12.7
Weir length, ft	1		
Overflow rate, gpd/ft ²	10,000	15,000	20,000
Number of tanks	1		
Clarifier			
Type	upflow	upflow	upflow
Volume, gal	1,580		
Surface dimensions, 7 ft 3 in by 4 ft			
Overflow rate, gpd/ft ²	347	521	868
Weir length, ft	4		
Overflow rate, gpd/ft	2,500	3,750	6,250
Volume of tank, ft ³	212		
Retention time, hr	3.8	2.53	1.52
Number of tanks	1		
Filter			
Sand			
Type	downflow, gravity		
Number	1		
Media	sand		
Depth of sand media, in.	16		
Depth of gravel, in.	4		
Filter cross section, 2 ft 6 in. by 1 ft 6 in.			
Filtration area, ft ²	3.75		
Filtration rate, gpm/ft ²	0.93	1.39	1.85
Maximum available head loss, ft	6		

(Continued)

*SWD = side water depth

Unit	Discharge Rate, gpd		
	10,000	15,000	20,000
Effective size of sand, mm	0.32		
Uniformity coefficient	1.76		
Dual media			
Type	downflow, gravity		
Number	1		
Media	sand and coal		
Depth of coal media, in.	8		
Depth of sand media, in.	16		
Depth of gravel, in.	4		
Filter cross section, 2 ft 6 in. by 1 ft 6 in.			
Filtration area, ft ²	3.75		
Filtration rate, gpm/ft ²	0.93	1.39	1.85
Maximum available head loss, ft	6		
Effective size of coal, mm	0.86		
Uniformity coefficient	1.75		
Clear well			
Size, 4 ft 6 in. by 2 ft 6 in. by 3 ft 3 in. SWD			
Volume, gal	275		
Backwash pumps			
Model	Hydromatic pump - SP 50		
Number of pumps	2		
Backwash waste storage tank			
Size, 2 ft 6 in. by 1 ft 6 in. by 9 ft SWD			
Volume, gal	250		
Backwash waste pump			
Model	Hydromatic pump - SP 50		
Number of pumps	1		

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

Cullinane, M John

Laboratory and pilot scale evaluation of coagulation, clarification, and filtration for upgrading sewage lagoon effluents / by M. John Cullinane, Jr., Richard A. Shafer. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.

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