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NUTRIENT CONTROL BY PLANT MODIFICATION AT EL LAGO, TEXAS

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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NUTRIENT CONTROL BY PLANT MODIFICATION AT EL LAGO, TEXAS

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report shows that control of nutrients in wastewater discharges can be effectively accomplished at municipal facilities.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

The Harris County Water Control and Improvement District #50 has constructed and operates an advanced wastewater treatment process at its El Lago, Texas, facility. Funds for the demonstration project were shared by the District and Environmental Protection Agency.

The need for advanced waste treatment at El Lago is based on the requirements of the Texas Water Quality Board to protect the receiving water, Clear Lake, from excessive pollution by organic carbon, suspended solids, ammonium nitrogen oxygen demand, and phosphorus. The nitrogen removal portion of the demonstration is not keyed to Clear Lake requirements, but is intended as a demonstration of the capability of this process.

All existing facilities of the nominal 0.3 mgd plant were utilized in the advanced waste treatment design. The processes control phosphorus by metallic salt addition to the primary settler, carbonaceous removal by trickling filters, nitrogenous oxygen demand by suspended growth second stage activated sludge, nitrogen removal via attached growth column denitrification, and tertiary solids removal by granular media filtration. These processes are operated in series.

Process evaluation shows that an effluent with the following residual concentrations can be obtained at the design flow of 0.3 mgd.

Biological oxygen demand, 5 day	4 mg/l
Chemical oxygen demand	25 mg/l
Suspended solids	2 mg/l
Total phosphorus	1 mg/l
Total nitrogenous content	2 mg/l

This project demonstrated the feasibility of modifying an existing small trickling filter plant to control nutrients in wastewater discharge.

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Lockwood, Andrews and Newnam, Inc., Houston, Texas, performed the detailed engineering design with E. Munson as principal design engineer. J. Hostettler and D. Roberts provided additional engineering services during change order modifications. J. Smith (EPA's Municipal Environmental Research Laboratory in Cincinnati, Ohio) provided design guidelines for the denitrification process. J. Cohen (MERL - Cincinnati) helped in the initial development of the scope of work, and E. Barth (also MERL - Cincinnati) conceived the process sequence described in this report.

J. Winter (MERL - Cincinnati, Analytical Quality Control Laboratory) furnished chemical reference samples for laboratory evaluation.

The phosphorus removal facilities were installed by George C. Cox, Inc., as general contractor. The nitrogen control facilities were installed by Don Love, Inc., as general contractor. Both firms are located in Houston, Texas.

F. Adams, J. McPherson and D. Baker operate the Harris County Water Control and Improvement District #50 facilities. J. Cornett was plant superintendent until his retirement in December 1972.

Secretarial services for the District were performed by Mrs. J. Dirnberger and Mrs. A. Kleabonas.

B. Ryan, District General Manager, served as project engineer.

SECTION I

CONCLUSIONS

1. A small municipal facility can be converted to an advanced wastewater treatment plant with no disruption of services.

2. Existing capital equipment can be retained and utilized as useful components of an advanced waste treatment facility.

3. High quality effluent can be produced by the proper combination of chemical - physical - biological processes to meet effluent requirements for biological oxygen demand, suspended solids, phosphorus, and nitrogenous pollutants.

4. A series designed and operated stage system lends itself to flexible operation.

5. A full-time resident engineer is needed for plant startup and for initial evaluation of plant processes.

6. Operators can adapt to advanced waste treatment control processes.

7. Attached growth microbial denitrification in packed columns has been demonstrated on a full scale.

8. Dosing of metallic salts for phosphorus control did not interfere with anaerobic digestion or overload the installed sand drying bed capacity at El Lago, Texas.

9. Tertiary filtration of wastewater effluent to control particulate matter enhances the visual qualities of the final product.

SECTION II

RECOMMENDATIONS

Because the full scale feasibility of simultaneously controlling the major wastewater pollutants such as organic carbon, suspended solids, phosphorus, and nitrogenous material, by a combined biological-chemical process has been firmly established at El Lago, Texas, it can be instituted at other sites, where the need exists.

Due to the flexibility of the stage treatment concept designed into this facility, several alternate operational schemes could be studied.

The basic operational mode could be optimized to produce lower effluent residuals.

Eventually limited reuse of the effluent could be approached by converting one of the column denitrification systems into a carbon adsorption process.

Long term evaluation of the operational manpower requirements, operational cost, and effluent residual variability is recommended.

SECTION III

INTRODUCTION

On July 6, 1970, the Board of Directors of Harris County Water Control and Improvement District #50 (HCWCID #50) made application to the United States Environmental Protection Agency (EPA) for a Research, Development and Demonstration Grant. The impetus for the application was Proposed Board Order No. 69-9 of the Texas Water Quality Board, dated March 27, 1969. This proposed order provided an implementation plan for protection of Clear Lake from excessive eutrophication. Two options were permissible. Plan I called for diversion of effluent discharges from Clear Lake. Plan II allowed discharge into the lake if "The implementation of advanced waste treatment techniques which would effectively limit the nutrients (nitrogen and phosphorus) being discharged into the lake . . ." were instituted.

Clear Lake is fed by a watershed of 260 mi^2 and has a surface area of 1,542 acres. It is connected to Galveston Bay by a 1 mi long channel which is about 200 ft wide. The lake is normally 2 to 12 ft deep and is subject to tidal variations.

In July 1970 there was sparse information available on either diversion plans or treatment techniques upon which the Board could make a cost effective decision between Plan I or Plan II. Due to the fact that approximately 20 separate municipalities and water districts discharge wastewater treatment plant effluent to the Clear Lake basin, a regional or diversion plan would pose legal, right-of-way, and taxing complications. Also a diverted flow might require additional treatment in any case. The Board elected to pioneer advanced wastewater treatment at their small municipal facility in order to implement an action plan for compliance with the Texas Water Quality Board order and to collect information on alternate Plan II which could be used for future decisions.

The EPA was receptive to the grant application because the Board of Directors and other residents of the District were technically oriented due largely to the close proximity of the Lyndon B. Johnson Space Center, and also because the daily volume of wastewater was large enough to be classified as full scale operation, but small enough that huge capital outlays would not be necessary. In addition, there existed a need for a national demonstration of nutrient control technology, because there was no single facility in operation that was specifically designed and successfully operated for phosphorus and nitrogen removal.

Personnel from the EPA and the District met and agreed on a conceptual design, analytical evaluation, operational schedule, period of performance, and project objectives. The main objective would be the production of a final effluent that had the following nominal pollutant concentrations:

Five Day Biochemical Oxygen Demand (BOD_5)	5	mg/l
Chemical Oxygen Demand (COD)	30	mg/l
Suspended Solids (SS)	10	mg/l
Total Nitrogen (TN)	2	mg/l
Total Phosphorus (TP)	1	mg/l

The grant started on September 15, 1970, and was for a period of 3 years. Three time extensions changed the period of performance to 4 years and 11 months, terminating August 15, 1975.

SECTION IV

PRELIMINARY STUDIES

The HCWCID #50 covers an area of 300 acres and serves a population of 3,000 with 700 tax accounts. Aside from single family dwellings, the District includes the following:

2 - Apartment complexes
3 - Service stations
2 - Small grocery stores
3 - Boat and marine supply dealers
1 - Appliance and auto parts store
1 - Fraternal lodge
1 - Church
1 - Real estate brokerage office
1 - Insurance office

The District supplies both drinking water and wastewater treatment services. As of 1975 the monthly charge for water was $2.75 for 5,000 gallons minimum and $0.55 for each additional 1,000 gallons and the sewer charge was a flat $4.25 per month.

Figure 1 is a schematic flow diagram of the El Lago wastewater treatment plant as it existed in September 1970. The facility consisted of two side-by-side plants. Plant #1 is a 200,000 gpd trickling filter plant constructed in 1962. Plant #2 is a 300,000 gpd trickling filter plant constructed in 1969. Influent to the treatment process is from a common wet well, and the flow to each plant is controlled to provide proper residence time in the two slightly different size facilities; therefore, loading parameters can be calculated on the summation of the dual plant capacity. Table 1 gives the calculated loadings for this municipal trickling filter facility. The loadings on the plant processes are in the upper range of a typical low-rate trickling filter design.

The second column in Table 2, titled Raw Wastewater, gives the pollutional characteristics of El Lago wastewater calculated from data accumulated over a 3 year period. Each value was determined from analytical results of approximately 40 samplings. The values indicate a typical domestic strength waste with high and low extremes influenced by moderate infiltration as evidenced from the average dry weather flow compared to the wet weather flow.

The performance of the plant before starting the advanced waste treatment demonstration is tabulated in the third and fourth columns of Table 2. These show the quality of the primary effluent applied to the trickling filters and the quality of the final effluent discharged to Clear Lake prior to July, 1972.

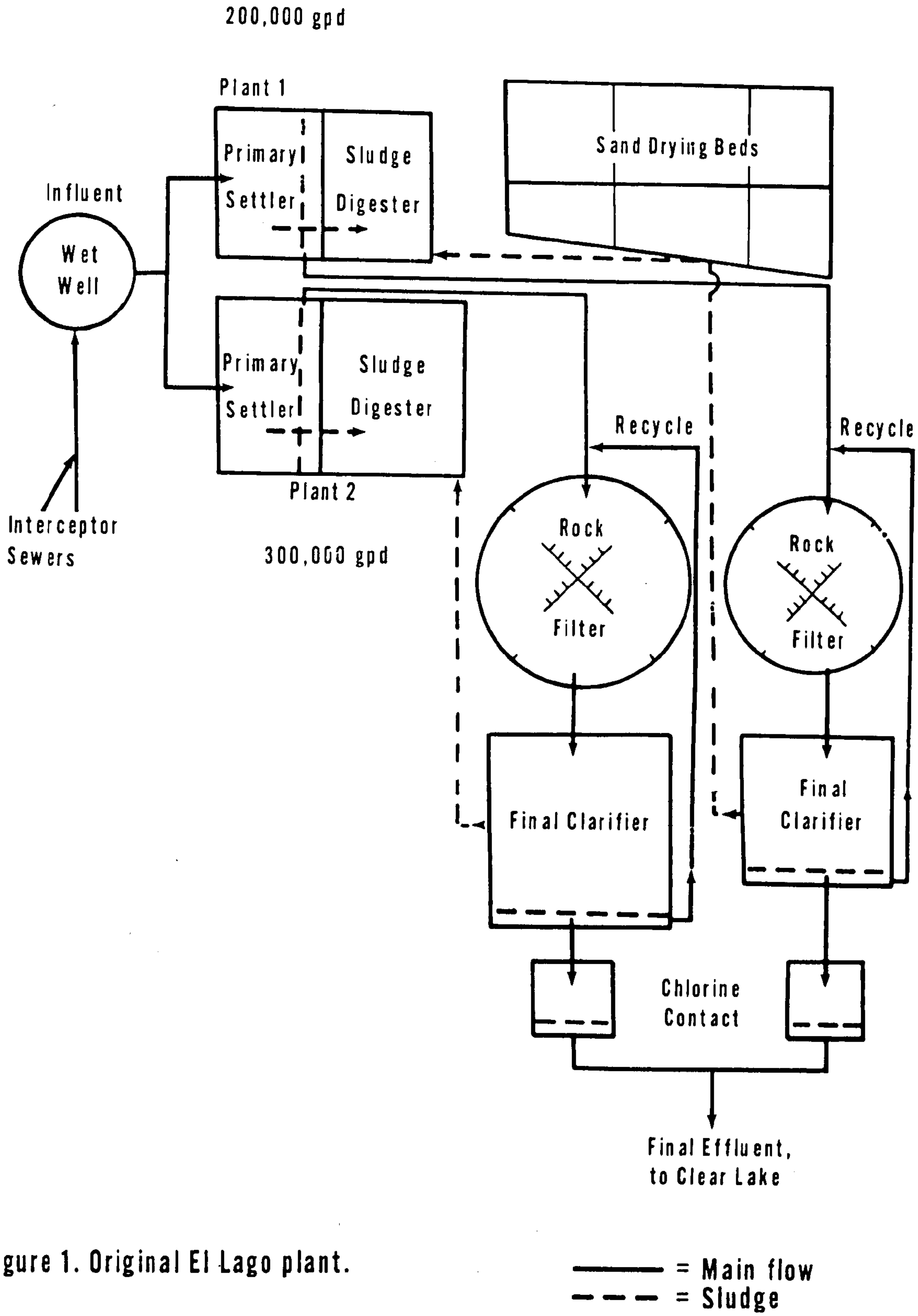

Figure 1. Original El Lago plant.

Table 1. CALCULATED LOADINGS FOR THE EL LAGO FACILITY*

Unit/Measurement	Average dry weather (ADW)	Maximum dry weather (MDW)	Wet weather (WW)
Influent flow, mgd	0.3	0.5	1.0
Primary settler			
Detention time, hr	3.4	2.1	1.0
Surface overflow rate, gpd/ft^2	524	873	1,745
Trickling filter+			
Organic load, lbs/day/1000 ft^3	17	--	--
Hydraulic load, gpd/ft^2	92	155	310
Final clarifier‡			
Detention time, hr	5.4	3.0	1.5
Surface overflow rate, gpd/ft^2	320	530	1,060
Chlorine contact tank			
Detention time, hr	1.0	0.6	0.3

*The El Lago facility serves a population of 3,000. Anaerobic digester volume (non-mixed, non-heated) is 8,830 ft^3 or 2.9 ft^3 per person.

+Natural rock (4-in. dia), 6.5 ft depth. Recirculation is constant at 0.3 mgd during dry weather.

‡Chain and wood flight scrapers.

Table 2. AVERAGE VALUES FOR EL LAGO RAW WASTEWATER AND PRIMARY AND FINAL EFFLUENTS, mg/l*

Measurement	May '70-Aug '73	May '70-Jun '72	
	Raw wastewater	Primary effluent	Final effluent
BOD_5			
Avg	161	121	12
Range	93-223	70-140	5-25
COD			
Avg	287	229	67
Range	89-654	119-260	52-80
Suspended solids			
Avg	195	56	12
Range	18-256	30-106	4-20
Total phosphorus			
Avg	13.6	13.6	13.8
Range	3.7-27	10-20	8-19
Ammonium nitrogen			
Avg	24	15.7	5.5
Range	2.4-49	14-17	5-10
Organic nitrogen			
Avg	13.5	3.5	2
Range	2.4-25	2-5	1-2
Oxidized nitrogen			
Avg	0	0	11
Range	-	-	5-12
Alkalinity, as calcium carbonate			
Avg	345	-	-
Total oxygen demand			
Avg	456	315	101
pH units			
Median	7.6	7.2	7.5
Range	7.0-8.1	6.9-7.8	7.0-8.0

*Except pH

Normal treatment at El Lago during this earlier period included the use of Nalcolyte 603 polymer, injected into the wet well, for aid in settling suspended solids in the primary clarifier. In comparing the values for primary effluent and final effluent, the efficient operation of the trickling filter secondary system is evident. The existing plant facilities were adequate for the control of BOD_5, suspended solids and COD to meet secondary standards. However, essentially no removal of phosphorus was achieved. Because of the mild climate in the El Lago area and the conservative design of the trickling filters and final clarifiers, partial nitrification was accomplished. Total oxygen demand (TOD) was greatly reduced. TOD values given in Table 2 were calculated by summing the COD values and the oxygen equivalent of ammonium nitrogen and organic nitrogen. The value of 4.5 was used as the oxygen equivalent of the nitrogen species. A summation of the nitrogen value shows that there was only very slight removal of total nitrogen after primary treatment.

There was very little change in pH through the process due to the buffering action of the rather highly alkaline water.

Table 3 gives the efficiency of the plant during conventional operation in terms of percent removal of pollutants from raw wastewater through primary treatment, and an overall removal based on the average values for raw and final waste streams. The degree of phosphorus removal was so slight that calculations based on average values indicated essentially zero removal.

Digested sludge that accumulated in the anaerobic digester was periodically discharged to sand drying beds. This wet sludge had a total solids content of 8 percent and an ash content of 68 percent. After drying, the cake was raked off the beds and used by local residents for soil conditioning or spread on the fringe areas of the treatment plant grounds. The filtrate from the sand beds and the supernatant from the anaerobic digesters were both recycled to the influent wet well.

The above tabulations reflect the fact that the El Lago facility was producing an acceptable effluent in terms of the usual pollutants that were of major concern when the facilities were originally designed and placed into operation; however, Board Order 69-9 proposed control of phosphorus and nitrogenous pollutants. A study of the nitrification capabilities of the plant was done for a short 2 month period. The trickling filters were operated in series, rather than in the normal paralled operation to see if nitrification could be increased. No improvement in nitrification capability was noted. This finding influenced the design considerations necessary to implement nutrient control into the El Lago plant.

Due to the good operation of the facilities, all existing unit processes were retained in the advanced waste treatment design. The design, construction and operation of the additional facilities were carried out in two phases. Phase I involved phosphorus control, and Phase II involved phosphorus and nitrogen control.

The goal of the El Lago project was to provide full scale demonstration of nutrient control process capability, not to build a research facility for collection of design data. Conservative design values, from numerous pilot plant investigations, were selected for the construction.

Table 3. PERCENT REMOVAL EFFICIENCY OF THE EL LAGO PLANT THROUGH JUNE 1972

Measurement	Raw wastewater to primary effluent	Raw wastewater to final effluent
BOD_5	25	92
COD	20	77
SS	71	94
TP	0	0
TN	48	51
TOD	31	78

SECTION V

PHOSPHORUS CONTROL

DESIGN AND CONSTRUCTION

The construction and installation of the capital equipment for phosphorus control started in August 1971. The process selected was chemical precipitation by metallic salt and polymer addition into the influent wastewater for removal of the phosphorus in the primary settler. Figure 2 is a schematic showing Phase I additions to the plant.

Construction consisted of general earthwork, concrete pad and dike for chemical storage tanks, concrete pad for pump house, laying of chemical dosing pipe, increased electrical capacity, installing electrical motor control lines, erection of pump house, and miscellaneous related tasks.

To allow for economic purchase of liquid metallic salts, two chemical storage tanks (Western Fiberglass) were provided. These are of fiberglass construction, and each has a 4,000 gallon capacity. A horizontal configuration was necessary because of height limitations on structures in the community. Figure 3 is a picture of the installed tanks.

The pump house (Warminster Fiberglass Co.) is also of fiberglass construction for chemical resistance. The prefabricated structure, which measures 8 x 8 x 6.6 ft, houses two metal salt dosing pumps and two polymer pumps and tanks. Experience has shown that a larger building would offer more comfortable operating conditions.

The dual-head metal salt pumps (Wallace & Tiernan, Series 748) have a combined pumping capacity of approximately 20 gal/hour at 12 strokes/min and a 10:1 range in delivery rate by manual adjustment of stroke length. Each pump motor is connected to one of the wet well pump circuits and a metal salt pump operates when its respective wet well pump is in operation. The metal salt solution is added to the raw wastewater at a point between the intakes to the two wet well pumps.

Two polymer pumps deliver diluted polymer solution in the waste stream as it flows through the riser pipe from the wet well to the primary settlers. Each polymer pump (Wallace and Tiernan Series A-745) has a capacity of 30 gal/day with a 10:1 adjustment range.

Like the metal salt pumps, the polymer pumps are connected to the wet well pump circuits. The polymer solution is made up in 50 gallon polyethylene tanks equipped with electric mixers. Figure 4 is a picture of the interior of the pump house.

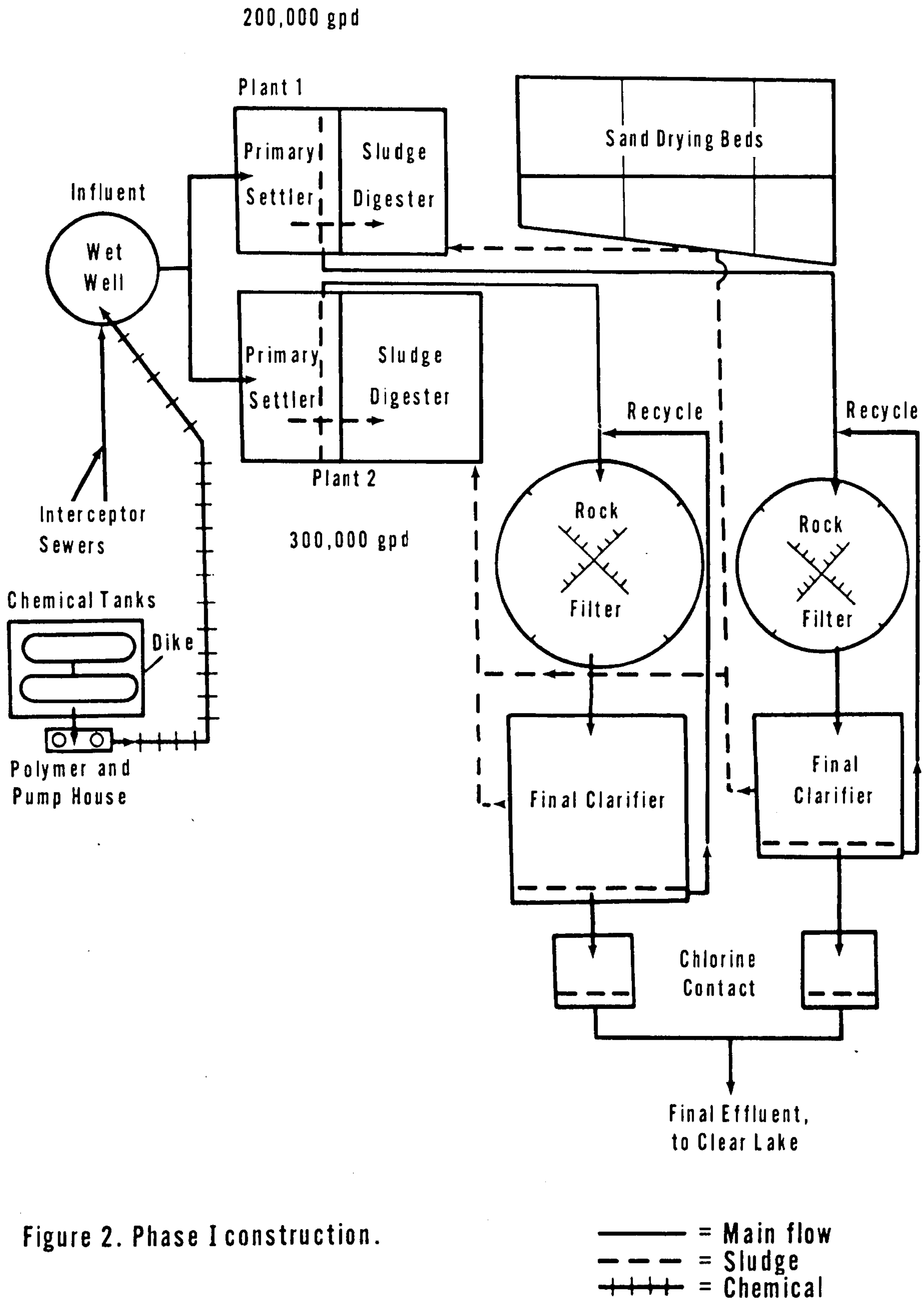

Figure 2. Phase I construction.

Figure 3. Installed chemical storage tanks and pumps

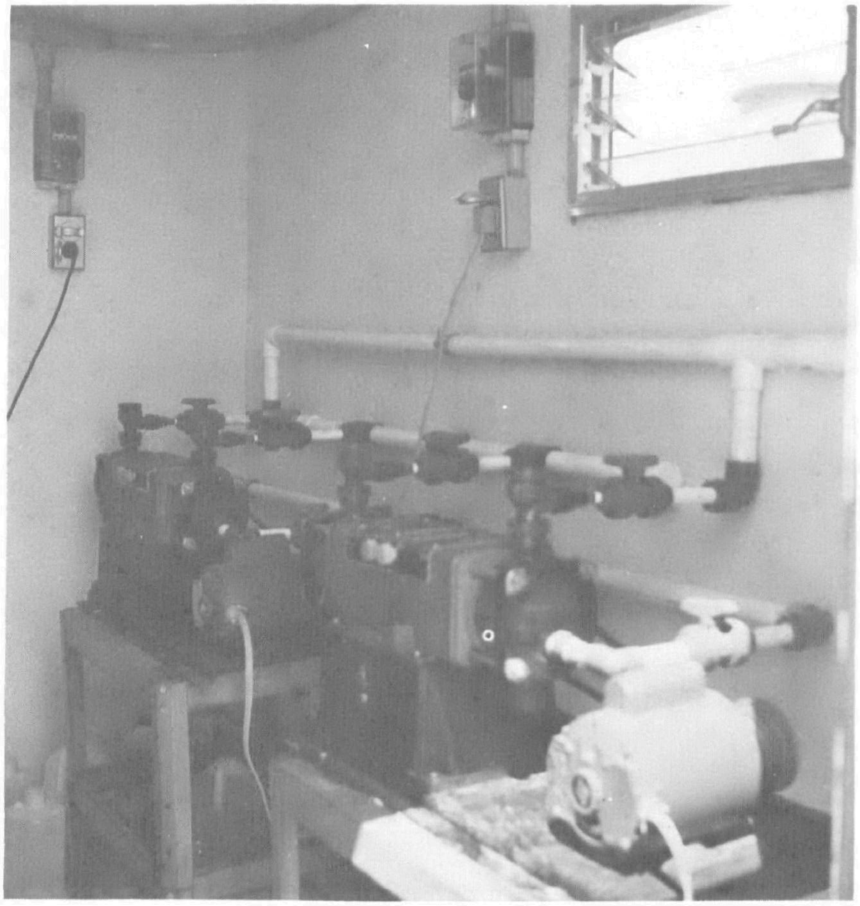

Figure 4. Interior of pump house

Within each chemical dosing system the respective storage reservoirs and pumps are interconnected so that solutions can be pumped while one unit is off-line for filling, cleaning or making repairs.

In a small facility such as this, it is not feasible to dose metal salt in proportion to both flow and concentration. The arrangement of connecting the chemical pump motors to the two wet well pumps allows chemical to be added in relation to flow. Since recycle flows of digester supernatant, said bed filtrate, and filter backwashes also enter the wet well, they also create a demand for chemical addition.

Phase I design for phosphorus removal was not intended for highly efficient removal. Utilization of the existing facilities placed several constraints on the phosphorus process selection. The advanced nutrient control design was a multi-stage system with the first stage being the existing El Lago trickling filters for carbonaceous oxidation. Therefore, metallic salts could not be added to the first stage biological process, as is usually done when suspended growth systems are employed. Dosage of metal salts to the trickling filter underdrain for efficient phosphorus capture was not possible because the existing final clarifiers were to be converted to immediate stage clarifiers in Phase II construction. Removing the major fraction of the phosphorus by adding metal precipitants to the planned second stage suspended growth nitrification reactor was not considered good practice due to the need to control the biological solids sludge age in this process to assure nitrification. This approach would build up inert solids in the reactor due to the sludge production that occurs from the phosphorus-metal precipitation.

Under these circumstances it appears that the best approach was to add metal salt and polymer in the primary stage for the removal of the bulk of the phosphorous and associated sludge ahead of the other unit processes, in spite of the fact that organic and polyphosphates would not be efficiently removed. To compensate for this and obtain the 1 mg/l phosphorus goal, Phase II provided for a polish dose of metal ion at the nitrigication reactor and another dose of polymer immediately prior to final filtration.

OPERATION AND RESULTS

Table 4 provides data from a 3 month period (August, September, October 1972) when ferric chloride and Dow A-23 polymer were injected into the wet well and riser pipe, respectively. The total phosphorus concentration of the raw wastewater was in the range of the typical values given in Table 2. Eighty-three percent of the influent phosphorus was soluble. This rather high soluble content probably explains the very negligible removal of the phosphorus by the El Lago facility during conventional treatment. Ferric chloride and polymer injection was about 80 percent effective in both insolubilizing the phosphorus and coagulating the precipitate to cause removal with the primary sludge. The weight and mole ratios given in Table 4 are similar to other reported experience to obtain 80 percent removal in a primary treatment process. Very slight additional removal was obtained through the trickling filter secondary process. When the values for soluble phosphorus in the primary effluent and final effluent are

Table 4. EFFECTIVENESS OF PHOSPHORUS REMOVAL* AUGUST - OCTOBER 1972.

Measurement	Raw wastewater	Primary influent (after recycle flows)	Primary effluent	Final effluent
Phosphorus, mg/l				
total	14.9	13.0	3.0	2.8
soluble	12.3	1.5	1.3	1.8
Percent soluble	83	12	43	64
Ferric chloride as iron mg/l	--	33	--	--
Weight ratio iron/total phosphorus	2.2	2.5	--	--
Mole ratio iron/total phosphorus	1.2	1.4	--	--
A-23 Polymer, mg/l	--	0.21	--	--
Cumulative percent removal of total phosphorus	--	--	79.8	81.2

* Each value represents the average of 55 individual analyses.

compared, there is an indication that small amounts of previously insolubilized phosphorus reverted to a soluble form during secondary treatment.

The plant efficiency for BOD_5, COD and SS removal remained essentially the same during this chemical dosing period as for conventional operation as reported in Table 3. No reduction in the pH of the primary effluent was noted in response to the introduction of the acidic ferric chloride.

Table 5 presents phosphorus removal data from three later periods during operation of Phase II nitrification and denitrification facilities. The dosing of ferric chloride and polymer was continued during these periods, but the ferric chloride dose was split about 2 to 1 between the wet well and the nitrification reactor and the polymer dose was divided equally between the riser pipe to the primary clarifier and the inlet piping to the final polishing filters.

During the first period for which data are shown in Table 5, the ratio of ferric chloride to total phosphorus content of the primary influent was increased 36 percent above that for the August - October 1972 period. Removal of total phosphorus between primary influent and final influent increased from 78.5 percent to 96.8 percent. This increase in removal effectiveness was attributed to the increase in ferric chloride and split dosing of both chemicals.

During the two following periods (31 days and 41 days), the ratio of ferric chloride to total phosphorus content of the primary influent was the same as that for the August - October 1972 period, but removal of total phosphorus between the inlet to the primary settler and the plant discharge was increased from the previous 78.5 percent to 93.6 percent and 94.0 percent, respectively. Total phosphorus removal efficency increased about 15 percent, and it was assumed that this was due primarily to split dosing of ferric chloride and polymer since calculations indicated that wasting of bacterial mass from nitrogen control facilities would account for very small amounts of phosphorus. Since this data showed that the target residual of 1 mg/l total phosphorus could be obtained with a split dose of ferric chloride at a 2.5 to 1 weight ratio between ferric iron and phosphorus, that dosage has become routine at El Lago.

Table 6 gives analytical values for anerobic digester samples. Primary sludge cannot be sampled at El Lago because the settled primary sludge is transferred through a submerged standpipe to the anaerobic digester by the difference in hydraulic head between the settler and the digester. Digester supernatant at this plant has always been a good quality, and the most notable change after chemical treatment was the reduction in total phosphorus concentration. Marginal increases in COD, SS and alkalinity were noted. The pH remained in a satisfactory range. The most striking change occurred in the phosphorus content of the digested sludge. Before chemical treatment, digested sludge contained 0.7 percent phosphorus by weight. After chemical precipitation in the primary settler the phosphorus content increased to 4 percent. A thicker sludge was also produced, as evidenced by the increase in total solids from 8 percent to 9 percent. Alkalinity and pH of the digested sludge remained within the normal range; and good digestion, both before and after chemical treatment, is indicated by the high ash content of both samples. Figure 5 is a view of the well drained and cracked iron phosphate digested sludge on the sand drying beds.

Table 5. EFFECTIVENESS OF PHOSPHORUS REMOVAL, SEPTEMBER 1974 - FEBRUARY 1975

Period		Ferric iron dose*			Total phosphorus, mg/l				Soluble phosphorus, mg/l				Percent TP removal
		Fe^{+3} mg/l	Weight ratio	Mole ratio	Prim infl	Prim effl	Denit effl	Final effl	Prim infl	Prim effl	Denit effl	Final effl	
9/23/74 to 11/ 8/74 (47 days)	Avg	41	3.4	1.9	12	3.4	3.0	0.39	2.1	1.0	0.39	0.38	96.8
	Range	20-79			8.1-16	1.3-4.5	1.0-4.5	0.15-0.77	<0.01-5.7	<0.01-2.2	0.01-0.90	0.13-0.74	
11/16/74 to 12/16/74 (31 days)	Avg	27	2.5	1.4	11	5	2.4	0.7	3.0	1.9	0.6	0.6	93.6
	Range	14-43			6.0-14	2.6-10	1.6-4.4	0.28-1.3	1.2-10	0.71-6.5	0.27-1.5	0.25-1.3	
1/ 5/75 to 2/14/75 (41 days)	Avg	25	2.5	1.4	10	4.0	2.4	0.6	1.1	0.50	0.50	0.53	94.0
	Range	14-57			5.9-12	2.8-5.4	1.7-3.9	0.29-1.2	0.41-2.0	0.33-0.70	0.40-0.58	0.27-0.91	

*Weight ratio and mole ratio are ferric iron to total phosphorus in the primary influent wastewater.

Table 6. AVERAGE VALUES FOR ANAEROBIC DIGESTER SAMPLES BEFORE AND AFTER CHEMICAL TREATMENT

Measurement	Digester supernatant		Digested sludge	
	Before	After	Before	After
COD, mg/l	291	381	-	-
SS, mg/l	194	290	-	-
TP, mg/l	23	11	683	3,670
Alkalinity, mg/l calcium carbonate	866	1,048	1,593	1,760
Total solids, %	-	-	8.0	9.0
Ash, %	-	-	67.5	64.4
pH, median	6.6	6.9	6.4	6.8
Number of samples	10	13	3	12

Figure 5. Sand drying beds with digested sludge

During Phase I of the project, both alum and ferric chloride were evaluated for phosphorus control. Equal mole ratios of Al^{+3} and Fe^{+3} worked equally well from the standpoint of phosphorus removal and sludge handling characteristics. The final choice of Fe^{+3} for more extensive evaluation was based on the relative costs of alum and ferric chloride. Ferric chloride was much less expensive in the Houston area where it is available as a by-product.

This phase of the project demonstrated that a low rate trickling filter plant removing very little phosphorus under standard operation could be upgraded to 80 percent removal by addition of ferric chloride and polymer to the wastewater; and routine removal of over 93 percent total phosphorus could be achieved by split dosing of the chemicals, followed by tertiary filtration.

SECTION VI

NITROGEN CONTROL

DESIGN AND CONSTRUCTION

The construction and installation of the capital equipment for nitrogen control started February 1972. The process selected was staged biological suspended growth nitrification followed by attached growth biological denitrification with tertiary filtration.

At the time of the initiation of the grant it was not clear whether the Texas Water Quality Board would require nitrogen removal or elect to establish nitrogen control on a total oxygen demand basis. To benefit both parties of the grant in relation to their financial interests, several compromises in design criteria were made. The phosphorus removal, nitrification and tertiary filtration facilities would be designed for a maximum dry weather flow of 0.5 mgd. Design for denitrification would be for average dry weather flow of 0.3 mgd since there was no established nitrogen removal standard. Flows in excess of 0.5 mgd could be routed around the nitrification and denitrification processes. Within these confines all the processes required to meet the state standards would be designed for maximum dry weather flow, and the experimental portion of the design - denitrification - would be evaluated at average dry weather flow and stressed to maximum dry weather flow. Wet weather flow in excess of 0.5 mgd occurs only about eight percent of the time at El Lago.

The preliminary studies had shown that, even in series operation, the existing trickling filters did not produce a completely nitrified effluent. Therefore, a suspended growth reactor was selected for Phase II. The feed to the nitrification reactor is the direct underdrain from the existing trickling filters. The final clarifiers were converted to intermediate clarifiers to separate the nitrification mixed liquor.

Attached growth denitrification was selected in contrast to the suspended growth nitrification process. Two media were chosen for comparison. One set of denitrification towers has large plastic media, and the other set of towers has fine sand media.

Tertiary filtration was deemed necessary to ensure meeting Texas Water Quality Board requirements and to produce a clear effluent for aesthetic reasons.

Construction consisted of general earth work, construction of the concrete nitrification reactor and nitrified effluent sump storage, installation of four air lift pumps in the intermediate clarifiers, construction of concrete pads for the denitrification towers, erection of the two fine media towers and the two large media towers, installation of two air blowers, installation of two five-stage centrifugal pumps and electrical flow control system, installation of two methyl alcohol dosing pumps, installation of process and backwash piping and valving, installation of the tertiary filter, installation of electrical wiring, laying of chemical feed lines, construction of a laboratory and control building, and miscellaneous related tasks. Figure 6 shows a schematic of Phase II additions to the plant.

The nitrification reactor and nitrified effluent sump occupy a rectangular tank which is divided into three bays by two common walls. The nitrification reactor, consisting of one or both of the first two bays, receives the trickling filter underdrain and was designed for biological oxidation of ammonium nitrogen to nitrate nitrogen. Separation into two bays gives flexibility to vary detention time for study of the nitrification process rates. The third bay serves as a sump for the nitrified effluent after it has passed through the intermediate clarifiers and before it is pumped to the denitrification towers. When not used for nitrification, the smaller of the first two bays can be interconnected with the third bay to double the sump capacity. This increased storage capacity helps equalize the flow to the denitrification towers. Design specifications for the nitrification reactor and the sump are given in Table 7. Figure 7 shows the two aeration bays of the nitrification reactor on the right and the sump on the left. The two centrifugal blowers (Lamson Div. of Diebold, Inc.) shown in Figure 8 are used to provide air for the aerobic nitrification process, for operation of air lift pumps and for air scouring of the small media denitrification towers. Each blower has a capacity of 450 ft^3/min and only one is used at a time. Routine operation is to switch units each day. Air from the blowers is discharged into the nitrification reactor through diffusers (Eimco Div., Envirotech Corp., Assembly No. 209). Figure 9 shows one of the two intermediate settlers with the air lift pump piping and header that returns settled nitrification sludge to the nitrification reactor inlet channel. Nitrified effluent flows from the section of the settlers seen in the foreground and enters the pump sump shown in Figure 10. The vertical pumps seen in this picture are five-stage industrial turbines with semi-open impellers (Goulds, Model VIT). Each can deliver 210 gpm at a total pumping head of 115 ft. The pumps are variable speed direct drive, and they are controlled by an Autocon Class 1900 Reactospeed Duplex Drive that receives a signal from an Autocon Model 174 Proportional Range Sensor and a self purging Bubbletrol system. The lead pump is alternated automatically each 24 hours. These pumps serve as feed pumps to the denitrification towers and as prime movers for the backwash of these towers. Following an initial evaluation period, two constant speed, four-stage turbine pumps (Fairbanks Morse, Model 6977) were added in parallel with the variable speed pumps. The new pumps each have a capacity to deliver 250 gpm at a total pumping head of 120 ft. These pumps commence operation after the water in the sump has risen past the level at which both variable speed pumps are at full speed. The combined pumping capacity of all four pumps is approximately 900 gpm.

Immediately downstream from the pump manifold, the discharge line is tapped to permit the injection of methyl alcohol into the nitrified wastewater before it enters the denitrification towers. Two diaphragm pumps (Wallace and Tiernan, Series A-747) with variable speed motors are used to dose the alcohol. Stroke

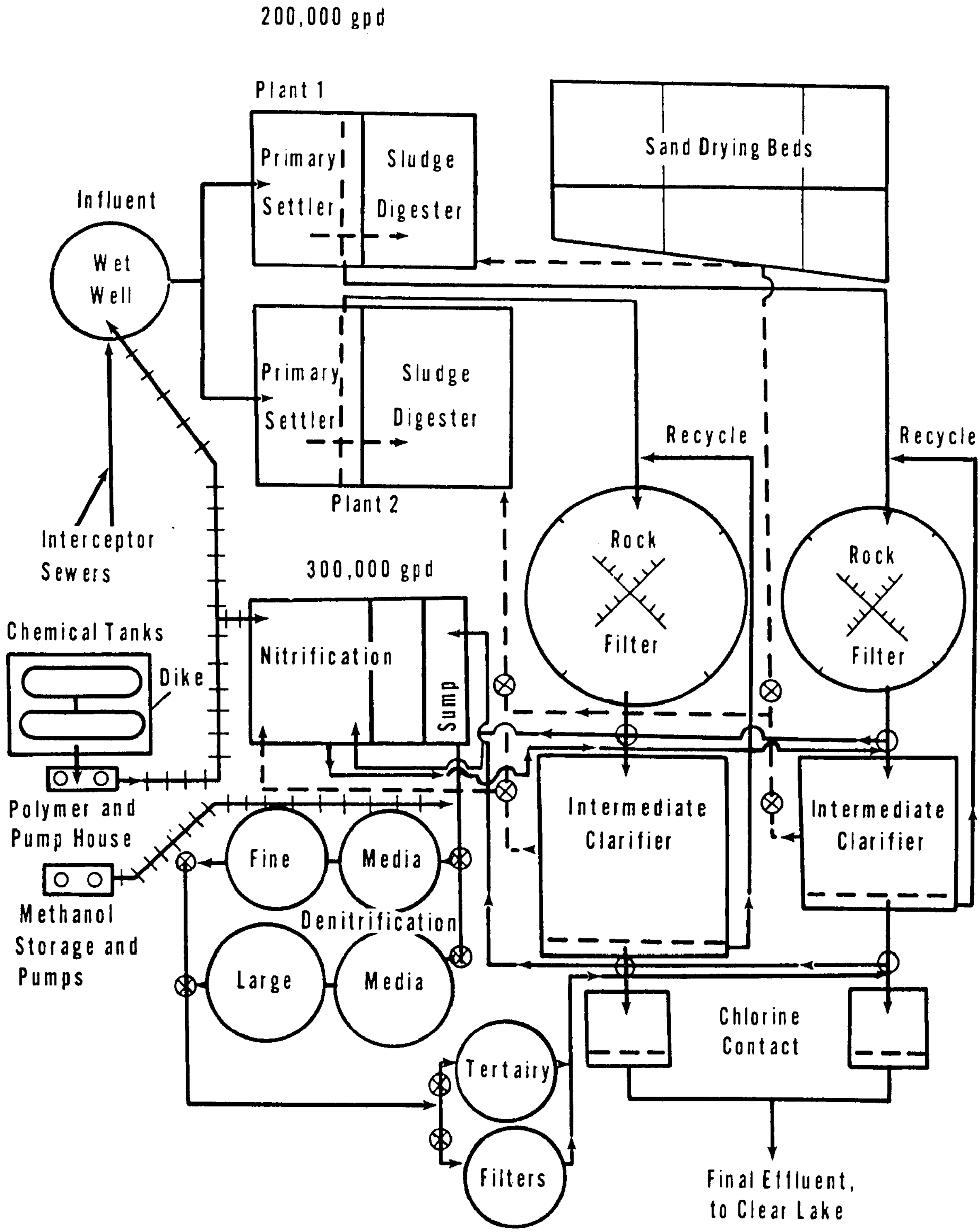

Figure 6. Phase II construction.

Table 7. SPECIFICATIONS FOR NITRIFICATION REACTOR

Section	Volume	Detention time, hr. ADW	Detention time, hr. MDW
Main Bay	56,988 gal	4.5	2.7
Second Bay	18,817 gal	-	-
Both Bays	75,805 gal	6.1	3.6
Nitrified Effluent Sump	18,817 gal	-	-

Diffusers:

Two headers in main bay 12.4 ft each, with diffusers spaced 1 ft. One header in second bay with diffusers spaced 1 ft. All headers located on south wall.

Compressors:

Two, 450 ft^3/min capacity, alternately operated; to supply air for nitrification bays, air lift pumps, and filter scour.

Air lift pumps:

Two each, located in each clarifier to return settled mixed liquor to main nitrification bay.

Intermediate clarifiers:

As shown on Table 1 as final clarifier.

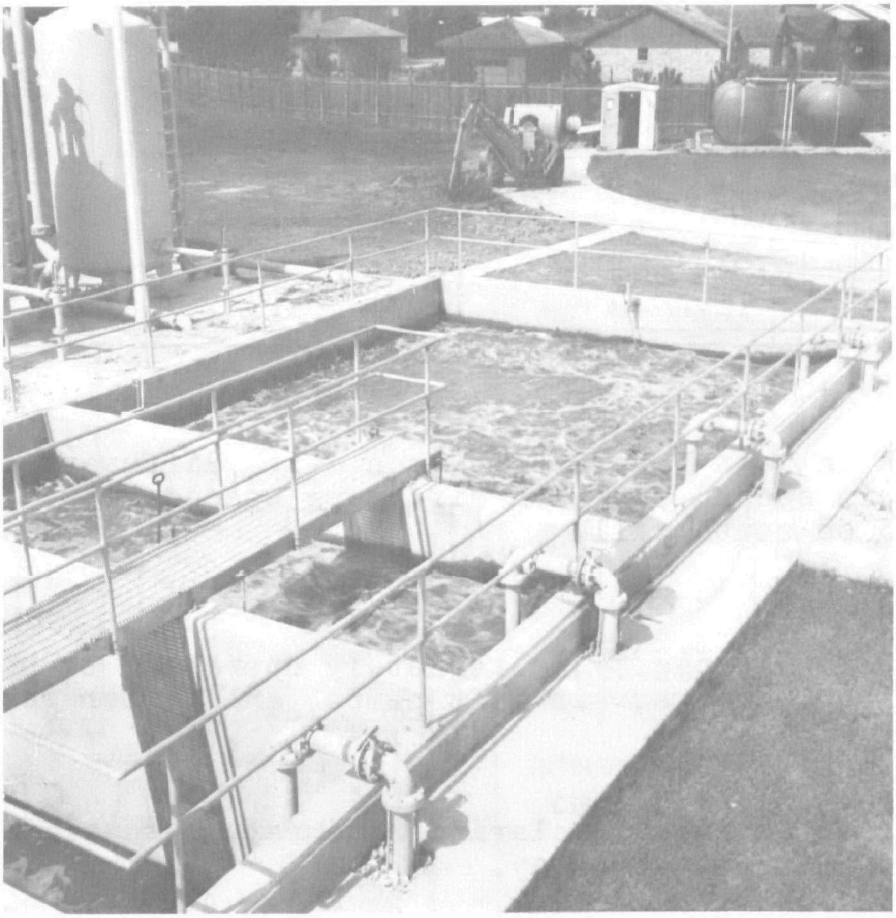

Figure 7. Nitrification reactor and sump

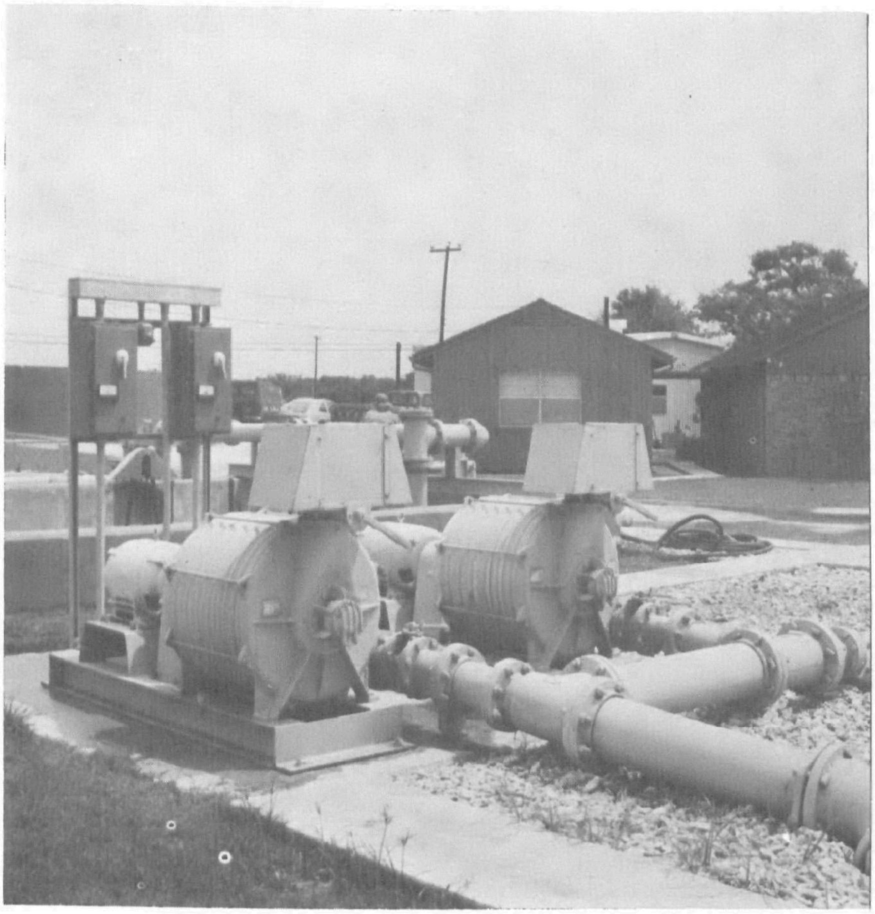

Figure 8. Centrifugal blowers

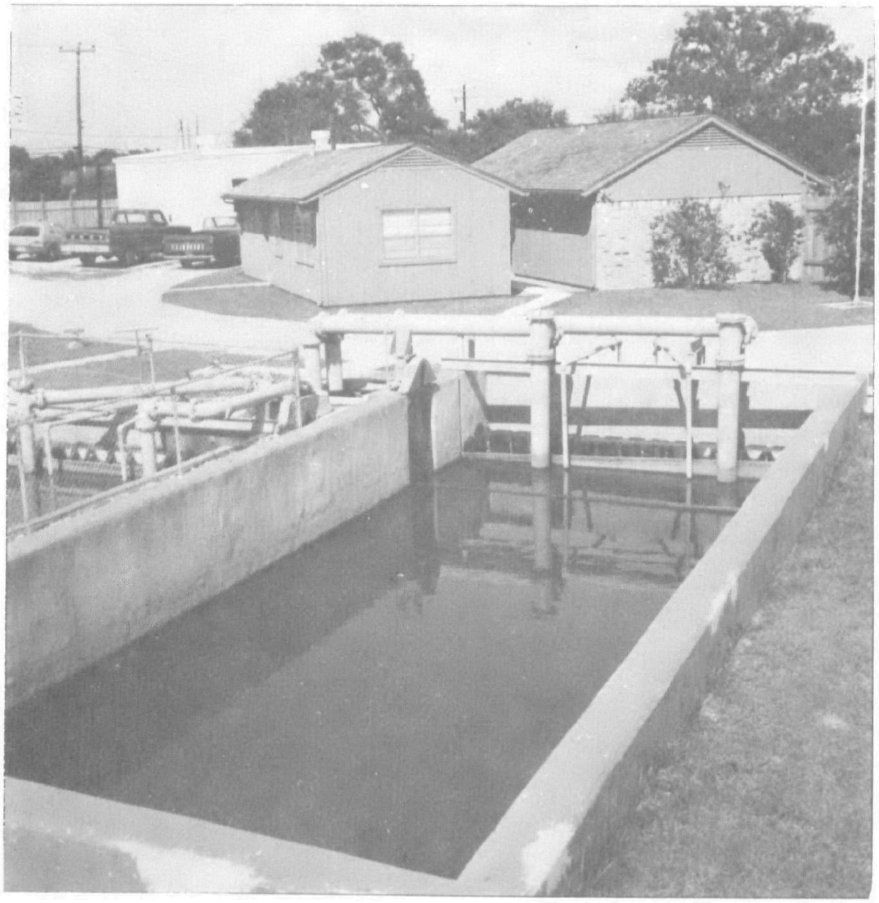

Figure 9. Intermediate clarifier and air lift pumps

Figure 10. Sump and vertical turbine centrifugal pumps

length can be manually adjusted to vary the feed rate. Maximum capacity of each pump is 25 gal/day at 15 psi. Initially, the speed of the alcohol pumps varied in response to the speed of the vertical centrifugal wastewater pumps controlled by the Autocon Duplex Drive. Experience soon revealed that the flow of wastewater through the denitrification towers was not directly proportional to centrifugal pump speed. This was due to changes in discharge head associated with changes in flow rate and varying degrees of plugging in the denitrification towers and the tertiary filters. As a result, higher alcohol dose rates occurred during periods of high flow and when tower and filter plugging created substantial restrictions to flow. In order to make the alcohol pump speed, and the alcohol feed rate, proportional to the rate of flow of wastewater, the controls were modified to accept a signal from a flow meter in the denitrification line. Very uniform alcohol dose rates are provided by the modified system. Figure 11 is a view of the two 500 gal. alcohol storage tanks and the two alcohol pumps. The pumps are located out-of-doors to ensure that alcohol vapors do not accumulate in the small pump house.

The denitrification towers are shown in Figure 12. The smaller front two towers are a proprietary design of Dravo Corporation and contain 3-4 mm rounded sand particles. The towers are operated downflow in series. Representative sand particles are shown in Figure 13.

The two larger towers in Figure 11 were shop-fabricated and field erected steel tanks designed specifically for this demonstration project. The media packing for this set of towers are 5/8 X 5/8 in. cylindrical polyethylene Flexirings (Koch Engineering, Inc.). These towers are operated upflow in series. The smallest cylinder on the extreme right in Figure 14 is the type used in the large towers.

To collect data on a realistic scale, each set of towers was designed for average dry weather flow. Thus, only one set can be evaluated at any time. Design specifications for the small sand media and the large plastic media towers are given in Tables 8 and 9, respectively.

Figure 15 shows the tertiary filter installed at El Lago. The units were shop-fabricated and field erected (Garchem Corp.). This filtration equipment was built to the specifications listed in Table 10. Filtered effluent is discharged to the chlorine contact tanks shown in Figure 16. The 150-lb. gaseous chlorine cylinders are visible in the background. Effluent from the contact tanks flows to Clear Lake after cascade aeration which occurs during a 6 ft drop from the discharge weir to the inlet of the outfall pipe.

Phase II construction was finished by the completion of the laboratory and control building shown in Figure 17. All analytical work reported for this study has been done by independent laboratory contract purchases. However, the building will have further utility if other grant studies are entered into and if local operator training courses are conducted at the El Lago facility. One section is also used as a visitor orientation room.

Figure 11. Methyl alcohol storage tanks and pumps

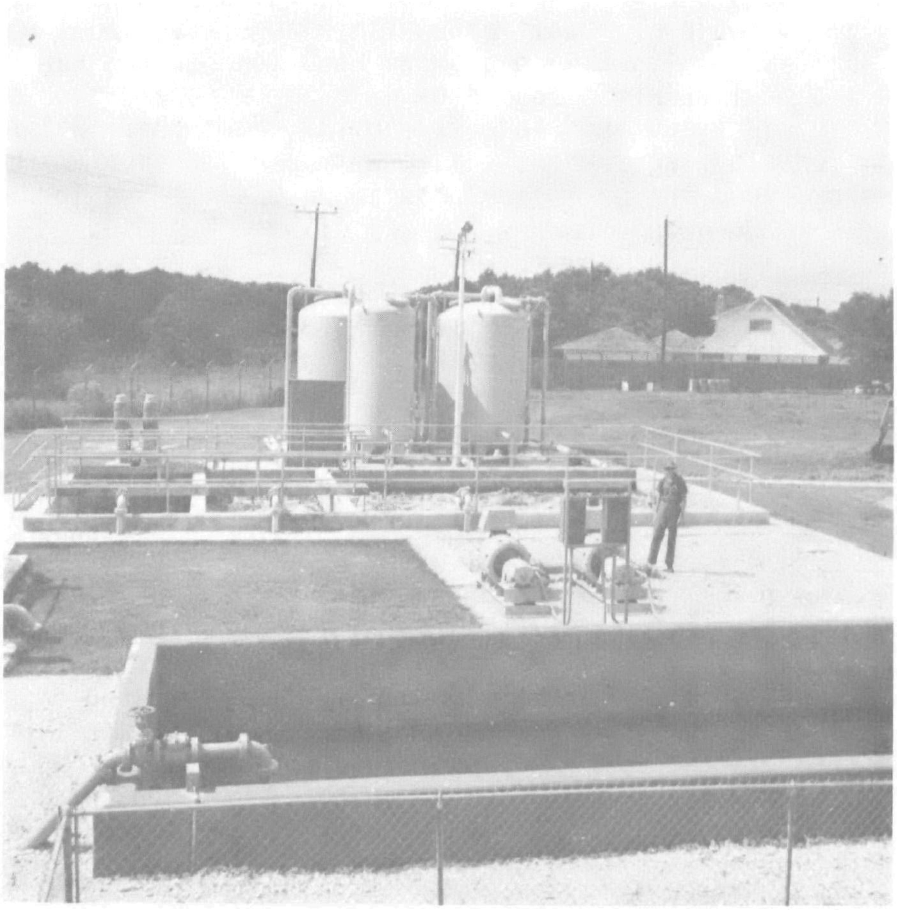

Figure 12. Packed bed denitrification towers

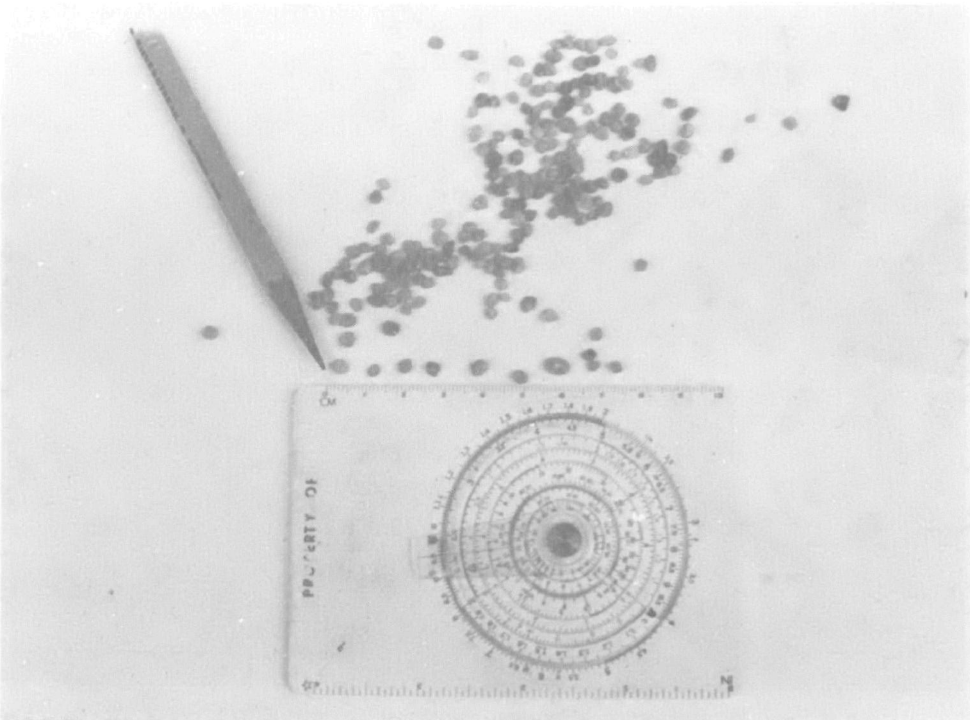

Figure 13. Small sand media packing

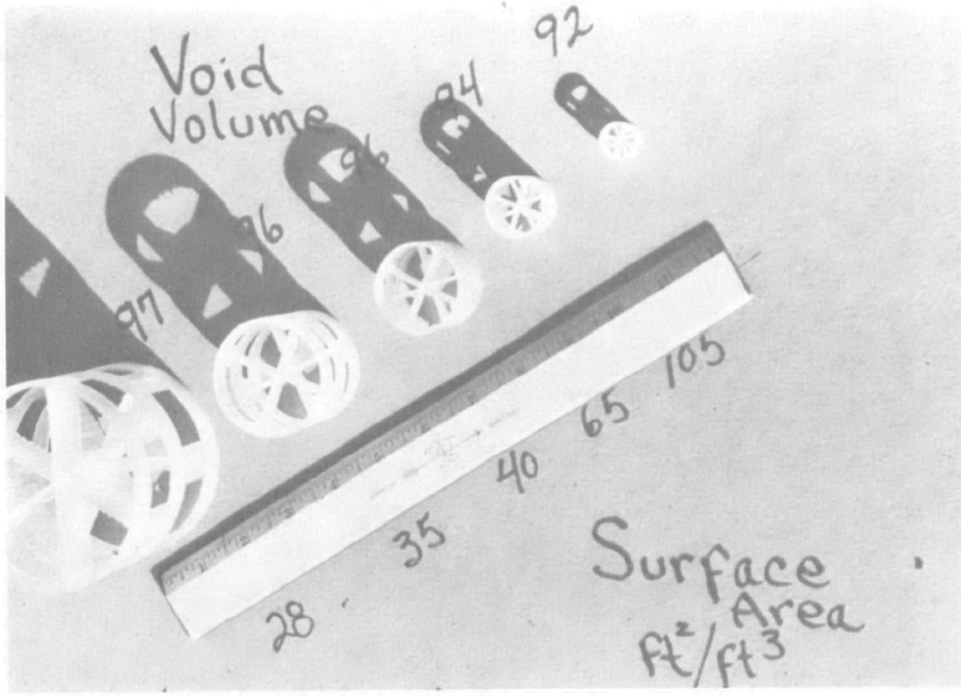

Figure 14. Plastic media packing

Table 8. DESIGN SPECIFICATIONS FOR FINE SAND MEDIA DENITRIFICATION TOWERS

Item	Specification
Vessels	2 - connected in series, downflow
Pressure test	to 50 psi
Material	steel tanks, sandblasted and shop coated
Diameter	6 ft
Media height	6.5 ft each tower
Media type	3-4 mm rounded sand of glacial origin
Porosity	40 percent. Surface area 250 ft^2/ft^3
Empty bed contact time	15 minutes
Process hydraulic rate	
at 0.3 mgd	7.4 gpm/ft^2
at 0.5 mgd	12.3 gpm/ft^2
Backwash water source	nitrified effluent
Backwash rate	20 gpm/ft^2
Air cleaning rate	8 cfm/ft^2
Freeboard	30 percent bed expansion

Table 9. DESIGN SPECIFICATIONS FOR PLASTIC MEDIA DENITRIFICATION TOWERS

Item	Specification
Vessels	2 - connected in series, upflow
Pressure test	to 50 psi
Material	steel tanks, sandblasted and shop coated
Diameter	10 ft
Media height	10 ft each tower
Vessel interior	divided into quarters by solid walls, from the bottom head to the top of the media - freeboard section common to all quarters - separate influent connections for each quarter - wire mesh across top of media
Media type	5/8-inch Flexirings, polypropylene
Porosity	92 percent - surface area 105 ft^2/ft^3
Empty bed contact time	60 minutes
Process hydraulic rate	
at 0.3 mgd	2.5 gpm/ft^2
at 0.5 mgd	4.1 gpm/ft^2
Backwash water source	nitrified effluent
Backwash rate	20 gpm/ft^2
Freeboard	Not needed - 2 ft at apex of cone above wire mesh

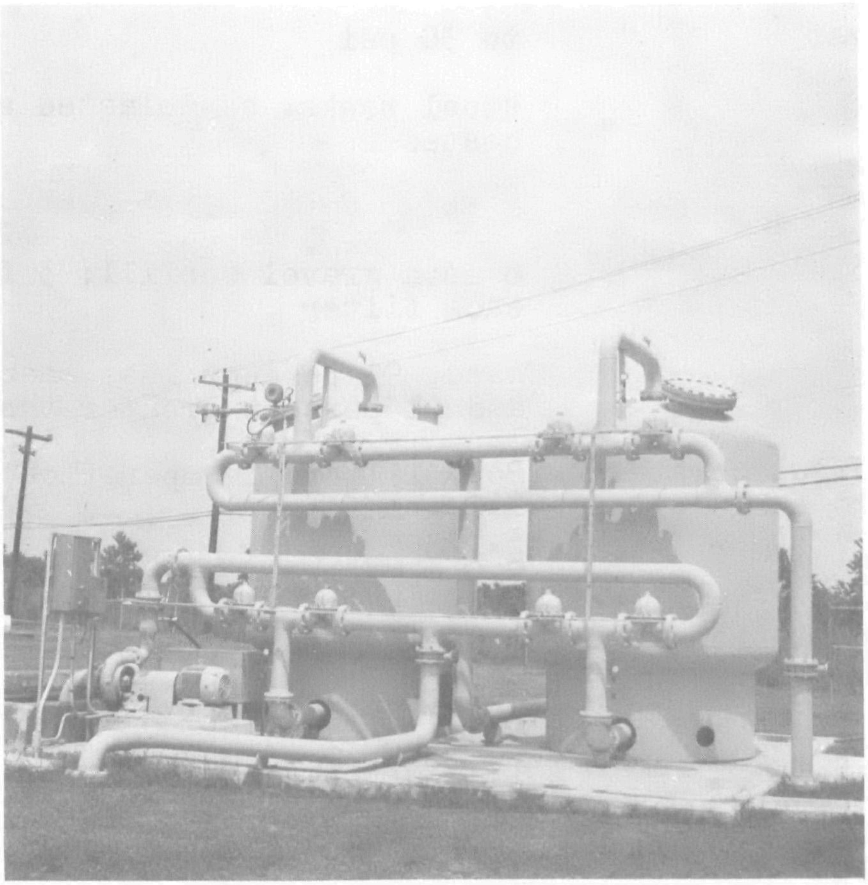

Figure 15. Tertiary granular media filter

Table 10. TERTIARY FILTER SPECIFICATIONS

Item	Specification
Vessels	2 - connected in parallel, downflow
Pressure test	to 30 psi
Material	steel tanks, sandblasted and shop coated
Diameter	8 ft
Media height	6 inch gravel subfill; 3 ft media, each filter
Media type	sand; 91 percent less than 0.8 mm and 91 percent greater than 0.3 mm
Process hydraulic rate:	Both filters in operation:
0.3 mgd	2.2 gpm/ft^2
0.5 mgd	3.5 gpm/ft^2
1.0 mgd	7.0 gpm/ft^2
Backwash initiation	manual - time clock - pressure
Backwash source	chlorinated final effluent
Backwash rate	15 gpm/ft^2, single filter
Freeboard	30 percent bed expansion
Influent suspended solids	40 mg/l
Effluent suspended solids	less than 10 mg/l
Inspection and instruction	Competent person to inspect construction and instruct operational personnel.
Period of performance	Six months to demonstrate capability.

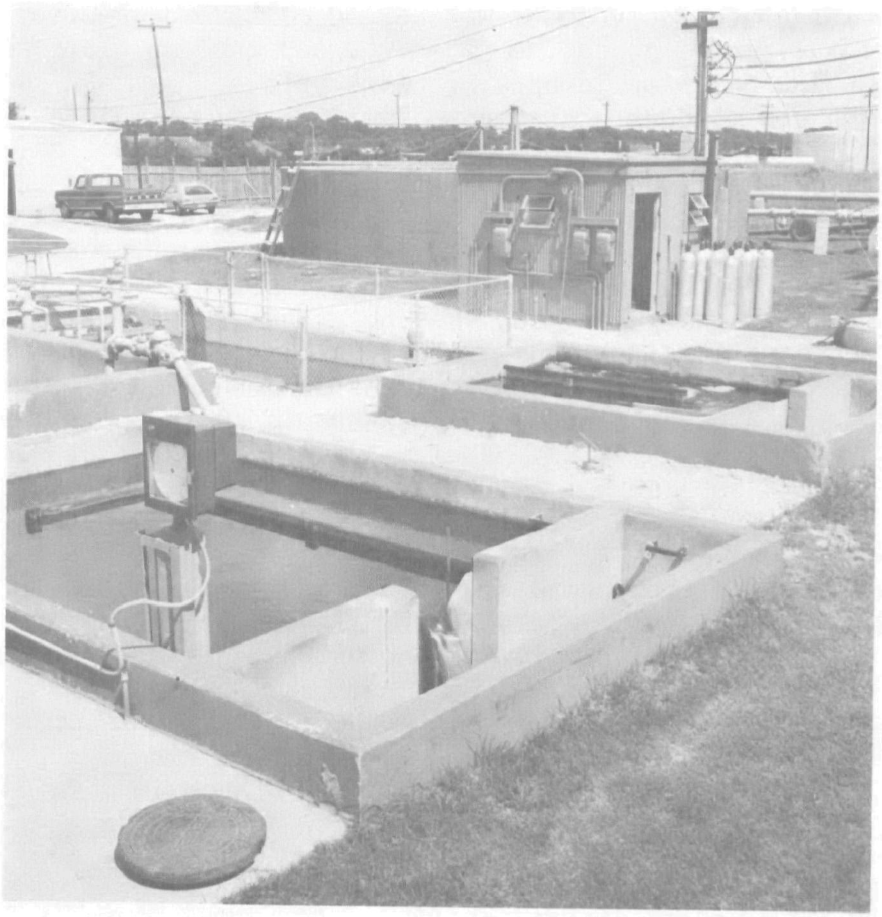

Figure 16. Chlorine contact tanks

Figure 17. Laboratory and control building

OPERATION AND RESULTS, NITRIFICATION

In order to obtain a high efficiency of total nitrogen removal by biological denitrification, a high degree of nitrification capability is needed. Table 3 shows that the existing trickling filters partially nitrified the wastewater; but to insure as complete as possible conversion of ammonium and organic nitrogen to nitrate nitrogen, the above described nitrification reactor was considered essential. This reactor was placed into operation in January 1973. Influent was the underdrain from the trickling filters. The concentration of BOD_5 in this influent proved to be too low to provide flocculant growth in the nitrification reactor. Consequently, most solids in the effluent were carried on through the intermediate clarifiers instead of settling out and being returned to the reactor by the airlift pumps. This problem was corrected by diverting a slip stream of primary effluent into the reactor from March 12 to March 26, 1973, along with the underdrain flow. Operational personnel were cautioned not to waste any nitrification solids from the clarifiers until the nitrification mixed liquor had a high solids content. By March 26, 1973, the suspended solids in the mixed liquor had increased from 40 mg/l to 1,000 mg/l and the slip stream was discontinued. By June 1973, the mixed liquor had reached an almost steady state level of 2,500 mg/l total suspended solids and 1,000 mg/l volatile suspended solids. With a volatile solids content of 1,000 mg/l, a flow of 0.3 mgd, no sludge wasting and a suspended solids content of 30 mg/l in the clarified effluent, a sludge age of about 10 days was maintained. Since January 8, 1974, the nitrification reactor has been operated with only the main bay in use.

An example of the overall nitrification performance is given in Table 11. It is impossible to gauge the unit performance of the nitrification reactor in this design because at average dry weather flow nitrified effluent at a ratio of 1:1 is recycled from the intermediate clarifier back to the rock trickling filter. This, of course, dilutes the ammonium nitrogen and organic nitrogen in the filter underdrain with nitrate nitrogen from the suspended growth reactor so the rock filter has an apparent high nitrification capacity. The table shows a loss of about 10 mg/l of total nitrogen from primary effluent to the nitrified effluent. This loss is to be expected as coincidental denitrification occurs when the nitrified effluent is recycled to the primary effluent before it passes over the trickling filter; and the filter underdrain flows in a closed channel to the nitrification reactor.

The combination of a low rate rock filter with a second stage suspended growth reactor for two-stage nitrification has proved to be very stable. Even during the months of February and March 1973, when solids were building up in the aerator, good nitrification was obtained. Twice during the early operational period, hydraulic washout of part of the aerator solids occurred during storm events. Nitrification capability was possible within two days, due to the seeding action of the trickling filter underdrain. The plant is now operated so that when storm flows in excess of 0.5 mgd occur a portion of the flow is routed around the nitrification and denitrification facilities.

Within two weeks after starting the practice of dosing a portion of the ferric chloride into the nitrification reactor,the suspended solids of the mixed liquor increased to 4,500 mg/l and the volatile fraction to 1,800 mg/l. This

Table 11. NITRIFICATION PERFORMANCE, mg/l*

Constituent	Raw wastewater	Primary effluent	Trickling filter underdrain	Nitrified effluent
NH_4-N				
Avg	15.4	15.1	2.3	1.0
Range	3.9-24.6	4.0-24.0	0.8-3.4	0.3-2.3
Org-N				
Avg	14.6	10.6	3.1	1.6
Range	10.0-15.4	8.0-11.5	1.4-5.4	0.5-5.3
NO_3-N				
Avg	-	-	15.6	13.6
Range	-	-	7.3-22.9	5.9-23.8

*From 33 sampling periods in July and August 1973 soon made it necessary to deliberately waste sludge from the reactor to prevent a high fraction of inert solids buildup and to alleviate a solids overload on the intermediate clarifiers. Solids are now wasted on an almost daily basis to keep settleable solids in the mixed liquor at about 160 ml/l. This normally corresponds to about 3,300 mg/l of total suspended solids and 1,300 mg/l of volatile suspended solids. A sludge volume index (SVI) of 50 is normal.

The air lift pumps which return solids from the clarifiers to the nitrification reactors were operated manually for several months. Efforts were made to adjust the air flow to the pumps to provide continuous return of solids to the reactor. Lack of success with this procedure led to the practice of returning solids for several minutes each hour that operators were on duty. This proved to be quite satisfactory for about nine hours each day, but almost all of the solids accumulated in the clarifiers during the fifteen hours when no one was present to operate the air lift pumps. To correct this problem, timers and solenoid valves were installed to provide automatic operation of pumps. Solids are now returned around the clock by the four air lift pumps which operate in rotation with each pumping about three minutes during each 20 minute cycle. All pumps are turned off for about one hour each day to permit an accumulation of solids in the clarifier hoppers from which the excess is wasted to the plant wet well.

OPERATION AND RESULTS, SMALL MEDIA DENITRIFICATION TOWERS

These towers were operated from May to mid-July 1973 for initial evaluation of process capability. The columns were placed into operation by gradual increases in the weight ratio of methyl alcohol to nitrate nitrogen. The ratio was increased from 1:1, to 2:1, to 3:1 over a ten-day period. A two-week period was necessary to establish an acclimated denitrifying population on the fine media. The towers are piped in series, and the lead column cannot be altered in sequence. The biological denitrification process utilizing methyl alcohol as an organic supplement has a cell yield of 0.2 parts of cells produced per part of alcohol oxidized. Since these fine media towers have a porisity of 40 percent, the growth of cellular material increases the resistance to flow through the tower. It was found necessary to backwash the lead tower each day in order to achieve satisfactory through-put. The second tower usually requires backwashing on alternate days.

The efficiency of the entire plant during use of the small media towers was initially calculated from data taken during the period from June 4 through July 6, 1973. After modifications to improve methyl alcohol dosing, data were again collected during operation of the small media towers from September 23 through November 8, 1974. Table 12 gives the general conditions at the plant during these two periods; and Tables 13A and 13B show the residual concentrations of pollutants through each unit process for these two periods.

It should be noted in Table 13A that suspended solids, as well as several other constitutents, showed an increase in concentration in the primary influent as compared to the raw wastewater. The substantial increase in suspended solids is due to the precipitates formed as a result of ferric chloride and polymer addition and to the return of solids from backwashing the small media denitri-

Table 12. CONDITIONS FOR EVALUATION OF SMALL MEDIA DENITRIFICATION TOWERS

	Jun - Jul 1973	Sept - Nov 1974
Length of study period:	33 days	47 days
Rain during study period:		
Total	12.2 inches	2.5 inches
Peak day	5.7 inches	0.6 inches
Total flow to plant:		
Average	0.307 mgd	0.255 mgd
Low day	0.160 mgd	0.202 mgd
High day	1.000 mgd	0.386 mgd
Flow to small media denitrification towers:		
Average	0.254 mgd	0.282 mgd
Low day	0.160 mgd	0.084 mgd
High day	0.420 mgd	0.384 mgd
Wastewater temperature:	78° F	78° F
Total number of analytical measurements:	433	1,081

Table 13A. INITIAL EVALUATION OF SMALL MEDIA DENITRIFICATION TOWERS, mg/l
(34 days: June 4 to July 6, 1973)

Measurement	Raw wastewater	Primary influent	Primary effluent	Nitrified effluent	Denitrified effluent	Final effluent
BOD_5						
Avg	175	222	-	65*	9	9
Range	-	220-223		58-72	6-12	5-18
COD						
Avg	297	488	181	121*	72	51
Range	89-391	244-720	101-240	51-224	16-176	36-90
TP						
Avg	12.8	15.4	8.4	7.3	6.6	4.8
Range	3.7-21.8	4.8-22.8	5.1-15.6	4.0-16.1	1.5-11.5	4.1-5.4
SP						
Avg	10.3	4.7	4.1	3.4	5.5	3.6
Range	2.4-17.0	0.9-12	1.6-6.9	2.1-3.9	1.0-11.0	2.1-5.0
SS						
Avg	113	289	72	37	17	3
Range	21-200	98-754	37-114	8-57	2-56	1-6
NH_4-N						
Avg	18.7	21.7	21.5	0.9	0.8	0.6
Range	2.4-35.2	16.2-26.2	16.2-23.9	0.4-2.2	0.5-1.8	0.4-0.7
TKN						
Avg	42.6	38.6	30.2	3.7	2.4	3.3
Range	7.7-64.7	30.8-49.3	29.3-31.6	0.8-10.8	0.9-6.2	1.5-6.2
NO_3-N						
Avg	-	-	-	15.2	2.6	2.3
Range				5.4-24.8	0-9.7	0-5.4
Methanol dose						
Avg	-	-	-	47	-	-
Range				20-81		

*Includes demand due to added methanol.

Table 13B. EVALUATION OF SMALL MEDIA DENITRIFICATION TOWERS, mg/l*
(47 Dyas: September 23 - November 8, 1974)

Measurement	Primary influent	Primary effluent	Nitrified effluent	Denitrified effluent from 1st tower	Denitrified effluent from 2nd tower	Final effluent
BOD_5						
Avg	-	-	60+	15	12	2.9
Range			38-83	10-27	7-20	<1.0-8.3
COD						
Avg	-	-	110+	43	34	17
Range			79-140	25-67	16-82	10-30
TP						
Avg	12	3.4	-	-	3.0	0.39
Range	8.1-16	1.3-4.5			1.0-4.5	0.15-0.77
SP						
Avg	2.1	1.0	-	-	0.39	0.38
Range	<0.01-5.7	<0.01-2.2			0.01-0.90	0.13-0.74
SS						
Avg	279	56	78	50	41	1
Range	190-682	25-158	26-160	8-94	1-106	<1-7
NH_4-N						
Avg	-	18	0.5	-	0.4	0.3
Range		15-20	0.2-0.8		0.2-0.7	<0.1-0.6
TKN						
Avg	-	24	2.6	-	1.5	0.9
Range		20-27	0.9-3.9		0.6-3.4	0.5-1.5
NO_3-N						
Avg	-	-	15	2.1	1.1	0.9
Range			11-16	0.5-5.2	0.1-3.8	<0.1-2.2
Fe^{+3} dose‡						
Avg	41	-	-	-	-	-
Range	20-79					
Polymer dose						
Avg	0.22	-	-	-	0.16	-
Range	0.05-0.45				0.00-0.33	
Methanol dose						
Avg	-	-	40	-	-	-
Range			35-47			
pH						
Median	7.3	7.3	7.7	7.9	7.9	7.6
Range	6.4-7.5	6.4-7.4	7.0-8.0	7.2-8.1	7.2-8.2	6.8-7.9

*Except pH
+Includes demand due to added methanol
‡Dose split approximately 2:1 between wet well and nitrification reactor

fication towers and the tertiary filters. Increases in BOD_5 and COD are due to recycle of digester supernatant and backwash water. The slight increase in total phosphorus is considered to be due primarily to the insoluble phosphorus backwashed from the final filters; and an increase in ammonium nitrogen is the result of the decomposition of organic nitrogen compounds. Table 13B shows no values for raw wastewater since emphasis during the final evaluation period was shifted more to the nitrification reactor and the denitrification towers. In order to better evaluate the denitrification process, sampling was commenced between the two towers in series. These samples were analyzed for suspended solids, nitrate nitrogen, pH, BOD_5 and COD.

During the initial evaluation period, high rainfall and concentration of effort on the startup of the denitrification process prevented optimum ferric chloride and polymer dosing for phosphorus removal; consequently, only 63 percent removal was achieved to produce a final effluent containing an average of 4.8 mg/l of total phosphorus. During the final evaluation of small media towers, ferric chloride and polymer dosage was more consistent and total phosphorus content was reduced from an average of 12 mg/l in the primary influent to 0.39 mg/l in the final effluent. The average total does of metal salt was 41 mg/l of Fe^{+3}. This application was split approximately 2 to 1 between the wet well and the nitrification reactor. The overall dose of metal salt was almost a 2 to 1 mole ratio of iron to total phosphorus in the primary influent.

Suspended solids reduction across the primary settlers was sufficient to prevent the overload of downstream processes. During the first period, the small media towers produced an effluent containing 17 mg/l of suspended solids which was somewhat higher than anticipated but was partly due to backwashing the towers with feedwater which contained 37 mg/l of solids. Effluent from the small media towers contained 41 mg/l of suspended solids during the final period. This was a marked increase over that for the first period; but the influent, also used for backwashing, contained 78 mg/l suspended solids, which was more than twice the concentration during the earlier period. Another probable cause of high solids in the effluent was intermingling of the different layers of supporting gravel with the fine media which resulted from improper backwashing. However, this created no serious problem since, even in the design stage, tertiary filtration had been deemed necessary as a backup solids removal system. The tertiary filter proved very capable of producing a polished effluent containing an average suspended solids residual of 3 mg/l during the first period; and after addition of facilities for adding polymer to the filter feedwater, the suspended solids in the effluent dropped to an average of 1 mg/l during the final evaluation. The tertiary filter effluent is of such quality that the floor of the chlorine contact tank is usually visible through a sidewater depth of almost 7 ft.

The nitrogen species behaved in a manner similar to the sequence given in Table 11; there was a gradual hydrolysis of organic nitrogen to ammonium nitrogen in the treatment processes with a small organic nitrogen residual (2.7 mg/l and 0.6 mg/l in the first and second evaluations, respectively) passing through the entire process. Nitrification was essentially complete with a residual ammonium nitrogen of less than 1 mg/l appearing in the nitrified effluent. The nitrified effluent dissolved oxygen content was 6 mg/l before dosing with methyl alcohol and that of the tower effluent was 0.5 mg/l as measured by galvanic probe. The source of the backwash water is also important to the nitrogen removal efficiency of the process at El Lago because the backwash water contains nitrate nitrogen, and the methyl alcohol pumps are turned off during backwash; therefore, when the tower is placed back on-line, high concentrations of nitrate will be discharged in the beginning of the cycle. In view of this and the short hydraulic detention time as shown in Table 8, the towers performed in a very efficient manner. During the initial evaluation period, the residual nitrate concentration in the final effluent was about 2 mg/l, the residual total nitrogen content was 5.6 mg/l and total nitrogen removal efficiency was about 87 percent. Comparison of methyl alcohol dosage data in Tables 13A and 13B shows a somewhat lower average dose rate but it was a much more consistent dosing. Improved alcohol dosing and a more uniform flow of wastewater are considered to be primarily responsible for improved nitrogen removal during the final evaluation period. Residual nitrate concentration in the final effluent dropped to 0.9 mg/l while total nitrogen content was 1.8 mg/l. Nitrite nitrogen was not found to be present in significant concentrations. The estimated overall removal of nitrogen was 94 percent. Ninety percent of the total nitrogen present in the influent to denitrification was removed prior to discharge. The data show that both towers in series are necessary to accomplish efficient nitrogen removal.

The organic content of the wastewater, as evidenced by BOD_5 and COD, was controlled by the combined processes of primary settling, trickling filtration, and aeration in the nitrification reactor followed by substantial polishing by the tertiary filter removing the suspended organic material. The oxygen demand values for the nitrified effluent in Tables 13A and 13B reflect the contribution by addition of methyl alcohol prior to the denitrification process. Lower effluent concentrations of both BOD_5 and COD were observed during the final evaluation as might be expected since the methyl alcohol dosage was lower and more uniform during this latter period and suspended solids removal was considerably improved. During this period the final effluent contained an average of 2.9 mg/l BOD_5 and 17 mg/l COD.

Recovery of denitrification efficiency following backwash was observed by determining nitrate nitrogen concentrations at three points in the flow stream immediately upon putting the towers back in operation and at 30-minute intervals during the succeeding four hours. Nitrate nitrogen concentrations in the influent to the first tower and in the effluent from each of the two towers for that 4-hour period are shown in Table 14. Denitrification efficiency appeared to be normal after 1 1/2 hours of operation following backwash of both towers.

OPERATION AND RESULTS, LARGE MEDIA DENITRIFICATION TOWERS

The large media media towers were placed in operation in early July 1973. After completion of construction, the vessels were wet tested and allowed to stand idle for six months while filled with nitrified effluent. Initiation of denitrification was rapid; and within three days, full denitrification capability was achieved. An acclimated biological film had apparently established itself on the plastic media surfaces during the idle interval.

The towers are piped in series, and the lead column cannot be altered. The high void volume of 92 percent of the plastic media allows these towers to

Table 14. SMALL MEDIA DENITRIFICATION TOWER PERFORMANCE FOLLOWING BACKWASH

Time following completion of backwash, hr	NO_3-N, mg/l		
	Denit influent	Denit #1 effluent	Denit #2 effluent
0.0	17	11	10
0.5	17	4.8	3.4
1.0	18	2.7	1.3
1.5	14	1.6	0.6
2.0	15	2.0	1.1
2.5	18	2.4	0.8
3.0	17	2.2	0.9
3.5	17	2.3	1.0
4.0	14	2.5	1.1

be operated without frequent backwash even though the biological denitrification produces biological solids. Initially, six weeks of operation was possible before backwash was necessary. Then the routine procedure for months was to backwash at wash was necessary. Then the routine procedure for months was to backwash at 4-week intervals. The need to backwash was not related to pressure drop through the towers, but arose to prevent excessive suspended solids in the tower effluent. This was in contrast to the operational experience with the small media towers which required daily backwash due to pressure drop. Late in the final evaluation period it was learned that denitrification efficiency could be improved by more frequent backwashing even though solids and pressure loss were not problems.

One important operational consideration was discovered during the initial evevaluation of the large media upflow towers after they had been taken out of service for two days and allowed to stand undisturbed. Upon resumption of operation it was found that a large amount of solids had floated to the top of each tower buoyed up by nitrogen gas bubbles. The effluent suspended solids completely blinded the down-stream tertiary filter. After that experience, routine operation provided for backwash before taking the towers offline and again immediately before placing them back on-line.

The efficiency of the entire plant when using the large media denitrification process was evaluated from July 8 through August 31, 1973, to ascertain the initial operational procedures that would have to be controlled for long term studies. Following modifications to improve methyl alcohol dosing, further studies were conducted to evaluate plant efficiency. These evaluation periods were 31 days from November 16 through December 16, 1974, and 41 days from January 5 through February 14, 1975. The test plan originally provided for one uninterrupted final evaluation period, but nonavailability of methyl alcohol forced the shutdown of the denitrification process for 20 days. Table 15 gives the general conditions at the plant during these three periods.

Tables 16A, 16B and 16C show the residual concentrations of pollutants through unit processes for the initial evaluation period and two final test runs, respectively. Rainfall was less during the initial evaluation of the large media towers than during the initial study of the small media towers. Also, by the time of the first large media study, the operational sequence to keep the multi-stage processes in operation simultaneously had been worked out with experience gained in the previous five weeks. Total phosphorus removal improved to 77 percent, but a residual soluble concentration of 2 mg/l was present. During the last week of the initial study of the large media towers, the ferric chloride dose was split 2 to 1 between the wet well and the nitrification reactor; but these few days of data did not significantly alter the average phosphorus value compiled for the 55 days of the study period. Tables 16B and 16C show the effectiveness of this technique during the final evaluation phases of large media denitrification. Suspended solids data for all three periods show the same general trend as during the small media studies, except for the concentrations in nitrification effluent and denitrification effluent which are substantially lower than during the final small media evaluation period.

Table 15. CONDITIONS FOR EVALUATION OF LARGE MEDIA DENITRIFICATION TOWERS

	Jul-Aug 1973	Nov-Dec 1974	Jan-Feb 1975
Length of study period:	55 days	31 days	41 days
Rain during study period:			
Total rain	9.9 inches	4.9 inches	3.3 inches
Peak day	2.5 inches	1.4 inches	0.9 inches
Total flow to plant:			
Average	0.320 mgd	0.366 mgd	0.410 mgd
Low day	0.171 mgd	0.248 mgd	0.267 mgd
High day	0.900 mgd	0.835 mgd	0.790 mgd
Flow to large media denitrification towers:			
Average	0.315 mgd	0.363 mgd	0.366 mgd
Low day	0.171 mgd	0.037 mgd	0.160 mgd
High day	0.632 mgd	0.555 mgd	0.538 mgd
Wastewater temperature:	81°F	75°F	73°F
Total number of analytical measurements:	1,254	473	573

Table 16A. INITIAL EVALUATION OF LARGE MEDIA DENITRIFICATION TOWERS, mg/l (55 days: July 8 - August 31, 1973)

Measurement	Raw wastewater	Primary influent	Primary effluent	Nitrified effluent	Denitrified effluent	Final effluent
BOD_5						
Avg	143	156	87	43*	15	8
Range	60-260	86-243	47-124	11-66	3-38	0.8-20
COD						
Avg	248	336	167	107*	52	38
Range	136-380	111-590	97-329	50-207	23-182	20-63
TP						
Avg	12.3	13.1	6.7	-	-	2.8
Range	6.2-18.5	6.5-22.1	1.0-17.4			1.0-8.2
SP						
Avg	10.3	3.1	2.4	-	-	2.3
Range	3.3-15.9	0.5-9.6	0-6.5			0.5-6.2
SS						
Avg	102	231	63	43	19	4.5
Range	43-219	104-456	17-136	2.0-90	2-71	0.4-24
NH_4-N						
Avg	16.3	14.6	14.4	0.9	1.2	0.9
Range	3.9-24.6	3.1-29.3	6.2-20	0.3-2.3	0.1-3.0	0.3-1.8
TKN						
Avg	29.7	31.8	26.7	2.6	2.5	1.7
Range	13.9-40.0	19.3-46.2	16.2-35.4	0.8-7.6	0.5-6.1	0.9-3.5
NO_3-N						
Avg	-	-	-	13.6	0.9	0.6
Range				5.9-23.8	0-3.0	0-3.5
Methanol dose						
Avg	-	-	-	34	-	-
Range				16-69		

*Includes demand due to added methanol.

Table 16B. EVALUATION OF LARGE MEDIA DENITRIFICATION TOWERS, mg/l
(31 days: November 16 - December 16, 1974)

Measurement	Primary influent	Primary effluent	Nitrified effluent	Denitrified effluent from 1st tower	Denitrified effluent from 2nd tower	Final effluent
BOD_5						
Avg	-	-	35+	20	11	4
Range			16-42	8.5-38	2.7-24	1.3-11
COD						
Avg	-	-	69+	47	32	25
Range			43-97	28-97	16-70	8-40
TP						
Avg	11	5	-	-	2.4	0.7
Range	6.0-14	2.6-10			1.6-4.4	0.28-1.3
SP						
Avg	3	1.9	-	-	0.6	0.6
Range	1.2-10	0.71-6.5			0.27-1.5	0.25-1.3
SS						
Avg	207	64	36	28	13	2
Range	98-304	51-88	22-63	7-91	2-57	1-6
NH_4-N						
Avg	-	16	0.7	-	0.5	0.5
Range		3.4-21	0.3-1.7		0.1-1.9	0.2-1.7
TKN						
Avg	-	21	2.7	-	1.7	1.1
Range		11-27	1.7-3.6		0.8-3.6	0.6-2.8
NO_3-N						
Avg	-	-	11	5.6	2.6	3.0
Range			6.7-15	2.1-8.8	0.6-7.0	0.1-7.0
Fe^{+3} dose‡						
Avg	27	-	-	-	-	-
Range	14-43					
Polymer dose						
Avg	0.21	-	-	-	0.16	-
Range	0.00-0.29				0.00-0.26	
Methanol dose						
Avg	-	-	36	-	-	-
Range			20-49			
pH						
Median	7.4	7.3	7.8	7.7	7.7	7.4
Range	7.3-8.0	7.3-7.8	7.5-7.9	7.6-7.8	7.5-7.9	7.3-7.6

*Except pH
+Includes demand due to added methanol
‡Dose split approximately 2:1 between primary influent and nitrification reactor

Table 16C. EVALUATION OF LARGE MEDIA DENITRIFICATION TOWERS, mg/l*
(41 days: January 5 - February 14, 1975)

Measurement		Primary influent	Primary effluent	Nitrified effluent	Denitrified effluent from 1st tower	Denitrified effluent from 2nd tower	Final effluent
BOD_5	Avg	-	-	55+	24	13	9
	Range			23-87	13-50	1.8-47	2.2-29
COD	Avg	-	-	100+	57	38	29
	Range			56-150	31-110	12-99	12-61
TP	Avg	10	4.0	-	-	2.4	0.6
	Range	5.9-12	2.8-5.4			1.7-3.9	0.29-1.2
SP	Avg	1.1	0.50	-	-	0.50	0.53
	Range	0.41-2.0	0.33-0.70			0.40-0.58	0.27-0.91
SS	Avg	251	72	36	24	13	2
	Range	146-404	48-134	17-65	3-70	<1-79	<1-5
NH_4-N	Avg	-	16	0.6	-	0.5	0.5
	Range		10-20	0.2-1.4		0.1-1.2	0.2-1.1
TKN	Avg	-	21	4	-	2.2	1.7
	Range		15-26	2.2-16		1.7-3.4	0.9-2.8
NO_3-N	Avg	-	-	14	5.6	1.6	1.7
	Range			9.7-18	2.9-8.8	0.2-7.2	0.1-3.7
Fe^{+3} dose‡	Avg	25	-	-	-	-	-
	Range	14-57					
Polymer dose	Avg	0.22	-	-	-	0.12	-
	Range	0.15-0.32				0.00-0.20	
Methanol dose	Avg	-	-	44	-	-	-
	Range			33-55			
pH	Median	7.4	7.3	7.7	7.7	7.8	7.5
	Range	7.1-7.6	7.1-7.5	7.6-8.0	7.6-8.0	7.7-8.0	7.1-7.9

*Except pH
+Includes demand due to added methanol
‡Dose split approximately 2:1 between wet well and nitrification reactor

The nitrogen transformations were similar to those previously observed, and essentially complete nitrification was obtained as evidenced by an average residual ammonium nitrogen of less than 1 mg/l in both nitrified effluent and final effluent during all three study periods. Biological denitrification was more complete during the initial evaluation of the large media than during small media studies even though the ratio of methyl alcohol to nitrate nitrogen content of the nitrified effluent was significantly lower. Nitrate reduction was 93 percent with a 2.5:1 weight ratio of methyl alcohol to nitrate nitrogen. This higher efficiency was probably due, at least in part, to the more uniform methyl alcohol dosing since the large media towers did not develop large pressure losses that had such a pronounced effect on the original alcohol dosing system. Data from the two final evaluation phases, shown in Tables 16B and 16C, include analytical results of samples taken between the two towers being operated in series. The levels of nitrate nitrogen, BOD_5 and COD show that considerable denitrification was occurring in the second tower which is considered essential to efficient operation. Data from the last two study periods failed to confirm the higher efficiency of the large media towers as compared to the towers with small media. During the first of the two final evaluation periods, 76 percent reduction in nitrate nitrogen was attained with a 3.3:1 weight ratio of methyl alcohol to nitrate nitrogen. The last evaluation showed 80 percent reduction in nitrate nitrogen with the methyl alcohol dosing being slightly reduced to a weight ratio of 3.1:1. The improved efficiency during the last evaluation period may be the result of backwashing more frequencly than in the earlier runs. The towers were backwashed 7 times during the last 15 days in an attempt to prevent channeling which could have been caused poor denitrification by reducing effective detention time. The improvement of denitrification with more frequent backwashing tends to support this channeling theory, but experience is too limited for a firm conclusion.

SECTION VII

DISCUSSION OF MODIFIED PLANT OPERATION AND RESULTS

Plant operation and evaluation were complicated by reliance upon a succession of commercial laboratories for analytical services. Several of these were found to be unsatisfactory due to excessive time required for reporting analytical results and to poor performance in analysis of EPA reference samples. Unreliable analytical results led to delays in optimizing chemical dosages and operating procedures as well as to discarding data covering several periods of evaluation. Data presented in this report were provided by laboratories which reported acceptable values for EPA reference samples. In addition, the laboratory which provided analytical services for final study phases of denitrification was also evaluated by comparing their analytical results on both plant and EPA reference samples with those of a local referee laboratory and two competing laboratories.

The wide range of values for each of the various pollutant concentrations is evident in Tables 13A, 13B, 16A, 16B and 16C. This is typical of the occurrence of wastewater constitutents at a small domestic treatment plant with a short lateral and interceptor system. Recycle flows within the plant also contribute to this variability. Such wide ranges in pollutant concentrations make it difficult to achieve maximum efficiency in processes requiring stoichiometric addition of chemicals. Since the El Lago facility is manned on the day shift only, chemical dosing pumps must be set to deliver a dose based on average concentration of pollutants. In the case of phosphorus, peak concentrations will not be insolubilized and inefficient removal will occur. For denitrification, the average dose of methyl alcohol is inadequate for optimum removal of nitrate nitrogen during periods of maximum concentrations of that constitutent. Moreover, during periods of low nitrate nitrogen concentration, the average does provides an excess of methyl alcohol which passes through the denitrification towers. Since no aerobic biological process follows denitrification at El Lago, any excess methyl alcohol could cause a high organic content (COD and BOD_5) in the final effluent. A tertiary carbon adsorption bed would not correct this problem, since methyl alcohol is hydrophilic and very polar and does not adsorb onto activated carbon.

There are two possible solutions to this problem of variation in pollutant concentrations. One would be to provide an equalization tank for the primary influent flow, including digester supernatant, sludge drying bed underdrain, solids wasted from the nitrification reactor, and backwash from denitrification towers and tertiary filters. Another solution would be the implementation of automatic analytical determinations of phosphorus and nitrate nitrogen with the on-line analyzers and plant flow meters providing signals for control of the chemical dosing pumps. Neither of these appears economically practicable for a small facility like El Lago.

While both large and small media towers provided high degrees of biological denitrification, the better performance of the small media towers would appear to justify the additional effort and expense required for daily backwashing if nitrate nitrogen must be reduced to the order of 1 mg/l. Furthermore, the data on small media denitrification tower performance following backwash indicate that greater removal of nitrate nitrogen could be achieved if provision were made for recycling the denitrification tower effluent for the first hour following backwash.

The performance of the tertiary filter system during the three final evaluation periods is summarized in Table 17. These filters are considered essential in meeting project goals for final effluent concentrations of suspended solids, total phosphorus, total nitrogen, BOD_5, and COD. While no significant reduction in ammonium nitrogen and nitrate nitrogen can be attributed to these filters, the reduction in organic nitrogen by removal of biological solids enabled the plant to produce an effluent containing less than 2 mg/l total nitrogen during the final evaluation of the small media denitrification towers. It is also evident that substantial quantities of insoluble phosphorus was removed by the filters and an appreciable reduction in BOD_5 and COD accompanied the suspended solids removal.

During evaluation of the small media denitrification towers, the tertiary filters received an influent containing an average of 41 mg/l suspended solids at a 1.9 gpm/ft^2 average filter rate. The average filter run was 5.9 hours with the controls set to initiate a backwash cycle by time clock once each day and by pressure when head loss reached 28 feet of water. Backwash water returned to waste was 17.3 percent of filter influent.

Since the El Lago plant is attended only during daylight hours, the chlorine feed to the contact tanks is normally adjusted twice daily to maintain 1 to 3 mg/l residual after contact time of 78 minutes at average dry weather flow. Lower residuals occur during peak late morning and evening flows while higher residuals appear in the very early morning effluent when flow is lowest. Contact time during maximum wet weather flow is 23 minutes; therefore, the Texas Water Quality Board requirement of at least 1 mg/l of residual chlorine after 20 minutes contact time is consistently met.

Prior to the grant period, no microciological assays for the coliform content of the final effluent had been performed. Determination of coliforms during the period from June 19, 1974, to February 14, 1975, resulted in data shown in Table 18. It is significant to note that all samples of final effluent had an MPN of less than 2.2 coliforms per 100 ml. This disinfection was obtained with an average chlorine dosage of 10 mg/l. The high degree of disinfection with this quantity of chlorine is related to the chemical and physical quality of the El Lago effluent. After the operational sequence of the biological and chemical processes, the effluent from the tertiary filter has a low ammonium nitrogen and suspended solids content which is conducive to efficient disinfection by chlorine.

Table 17. TERTIARY FILTER PERFORMANCE

Period	Denit towers used	Avg filter rate gpm/ft^2	Avg filter run hr	Backwash water % of flow	Suspended solids, in mg/l	Suspended solids, out mg/l	Suspended solids removal, %
Sept 23 - Nov 8, 1974	small media	1.9	5.9	17.3	41	1	98
Nov 16 - Dec 16, 1974	large media	2.5	5.0	15.8	13	2	85
Jan 5 - Feb 14, 1975	large media	2.5	6.1	12.9	13	2	85

Table 18. COLIFORM CONTENT OF EL LAGO WASTEWATER SAMPLES*
MPN/100ml

Process	Total coliform	Fecal coliform
Primary effluent	7,400,000	-
Tertiary filter effluent	60,000	-
Chlorine contact effluent	0	0

* Each value is the geometric mean of results from 16 samples, March 1974 - February 1975.

Figure 18 shows percent BOD_5 and COD remaining in the process stream following nitrification, settling and addition of 40 mg/l of methyl alcohol during the final evaluation of the small media denitrification towers. BOD_5 and COD data were not taken on raw wastewater, primary settler effluent and trickling filter effluent during this period. Cumulative frequency data on BOD_5 and COD in final effluent are shown in Figures 19 and 20, respectively.

Percent solids and total phosphorus remaining in the process stream are shown in Figure 21. Data on percent solids in nitrified wastewater were taken after intermediate settling for separation of nitrifying bacteria. Cumulative frequency data on total phosphorus in the final effluent are shown in Figure 22.

Percentages of various forms of nitrogen remaining in the process stream during the final evaluation of the small media denitrification towers are presented in Figure 23. Percent reductions in total nitrogen, organic nitrogen and ammonium nitrogen are based on the content in the primary settler effluent as 100 percent since nitrogen data were not taken on raw wastewater during this period. Nitrate nitrogen in the nitrified, settled wastewater was taken as 100 percent of that form of nitrogen. Organic nitrogen shows an appreciable decrease between denitrification and chlorine contact chamber effluent due to the removal of biological solids in the final polishing filter and is correlated with the decrease in suspended solids shown in Figure 21. Cumulative frequency data on total nitrogen in the final effluent are shown in Figure 24.

Table 19 compares the residual concentrations of pollutants chosen as parameters for defining the objectives for the demonstration in 1970 with the average residuals of the pollutants found during the final small media study period as reported in Table 13B. The objectives were met in all cases; and the demonstration at El Lago showed that with proper operator attention and rudimentary instrumentation an existing trickling filter plant can be modified to produce effluent containing low residuals of pollutants.

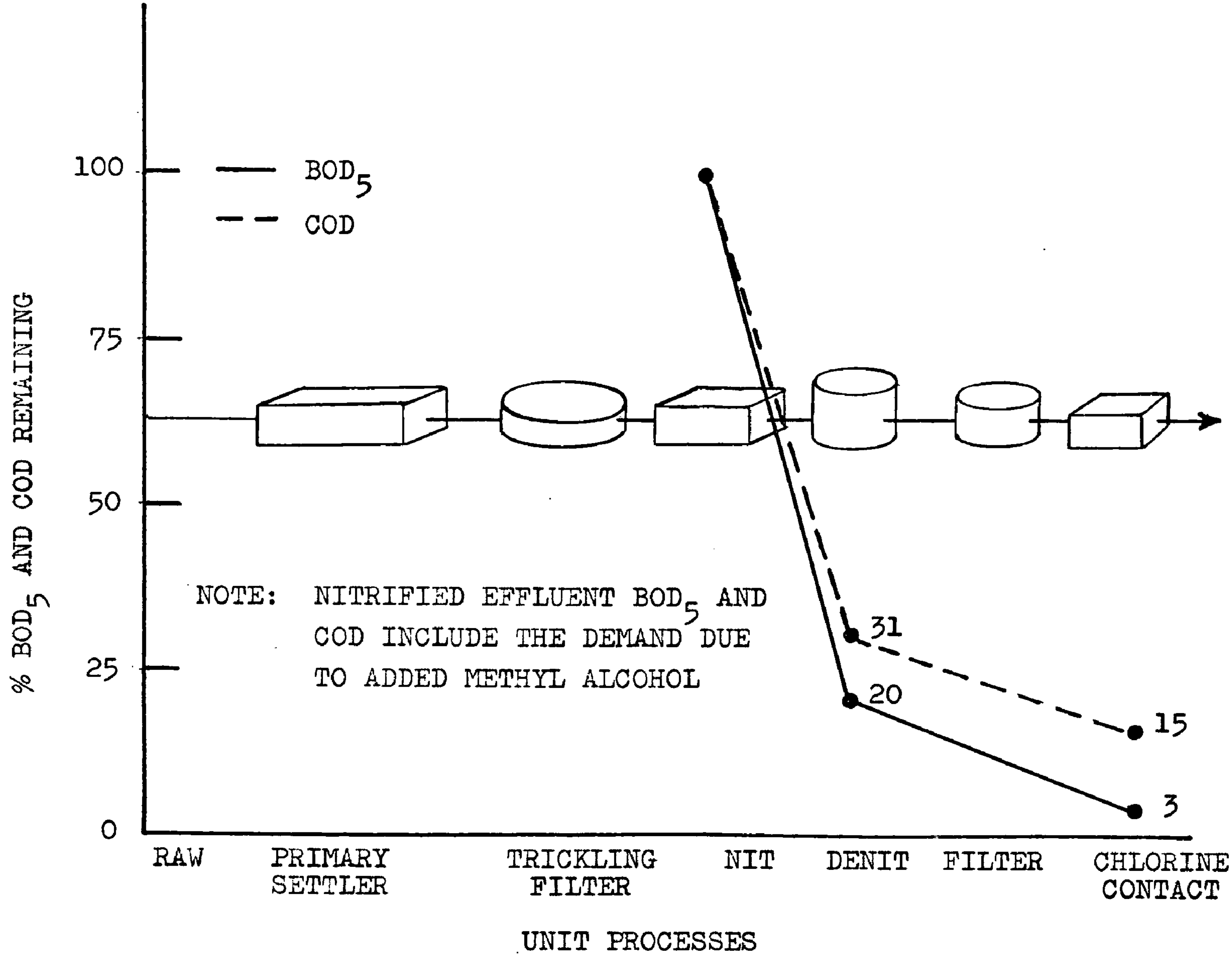

Figure 18. Percent BOD_5 and COD remaining, September 23 - November 8, 1974 (small media denitrification)

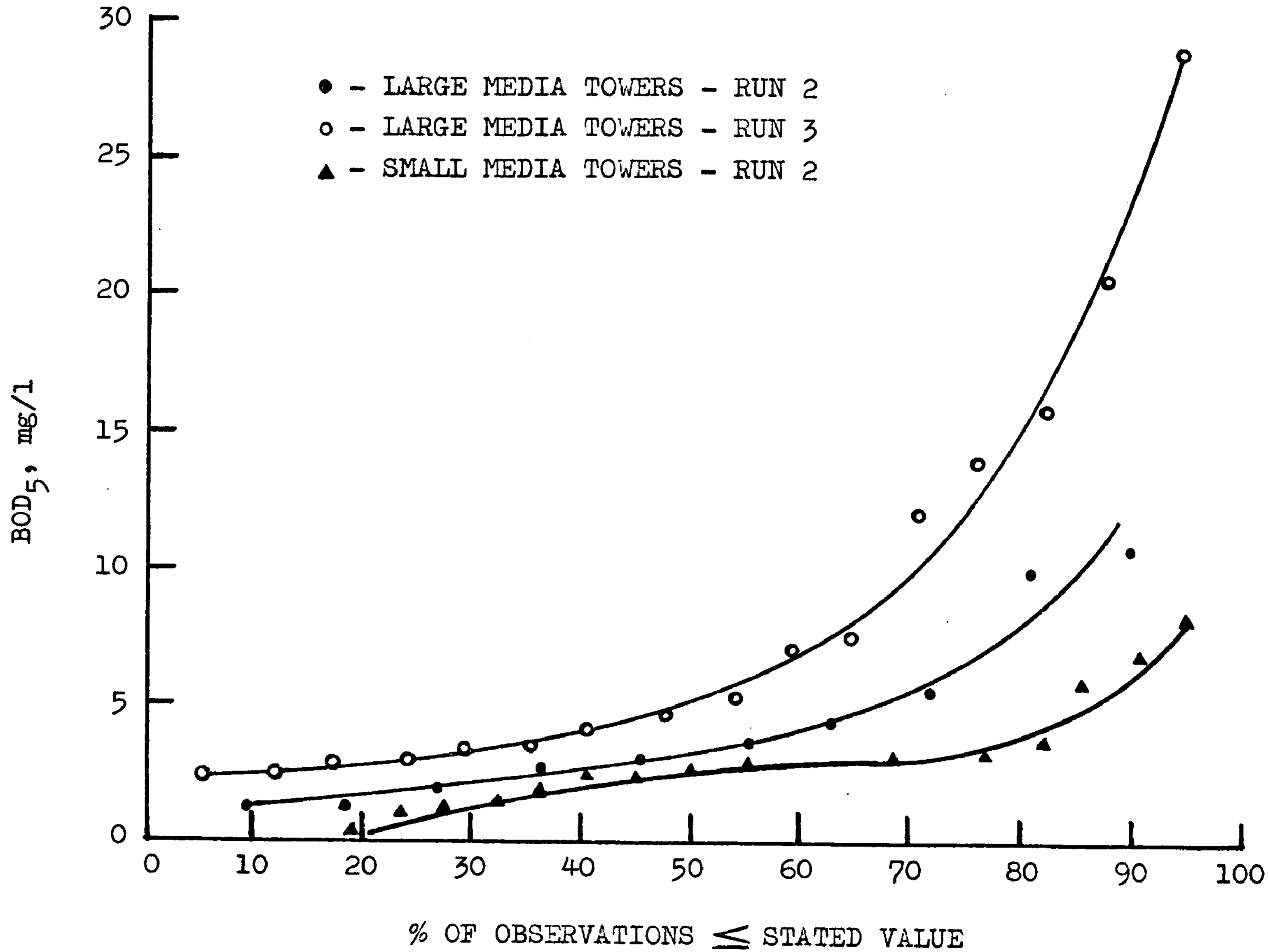

Figure 19. Cumulative frequency data on BOD_5 in final effluent

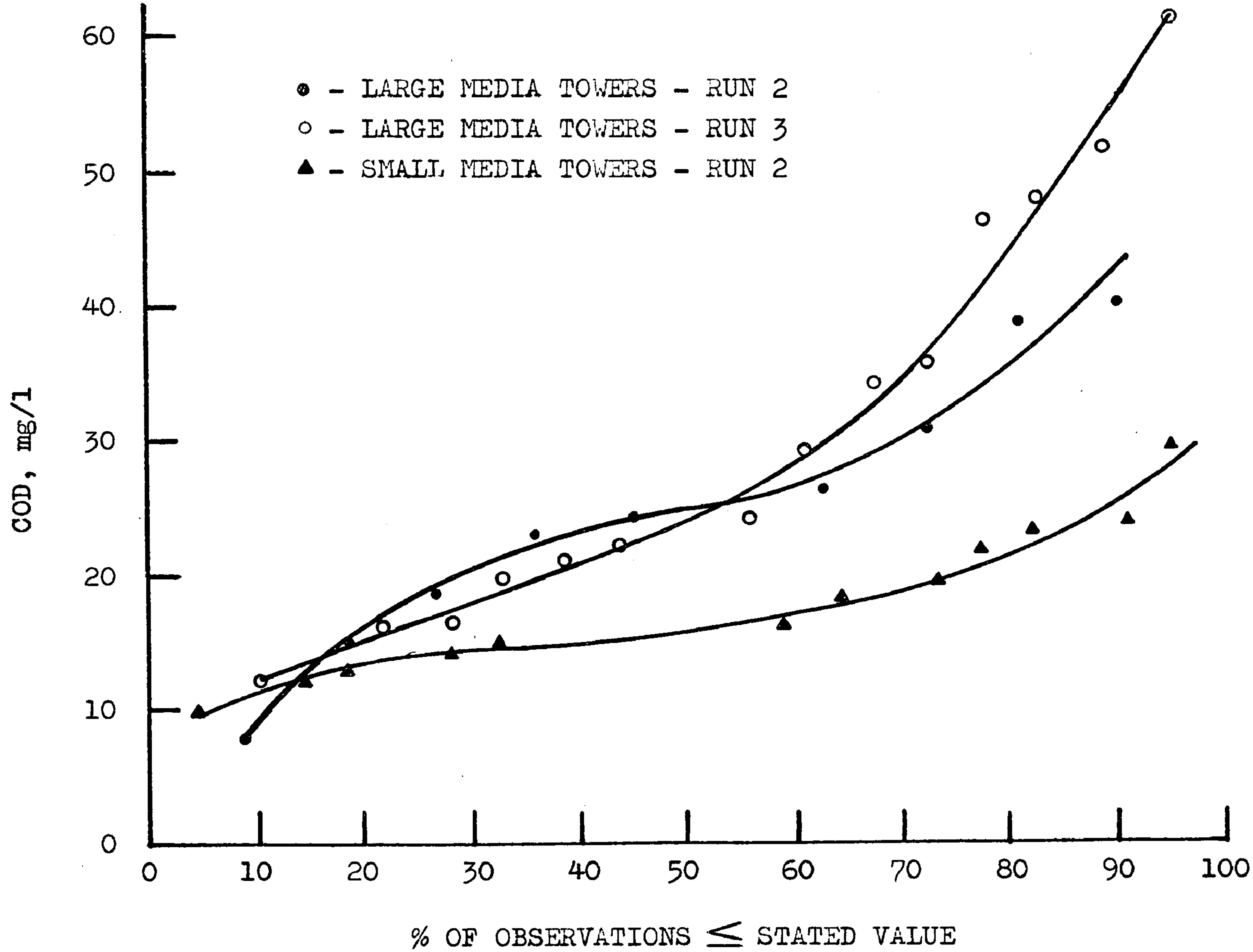

Figure 20. Cumulative frequency data on COD in final effluent

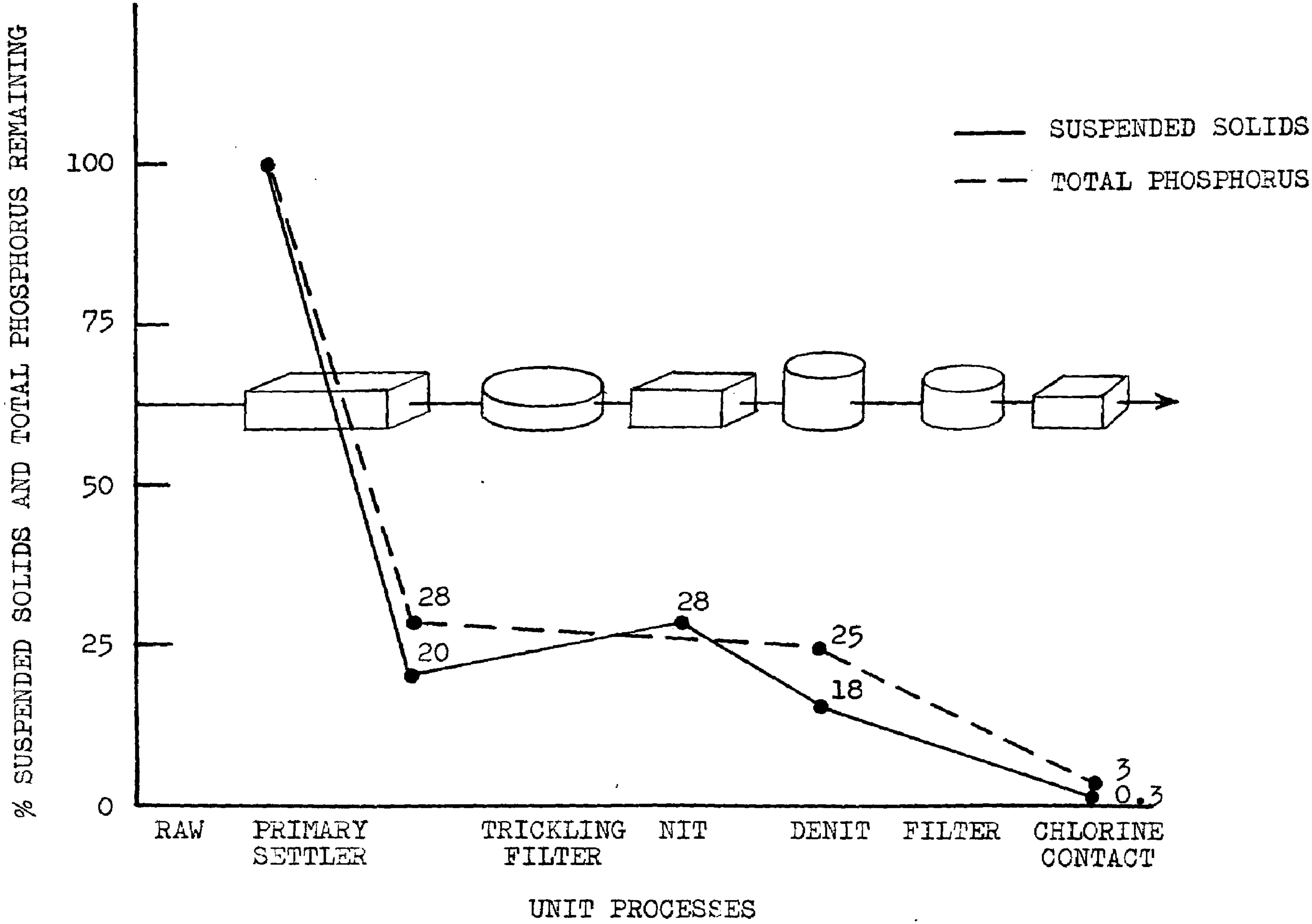

Figure 21. Percent suspended solids and total phosphorus remaining, September 23 - November 8, 1974 (small media denitrification)

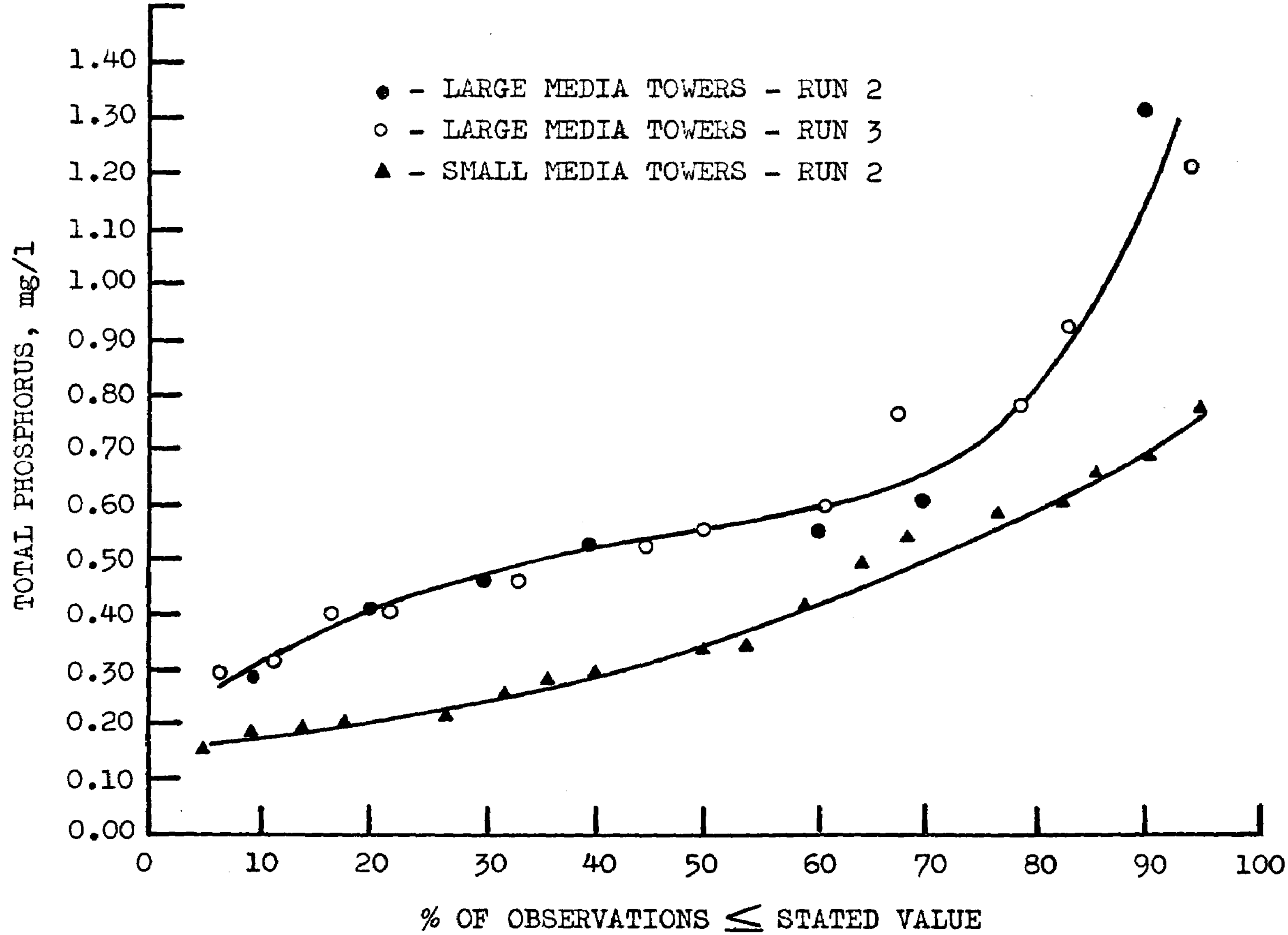

Figure 22. Cumulative frequency data on total phosphorus in final effluent

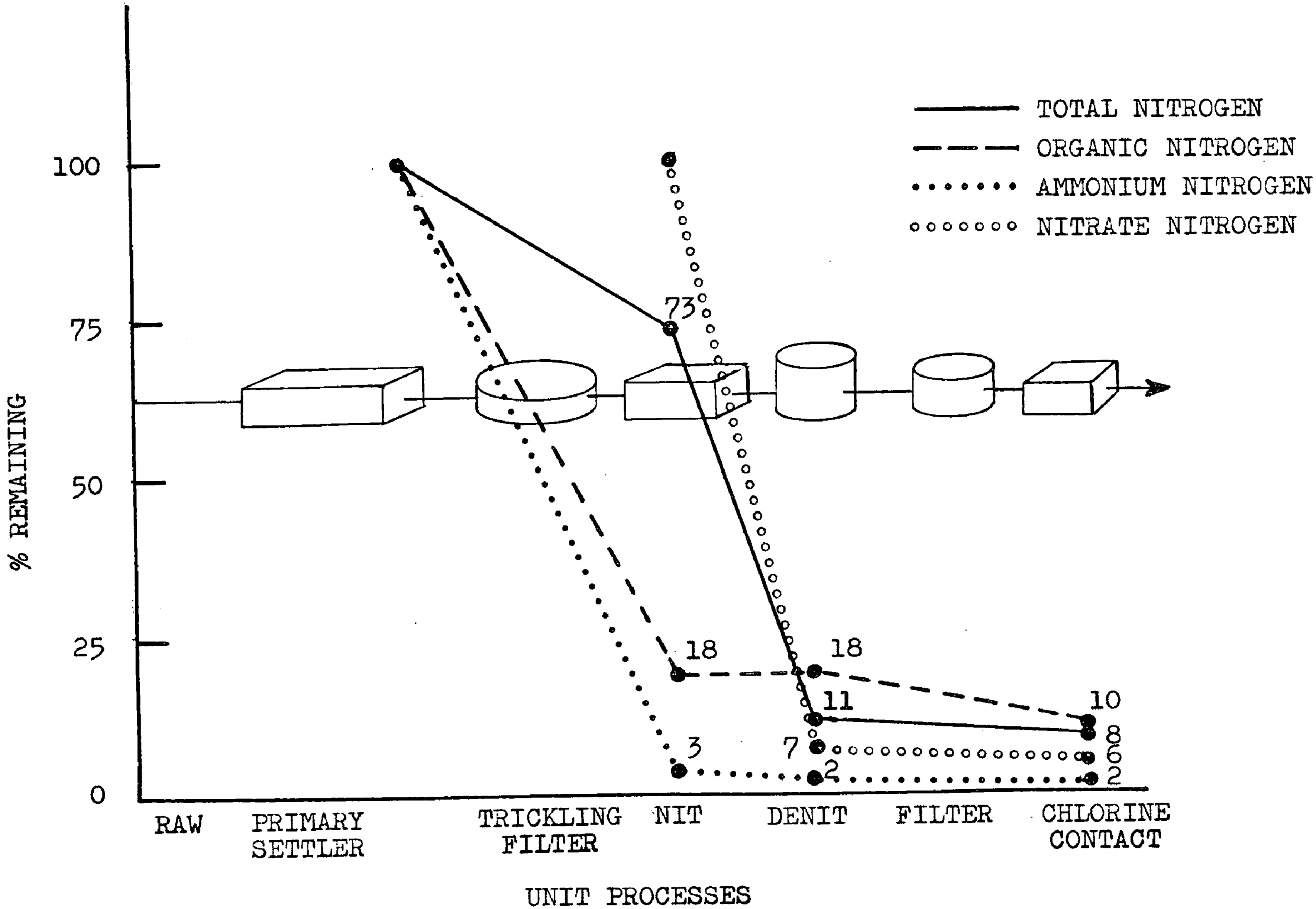

Figure 23. Percent of various forms of nitrogen remaining, September 23 - November 8, 1974 (small media denitrification)

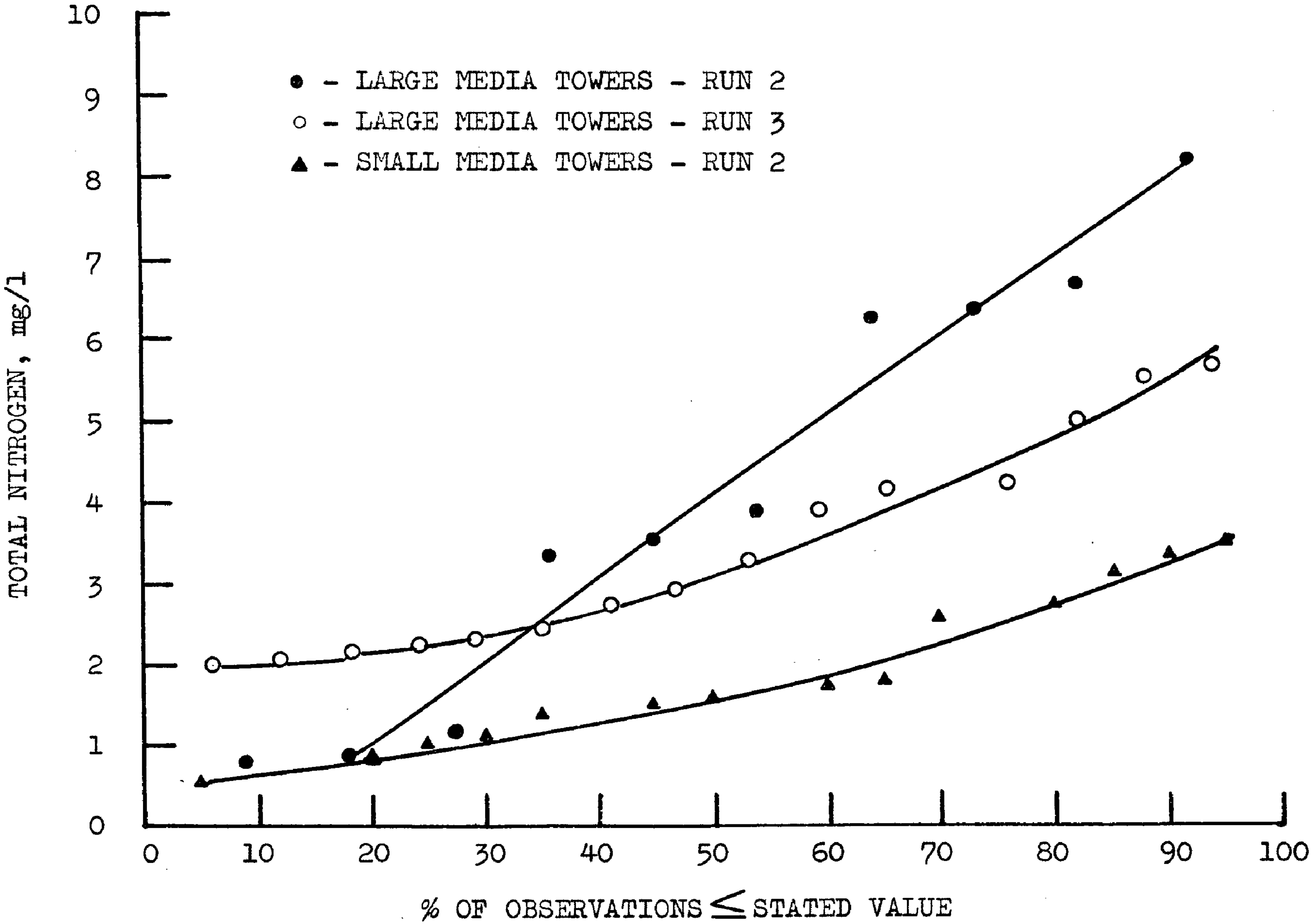

Figure 24. Cumulative frequency data on total nitrogen in final effluent

Table 19. FINAL EFFLUENT RESIDUAL OBJECTIVES COMPARED WITH DEMONSTRATION RESULTS, mg/l

Objective/Result	BOD_5	COD	SS	TN	TP	TOD
Original objectives July 1970	5	30	10	2	1	-
Demonstration results Sept-Nov 1974	2.9	17	1	1.8	0.39	21

SECTION VIII

COSTS

CAPITAL COSTS

The construction costs for the El Lago facility as described in the previous sections, including all change orders but exclusive of engineering costs, were as follows:

Phase I	-	Phosphorus control	-	$ 36,400
Phase II	-	Nitrogen control and filtration (Including $65,460 for small media denitrification towers and $50,000 for large media denitrification towers)	-	276,038
Total construction costs			-	$312,438

The Phase II cost of $276,038 included both small media and large media denitrification towers so that the effectiveness of both types of media could be evaluated. This redundancy would not be provided in a strictly operational facility, and construction costs would have been approximately $60,000 less if only small media towers had been installed. The reduction in cost would have been due to elimination of $50,000 for the large media towers and to a reduction of $10,000 in costs of concrete slab and piping.

Construction costs of an operational facility with small media denitrification towers would have been as follows:

Phosphorus control	-	$ 36,400
Nitrogen control and filtration	-	216,038
Total construction costs	-	$252,438

OPERATIONAL COSTS

The chemical cost for phosphorus removal is based on an influent phosphorus concentration of 12 mg/l, a 41 mg/l dose of iron added as ferric chloride, and a polymer does of 0.4 mg/l. Ferric chloride was purchased from Gulf

Chemical and Metallurgical Co. for 25¢/lb of iron content plus transportation charges of 40¢/ 100 lb. of ferric chloride solution. Dow Purifloc A-23 polymer was purchased in small lots for $2.80/lb.

The chemical cost for nitrogen removal is associated with the purchase of methyl alcohol. The average nitrate nitrogen value of 14 mg/l required 40 mg/l of alcohol for denitrification. Methyl alcohol was purchased in 1,000 gal quantities from McKesson Chemical Co. for 58¢/gal delivered to the site. Two 540-gal storage tanks were provided by the supplier at no charge to the District.

Electrical power costs for the advanced wastewater treatment are incurred in the operation of centrifugal blowers, turbine pumps, tertiary filter backwash pump, and small chemical dosing pumps. Power costs per 1,000 gal of wastewater are approximately 1¢ for phosphorus removal and 2¢ for nitrogen removal.

Since HCWCID #50 operates the water system and maintains the storm sewers as well as the wastewater collection and treatment facilities with the same crew of three men, it is difficult to break out labor costs of advanced wastewater treatment as a clearcut figure. However, labor costs for operation and routine maintenance are estimated at 1¢/1,000 gal for phosphorus removal and 3¢/1,000 gal for nitrogen removal.

Costs for chemicals, electrical power and labor are summarized in Table 20.

Table 20. CHEMICAL, ELECTRICAL AND LABOR COSTS FOR REMOVING PHOSPHORUS AND NITROGEN, cents/1,000 gal.

Item	Phosphorus	Nitrogen
Ferric chloride	10	--
A-23 polymer	1	--
Methyl alcohol	--	3
Electrical power	1	2
Labor	1	3
Total for chemicals, power and labor	13	8

SECTION IX

PROBLEMS ENCOUNTERED

The El Lago facility was designed and put into operation as a unique, one-of-a-kind facility, and problems of several natures were experienced. A topical listing of the major problems that caused delay in construction and difficulty in evaluation of performance follows.

Two natural events caused several weeks delay; these were hurricanes Agnes in 1972 and Delia in 1973. Both swept along the Gluf Coast. The effects at the plant were immediate in that there was heavy rainfall and flooding, and prolonged in that vendors supplying equipment were temporarily out of business.

The chemical storage tanks had support piers which were so tall that the tanks protruded above the plant fence. Plant neighbors complained, and the piers had to be shortened.

Earth moving equipment used during Phase II construction severed the underground metal salt chemical feed lines installed in Phase I.

A vendor supplied the wrong series of polymer dosing pumps; and during early periods of Phase I, the proper quantity of polymer could not be dosed to the primary influent flow.

The air lift pumps installed in the intermediate clarifiers could not be controlled in a satisfactory manner to reduce the hydraulic flow through the nitrification tank, and periodic operator adjustments were needed. Time clock actuated solenoid valves were installed to improve operation.

One of the centrifugal five-stage pumps was delivered with only four stages, and the other pump had improper impellers.

The methyl alcohol injection line was installed into the wrong leg of the branched centrifugal pump discharge line.

Methyl alcohol dosage became erratic, and it was found that the pump heads supplied by the vendor were not compatible with methyl alcohol.

The tertiary filter was installed with only time clock actuated backwash, and automatic backwash had to be added. The first set of pressure switches failed rapidly since they were not exterior grade. New orifice plates and valves were necessary to control excessive vibration during backwash. No air relief valves were provided on the vessels.

One of the two air blowers developed electrical problems shortly after installation.

A 4-inch pipe supporting one of the air diffuser headers in the main nitrificaton tank snapped and dropped the header into the tank after only six months of operation.

The original large media towers supplied were of the wrong gauge metal and exhibited poor workmanship. The consultant would not take delivery, and new tanks had to be fabricated.

Major construction activities proceeded rapidly, but when finishing punch list items for final acceptance were discussed in the light of consultant-client-contractor-vendor-federal interests, much time was consumed.

During the grant period two different elected Boards of Directors of HCWCID #50 were seated, and reevaluation of project objectives was necessary.

The 1972-1973 Houston area weather was the wettest period for several years, influencing both construction and operation schedules.

Reliable contract laboratory analytical services were difficult to obtain.

SECTION X

PUBLICATIONS AND PATENT DISCLOSURES

The essential points of the El Lago design were presented at an Advanced Waste Treatment Seminar in Dallas, Texas, on July 27, 1971.

The objectives and design data for the El Lago Advanced Waste Treatment Facility were presented at the 2nd Annual Technical Conference, Southeast Section, Texas Water Pollution Control Association in Houston, Texas, on December 6, 1972.

A report of the operational results of the initial evaluation period was presented at a Technology Transfer Seminar in Shreveport, Louisiana, on August 21, 1973.

A thesis for the Master of Science degree titled Process Development Studies on the Biological Utilization of Nitrogen in a Domestic Wastewater Treatment System, based on early project data, was submitted to the University of Houston in December 1973.

A report on project progress was presented at the 3rd U.S./Japan Conference on Wastewater Treatment in Tokyo, Japan, in February 1974.

An interim report titled Description of the El Lago, Texas, Advanced Wastewater Treatment Plant was published by HCWCID #50 in March 1974.

A paper titled "Upgrading El Lago, Texas, Wastewater Treatment Plant to Provide Complete Nitrification" was presented at the 46th Annual Conference, Water Pollution Control Association of Pennsylvania at University Park, Pennsylvania, on August 8, 1974.

EPA office of Technology Transfer filmed a 28-minute documentary movie on site in July 1975. The purpose of the film is to inform municipal and regulatory officials of current wastewater treatment technology advances.

There have been no patent disclosures filed or anticipated as a result of this demonstration project that covers the time period of July 6, 1970, through August 15, 1975.

SECTION XI

ABBREVIATIONS

ADW =	average dry weather
Avg =	average
BOD_5 =	biological oxygen demand exerted in 5 days at 20°C
$CaCO_3$ =	calcium carbonate
cfm =	cubic feet per minute
cfm/ft^2 =	cubic feet per minute per square foot
C =	Centigrade
COD =	chemical oxygen demand (dichromate method)
denit =	denitrified
effl =	effluent
EPA =	Environmental Protection Agency
F =	Fahrenheit
Fe^{+3} =	ferric iron
ft =	foot
ft^2 =	square foot
ft^3 =	cubic foot
ft^2/ft^3 =	square feet per cubic foot
gal =	gallons (U.S.)
gal/hr =	gallons (U.S.) per hour
g =	gram

gpd =	gallons (U.S.) per day
gpd/ft^2 =	gallons (U.S.) per day per square foot
gpm =	gallons (U.S.) per minute
gpm/ft^2 =	gallons (U.S.) per minute per square foot
HCWCID #50 =	Harris County Water Control and Improvement District No. 50
hr =	hour (sidereal)
infl =	influent
l =	liter
lb =	pound (avoirdupois)
MDW =	maximum dry weather
MERL =	Municipal Environmental Research Laboratory (EPA) Cincinnati, Ohio
mg =	milligram
mg/l =	milligram per liter
mgd =	million gallons per day
NH_4-N =	ammonium nitrogen
mi =	mile (U.S., statute)
mm =	millimeter
NO_3-N =	nitrate nitrogen
Org-N =	organic nitrogen
pH =	negative logarithm (to the base 10) of the hydrogen ion concentration
pri =	primary settler or clarifier
psi =	pounds (avoirdupois) per square inch
sq mi =	square mile
SP =	soluble phosphorus
SS =	suspended solids

SVI =	sludge volume index
TKN =	Kjeldahl nitrogen
TN =	total nitrogen content
TOD =	total oxygen demand
TP =	total phosphorus
U.S. =	United States of America
WW =	wet weather
¢ =	cents (U.S.)
$ =	dollars (U.S.)

SECTION XII

APPENDICES

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APPENDIX A

OPERATIONAL DATA

The following pages summarize operational data for evaluation periods from June 1973 through February 1975.

The location of each sample point referred to is as follows:

Raw wastewater - Sample is taken from manhole in sanitary sewer main immediately before reaching the plant wet well; it contains no chemical additives or plant recirculation.

Primary influent - Sample is taken from the distribution trough in the primary settler; it contains metalic salt and polymer which are added for phosphorus removal.

Primary effluent - Sample is taken from overflow trough of the primary settler.

Denit influent - Sample is taken immediately prior to entry into denitrification columns; the wastewater has been through the trickling filters, nitrification reactor and intermediate clarifiers. Methyl alcohol for denitrification has been added, causing an increase in COD and BOD_5.

Denit effluent - 1 - Sample is taken immediately after it has passed through the first of two denitrification columns arranged in series.

Denit effluent - 2 - Sample is taken at exit from the second denitrification column.

Plant effluent - Sample is taken at the effluent weir of the chlorine contact tank and has undergone tertiary filtration and chlorination.

OPERATIONAL DATA - EL LAGO AWTF JUNE 1973

	DATE														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rainfall, inches				0.00	0.00	1.86	0.00	0.00	0.00	0.10	0.03	5.78	2.47	0.56	0.02
Plant flow, MG				0.161	0.265	0.364	0.246	0.243	0.240	0.247	0.240	1.000	0.780	0.560	0.424
Denit flow, MG				0.161	0.265	0.364	0.221	0.242	0.238	0.245	0.170	0.420	0.160	0.160	0.420
pH															
Primary influent								7.70			7.45				
Primary effluent								7.13			7.45				
Denit influent				8.28	8.28	8.12	8.18	8.40			8.23				8.10
Denit effluent - 2						7.85	8.15	8.10			8.30				7.75
Plant effluent				7.77	8.03	8.00	8.18	8.10			8.13	8.20	7.75		7.95
Suspended solids, mg/l															
Raw wastewater				21	135								94		
Primary influent								251			98				
Primary effluent								61			53				
Denit influent				8	45	39	44	24			47	34			30
Denit effluent - 2						45	19	10			5				26
Plant effluent				3	1	6	1	2			2				4
Phosphorus, mg/l P															
Total															
Raw wastewater				8.2	17.5								3.7		
Primary influent								4.8			8.5				
Primary effluent								5.8			6.9				
Denit influent				6.7	5.4	4.3									
Denit effluent - 2						4.1									
Plant effluent							4.2	8.7			9.5		5.2		1.5
Filterable															
Raw wastewater				7.7	17.0								2.4		
Primary influent								0.9			1.9				
Primary effluent								1.9			3.2				
Denit influent				3.9	3.9	2.1									
Denit effluent - 2						2.1									
Plant effluent							4.0	8.5			9.0		3.1		1.0

Nitrogen, mg/l N												
Ammonium nitrogen												
Raw wastewater	35.2	21.6								2.4		
Primary influent												
Primary effluent												
Denit influent	0.4	0.6	1.2	0.6	0.8			0.6	0.4			0.7
Denit effluent - 2			0.7	1.8	0.9			0.6				0.9
Plant effluent									0.4	0.7		
Total Kjeldahl nitrogen												
Raw wastewater	60.1	37.7								7.7		
Primary influent												
Primary effluent												
Denit influent	5.0	2.3	5.4	10.8	5.4			2.9	5.6			5.6
Denit effluent - 2			6.2	2.3	1.5			1.8				2.7
Plant effluent									2.2	6.2		
Nitrate nitrogen												
Denit influent	15.8	19.9	11.0	15.4	11.6			12.3	12.0			10.0
Denit effluent - 2			3.5	0.0	0.1			0.1				0.1
Plant effluent									1.5	5.4		
COD, mg/l												
Raw wastewater	338	391								89		
Primary influent					478			244				
Primary effluent					173			141				
Denit influent	96	51	77	77				163				
Denit effluent - 2			142	176				85				78
Plant effluent					90				54	70		47
BOD_5, mg/l												
Raw wastewater												
Primary influent												
Primary effluent												
Denit influent												
Denit effluent - 2												
Final effluent										5		
Methanol doseage, mg/l		56	76	66	46		64	66	47	47		33

OPERATIONAL DATA - EL LAGO AWTF JUNE 1973

	DATE														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Rainfall, inches	0.00	0.00	0.00	0.00	0.01	0.16	0.01	0.00	0.03	0.06	0.00	0.00	0.00	0.00	0.00
Plant flow, MG	0.310	0.240	0.220	0.284	0.256	0.248	0.238	0.242	0.240	0.202	0.251	0.266	0.268	0.234	0.257
Denit flow, MG	0.308	0.238	0.217	0.283	0.255	0.246	0.236	0.240	0.238	0.200	0.250	0.265	0.267	0.233	0.257
pH															
Primary influent				7.35	7.70	7.15	7.23								
Primary effluent				7.30	7.60	7.50	7.28								
Denit influent			7.90	8.00	8.00	7.85	7.88			7.85	8.20	7.85	7.80	7.88	
Denit effluent - 2			8.05	8.05	8.10	7.95	7.90			8.10	8.25	7.95	8.10	8.20	
Plant effluent					7.60					7.55				8.10	
Suspended solids, mg/l															
Raw wastewater														200	
Primary influent				754	256	344	170								
Primary effluent				37	63	71	114								
Denit influent			26	31	36	35	36			38	39	50	57	51	
Denit effluent - 2			3	7	3	21	2			7	9	25	56	14	
Plant effluent					2					2				6	
Phosphorus, mg/l P															
Total															
Raw wastewater														21.8	
Primary influent				22.8	16.0	13.0	20.3								
Primary effluent				5.1	7.5	7.1	12.4								
Denit influent										16.1					
Denit effluent- 2															
Plant effluent					5.2					5.9				11.5	
Filterable															
Raw wastewater														14.0	
Primary influent				1.6	3.4	3.5	12.4								
Primary effluent				3.4	5.4	3.9	6.9								
Denit influent															
Denit effluent - 2															
Plant effluent					4.9					5.5				11.0	

Nitrogen, mg/l N											
Ammonium nitrogen											
Raw wastewater										15.4	
Primary influent			16.2	24.6	16.9						
Primary effluent				21.6	23.7						
Denit influent	1.2	1.8	1.4	0.7	0.8	0.9	0.8	0.5	0.5	0.9	
Denit effluent - 2	0.6	1.1	0.8	0.5	0.5	0.9	0.5	0.5	0.7	0.7	
Plant effluent										0.7	
Total Kjeldahl nitrogen											
Raw wastewater										64.7	
Primary influent			40.0	39.3	29.3						
Primary effluent				30.8	30.0						
Denit influent	2.8	2.6	2.0	3.0	2.0	4.5	3.0	4.6	3.6	1.9	
Denit effluent - 2	2.0	1.8	2.0	2.8	1.4	3.0	2.0	3.5	2.3	2.0	
Plant effluent										1.5	
Nitrate nitrogen											
Denit influent	6.6	5.4	12.3	15.0	22.0	14.1	18.5	19.4	20.2	20.2	
Denit effluent - 2	0.0	1.5	3.9	9.7	9.7	0.9	5.3	0.9	0.9	0.9	
Plant effluent										0.0	
COD, mg/l											
Raw wastewater										372	
Primary influent		713	396	436	720						
Primary effluent		101	159	178	225						
Denit influent	117	124	89	115	66	150	111	116	204	148	
Denit effluent - 2	39	16	35	75	23	43	43	104	60	48	
Plant effluent			35			43				36	
BOD_5, mg/l											
Raw wastewater										175	
Primary influent			223								
Denit influent	58		65							72	
Denit effluent - 2	6									12	
Plant effluent			5							8	
Methanol doseage, mg/l	27	20	30	48	35	56	81	34	34	36	40

OPERATIONAL DATA - EL LAGO AWTF JULY 1973

DATE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rainfall, inches	0.00	0.00	0.00	0.00	0.50	0.66	0.10	1.85	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Plant flow, MG	0.2500	0.2700	0.2800	0.2500	0.2634	0.2938	0.2800	0.5890	0.2918	0.3075	0.2727	0.2619	0.3648	0.2600	0.5094
Denit flow, MG	0.2465	0.2648	0.2718	0.2450	0.2564	0.2878	0.2764	0.5890	0.2918	0.3075	0.2727	0.2619	0.3648	0.2600	0.5094
pH															
Primary influent		7.75	7.38		7.50	7.52			7.28	7.55	7.10	7.35	7.10		
Primary effluent		7.40	7.50		7.45	7.45			7.30	6.85	6.92	7.40	7.05		
Denit influent		7.95	7.85		7.90	7.90			7.90	7.75	7.65	7.80	7.65		
Denit effluent - 2		8.07	8.03		8.03	7.80			7.72	7.85	8.00	7.85	8.00		
Plant effluent		7.95	7.75		7.60	7.68			7.68		7.40				
Suspended solids, mg/l															
Raw wastewater															
Primary influent		295	179		404	136			104	234	262	234	263		
Primary effluent		41	81		88	113			36	17	22	75	50		
Denit influent		40	23		48	30			86	27	50	44	42		
Denit effluent - 2		14	11		19	35			25	41	5.0	2.0	8.0		
Plant effluent		1	1		4	4			11		0.8				
Phosphorus, mg/l P															
Total															
Raw wastewater															
Primary influent		13.5	20.9		18.9	15.0			9.0	10.3	12.0	16.2	14.9		
Primary effluent		6.0	15.6		7.2	10.4			2.5	1.0	2.0	9.2	5.9		
Denit influent						4.0			3.5		4.6	4.6	3.6		
Denit effluent - 2						5.4			2.7		2.3	4.6	1.3		
Plant effluent		7.3	4.1		10.8	4.7					2.0				
Filterable															
Raw wastewater															
Primary influent		2.7	8.2		5.9	6.0			0.6	1.0	0.5	5.8	0.5		
Primary effluent		1.6	5.3		3.2	5.9			0.7	0.5	0.5	5.8	0.6		
Denit influent						3.6			3.2	1.2	1.0	2.3	1.0		
Denit effluent - 2						5.0			2.5	3.3	1.2	2.3	0.8		
Plant effluent		6.8	3.9		4.2	3.6					1.9				

Nitrogen, mg/l N												
Ammonium nitrogen												
Raw wastewater												
Primary influent		26.2	21.6	20.8	25.4		10.7	8.5	15.0	8.5	9.2	
Primary effluent		23.9	16.2	23.1	21.0		12.3	7.7	16.9	12.1	15.4	
Denit influent		0.9	2.2	1.2	0.9		0.5	0.6	1.0	0.7	0.4	
Denit effluent - 2		0.9	1.4	0.8	0.9		0.4	0.5	0.8	0.8	0.1	
Plant effluent									0.4			
Total Kjeldahl nitrogen												
Raw wastewater												
Primary influent		44.7	30.8	49.3	37.0		21.6	33.9	24.6	30.8	26.2	
Primary effluent		29.3		31.6	29.3		19.3	21.6	30.0	30.0	29.3	
Denit influent		2.0	0.8	1.9	2.6		2.3	0.8	2.3	1.8	1.4	
Denit effluent - 2		2.8	0.9	1.4	2.6		1.9	2.2	1.6	1.4	0.7	
Plant effluent									1.2			
Nitrate nitrogen												
Denit influent		21.1	15.8	24.8	11.4		16.7	18.5	17.6	8.3	23.8	
Denit effluent - 2		0.9	4.4	1.8	4.4		0.9	0.9	0.0	2.5	0.0	
Plant effluent									3.5			
COD, mg/l												
Raw wastewater												
Primary influent		520	388	714	276		111	250	337	403	422	
Primary effluent		152	219	219	240		111	99	107	157	119	
Denit influent		224	123	104	156		107	131	99	97	108	
Denit effluent - 2		64	100	46	132		103	59	44	35	35	
Plant effluent		40	46	38	60		44		32			
BOD_5, mg/l												
Raw wastewater												
Primary influent				220					111			
Primary effluent									47			
Denit influent									29			
Denit effluent - 2									2.9			
Plant effluent				18					2.5			
Methanol doseage, mg/l	41	41	58	51	53	29	28	35	22	26	28	47

OPERATIONAL DATA - EL LAGO AWTF JULY 1973

	DATE															
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Rainfall, inches	0.15	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.00
Plant flow, MG	0.2759	0.1712	0.2608	0.2796	0.2726	0.3167	0.2544	0.2655	0.3103	0.3109	0.2762	0.3632	0.2785	0.2495	0.2425	0.2702
Denit flow, MG	0.2759	0.1712	0.2608	0.2796	0.2726	0.3167	0.2544	0.2655	0.3103	0.3109	0.2762	0.3632	0.2785	0.2495	0.2425	0.2702
pH																
Primary influent	7.30	7.23	7.65	6.95	7.28				7.35	7.40	7.40	7.22			7.50	7.50
Primary effluent	7.00	7.05	7.30	7.10	7.50			7.08	7.60	7.48	7.40	7.80			7.60	7.60
Denit influent	7.65	7.90	7.78	7.72	7.72			7.85	8.00	7.74	8.00	7.58			7.96	8.10
Denit effluent - 2	7.90	7.95	7.88	7.80	7.80			8.00	8.14	7.92	8.02	7.75			7.98	8.00
Plant effluent			7.70	7.70	7.65			7.58	7.89	7.95	8.00	7.57			7.98	7.90
Suspended solids, mg/l																
Raw wastewater					102			116	196	91	126	45			159	114
Primary influent	220	230	188	338	128			456	192	202	129	253			120	227
Primary effluent	104	99	42	36	70			114	106	56	46	69			59	107
Denit influent		60	67	90	50			10	34	32	42	27			27	38
Denit effluent - 2	7.6	6.0	11	62	60			22	10	7.0	10	27			2.5	6.5
Plant effluent			4.5	6.0	24			4.0	8.0	4.0	13	5.5			0.4	2.5
Phosphorus, mg/l P																
Total																
Raw wastewater					16.5			9.5		14.5	11.2	11.3			12.2	18.5
Primary influent	14.5	18.5	14.0	18.5	14.9			6.5	13.3	18.0	11.0	15.5			9.0	22.1
Primary effluent	8.0	13.0	5.0	10.4	5.6			6.9	11.4	6.0	5.4	7.0			5.6	17.4
Denit influent	9.0	5.0	7.5	5.0	3.1			2.4	4.8	4.0	4.6	3.4			5.4	6.6
Denit effluent - 2	3.5	2.0	2.0	6.3	3.1			3.1	4.2	4.6	5.4	4.4			3.0	4.2
Plant effluent			2.7	2.1	1.5			1.5	3.4	4.6	4.1	8.2			3.2	3.5
Filterable																
Raw wastewater					15.9			9.6		11.0	8.8	10.5			7.0	15.9
Primary influent	2.5	7.5	3.5	0.9	0.5			3.6	2.4	1.1	3.3	1.9			2.0	8.4
Primary effluent	1.8	4.0	1.5	1.8	1.0			0.0	4.6	2.0	2.0	3.0			2.0	5.1
Denit influent	1.5	1.0	1.5	1.4	1.0			1.0	2.4	1.9	2.4	2.5			3.5	2.5
Denit effluent - 2	3.0	1.5	1.5	2.3	1.5			2.1	3.1	4.2	4.2	3.1			2.9	3.2
Plant effluent			2.0	1.8	1.3			0.5	2.9	3.4	3.4	6.2			3.0	3.4

Nitrogen, mg/l N																
Ammonium nitrogen																
Raw wastewater					24.6			19.3	21.8	15.4	16.9	15.4			17.7	18.5
Primary influent	29.3	11.6	16.9	13.1	16.2			17.7	27.0	16.2	17.7	13.9			13.3	17.7
Primary effluent	16.9	19.3	16.9	11.6	13.9			16.9	20.0	13.9	16.9	14.6			16.9	18.5
Denit influent	0.5	0.5	0.5	0.7	0.5			0.7	0.7	1.4	2.3	1.2			0.5	0.3
Denit effluent - 2	0.5	0.8	0.8	0.8	0.8			1.6	1.1	1.5	3.0	1.2			2.0	0.4
Plant effluent			0.8	0.7	0.5			0.8	0.5	1.8	1.5	1.2			1.8	0.4
Total Kjeldahl nitrogen																
Raw wastewater					37.0			30.8	30.8	23.9	33.9	27.0			33.1	27.7
Primary influent	30.8	27.7	35.9	38.5	30.8			26.2	42.4	23.9	31.6	37.7			33.9	33.2
Primary effluent	33.9	32.2	26.2	27.0	26.2			26.2	23.9	23.1	27.7	26.2			26.2	32.3
Denit influent	3.2	2.0	1.6	3.6	1.5			1.2	1.4	2.4	4.7	5.1			1.5	1.9
Denit effluent - 2	1.4	1.6	1.6	3.6	2.7			6.1	1.6	3.1	4.1	3.2			3.1	1.8
Plant effluent			1.2	1.4	1.1			0.9	1.5	1.9	3.5	2.7			2.8	1.6
Nitrate nitrogen																
Denit influent	21.1	22.9	22.9	17.6	14.2			18.5	11.4	11.4	10.3	10.0			13.2	13.3
Denit effluent - 2	0.0	0.9	1.8	0.9	1.8			0.1	0.7	0.1	0.1	0.1			2.5	3.0
Plant effluent			0.9	0.0	0.0			0.0	0.0	0.0	0.0	0.0			2.5	2.5
COD, mg/l																
Raw wastewater					293			166	229	307	303	252			241	318
Primary influent	349	396	384	384	428			214	314	284	296	361			256	590
Primary effluent	221	239	161	180	178			150	186	160	154	140			186	229
Denit influent	169	81	123	119	83			99	109	123	188	124			50	93
Denit effluent - 2	47	31	54	85	48			36	31	54	65	54			58	27
Plant effluent			46	61	36			24	31	38	58	39			31	23
BOD_5, mg/l																
Raw wastewater					178			109	119	142					116	146
Primary influent			134	188				89	176	169					86	206
Primary effluent			86	124	82			70	78	86					84	110
Denit influent			64	66	27			57	52	49					11	47
Denit effluent - 2			24	34	38			27	4.7	9.2					4.3	4.5
Plant effluent			17	17	20			4.5	3.4	6.9					8.5	2.4
Methanol doseage, mg/l	39	69	44		32	36	23	54	37	37	53	63	0	0	0.0	49

OPERATIONAL DATA - EL LAGO AWTF   AUGUST 1973

	DATE														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rainfall, inches	0.00	2.46	0.05	0.00	0.00	0.64	0.00	0.44	0.00	0.66	0.12	0.00	0.04	0.00	0.01
Plant flow, MG	0.2557	0.9000	0.3470	0.2784	0.2724	0.2692	0.2775	0.3805	0.3669	0.5389	0.3360	0.2999	0.3048	0.3076	0.2766
Denit flow, MG	0.2557	0.6324	0.3470	0.2784	0.2724	0.2692	0.2775	0.3805	0.3669	0.5389	0.3360	0.2999	0.3048	0.3076	0.2766
pH															
Primary influent	7.02	6.73	7.56			7.65	7.40	6.92					7.30		
Primary effluent	6.97	7.10	7.35			7.60	7.10	7.03					7.25		
Denit influent	7.81	7.68	7.82			7.82	7.88	7.58	7.78	7.78			7.48		
Denit effluent - 2	7.92	7.68	7.80			7.90	7.85	7.80	7.60	7.72			7.90		
Plant effluent	7.98	7.60	7.90			8.00	7.90	7.88	7.90	6.92			7.52		
Suspended solids, mg/l															
Raw wastewater	116	96	82				219	89					180		
Primary influent	139	411	247			143	239	277					262		
Primary effluent	100	62	47			71	77	38					64		
Denit influent	44	33	28			28	38	39	34	35			60		
Denit effluent - 2	13	45	1.6			5.5	6.5	5.0	3.2	6.0			71		
Plant effluent	4.5	3.0	0.8			0.8	0.4	1.5	1.6	0.8			3.6		
Phosphorus, mg/l P															
Total															
Raw wastewater	11.3	6.2	7.4				14.4	16.0					7.5	15.5	
Primary influent	12.8	6.6	6.8			10.0	11.1	11.5					16.0	19.0	
Primary effluent	4.6	3.1	3.3			7.0	6.6	2.7					6.0	6.5	
Plant effluent	3.9	2.2	2.6			5.6	5.1	3.5		1.4			1.9	1.6	
Filterable															
Raw wastewater	9.0	3.3	6.6				13.2	10.0					4.3	8.0	
Primary influent	1.0	0.8	0.8			9.6	1.5	1.0					1.5	4.5	
Primary effluent	1.7	0.7	1.2			6.5	2.8	0.5					2.8	3.3	
Plant effluent	3.7	2.1	1.1			5.2	4.8	2.3		1.1			1.8	0.8	
Nitrogen, mg/l N															
Ammonium nitrogen															
Raw wastewater	18.5	4.6	8.5				15.4	13.9					17.7		
Primary influent	21.8	7.7	11.6			24.6	15.4	16.2					18.5		
Primary effluent	19.6	10.8	3.9			19.3	16.9	16.9					7.8		
Denit influent	0.3	1.6	1.5			0.9	0.5	0.4	0.0	0.0			0.9		
Denit effluent - 2	0.5	1.6	0.3			0.9	1.4	0.9	0.0	0.1			0.8		
Plant effluent	0.5	1.8	0.4			1.1	0.9	0.8	0.5	0.0			0.7		

Total Kjeldahl nitrogen															
Raw wastewater	30.0	13.9	19.3				33.9	26.2					33.9		
Primary influent	35.4	19.3	23.9			40.8	30.0	30.8					35.4		
Primary effluent	28.5	16.2	19.3			33.2	27.0	27.0					28.5		
Denit influent	1.2	3.8	1.8			3.2	2.7	2.3	1.4	7.6			4.2		
Denit effluent - 2	2.0	4.3	1.6			2.4	2.2	1.6	0.5	2.0			4.5		
Plant effluent	1.8	3.0	1.6			2.3	1.9	1.5	1.1	0.9			1.2		
Nitrate nitrogen															
Denit influent	14.4	8.6	10.6			10.8	8.6	5.9	11.2	10.0			13.2		
Denit effluent - 2	1.4	2.1	0.6			0.3	0.1	0.3	0.1	2.5			0.3		
Plant effluent	1.3	1.8	0.3			0.2	0.1	0.0	0.0	1.9			0.1		
COD, mg/l															
Raw wastewater	248	136	188				380	265					182		
Primary influent	388	407	236			281	306	341					407		
Primary effluent	186	97	108			243	190	126					116		
Denit influent	89	78	100			95	78	107	112	130			105		
Denit effluent - 2	43	62	36			32	47	24	39	40			124		
Plant effluent	31	35	32			32	43	20	34	36			35		
BOD_5, mg/l															
Raw wastewater	130							60							
Primary influent	163							164							
Primary effluent	101							55							
Denit influent	42							54							
Denit effluent - 2	5.6							16							
Plant effluent	4.5							0.8							
Methanol doseage, mg/l	20	19	34	16	27	38	16	34	43	27	30	42	45	41	29

OPERATIONAL DATA - EL LAGO AWTF   AUGUST 1973

	DATE															
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Rainfall, inches	0.00	0.18	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.16	0.22	0.00
Plant flow, MG	0.2591	0.2662	0.3252	0.3256	0.3331	0.3198	0.3021	0.2821	0.2964	0.2876	0.3453	0.2353	0.3105	0.4509	0.3095	0.2804
Denit flow, MG	0.2591	0.2662	0.3252	0.3256	0.3331	0.3198	0.3021	0.2821	0.2964	0.2876	0.3453	0.2353	0.3105	0.4509	0.3095	0.2804
pH																
Primary influent	7.68	7.40			7.43	7.38	7.23	7.55	7.41			7.45	7.88	7.52	7.35	7.20
Primary effluent	8.00	7.42			7.48	7.42	7.60	7.28	7.52			7.50	7.30	7.48	7.25	7.28
Denit influent	8.25	7.70			7.88	7.88	7.90	7.72	7.75			7.98	7.72	7.84	7.65	7.83
Denit effluent - 2	7.68	7.85			7.90	7.80	7.80	7.80	7.69			7.95	8.00	7.90	8.00	7.80
Plant effluent	7.80	7.68			7.60	7.75	7.68	7.65	7.55			7.78	7.85	8.00	7.62	7.50
Suspended solids, mg/l																
Raw wastewater	64	43			72	85	87	62	59			94	86	103	97	68
Primary influent	426	168			334	182	214	232	109			118	198	362	278	182
Primary effluent	45	47			37	63	44	48	51			53	61	64	136	57
Denit influent	84	46			2.0	42	42	6.5	56			50	38	55	53	39
Denit effluent - 2	54	3.0			22	7.5	8.0	5.0	37			35	25	22	9.0	12.
Plant effluent	6.0	2.5			2.0	2.0	3.0	7.5	1.2			3.5	6.0	4.0	2.5	8.0
Phosphorus, mg/l P																
Total																
Raw wastewater		13.0			6.3	11.4	11.5	14.0	11.3			13.5	16.2	7.6	11.5	18.1
Primary influent		9.0			10.5	18.5	14.5	15.0	8.8			13.5	14.5	11.5	12.5	12.8
Primary effluent		10.0			3.5	6.7	5.8	5.2	7.2			5.7	7.0	4.6	4.6	5.8
Plant effluent		1.0			3.1	2.8	2.3	1.0	1.7			2.6	2.5	1.2	1.6	1.7
Filterable																
Raw wastewater		12.3			5.8	10.0	10.5	12.5	9.6			13.2	14.6	6.7	11.0	17.4
Primary influent		4.5			2.5	7.6	5.0	3.7	4.5			3.5	5.5	1.3	3.0	5.1
Primary effluent		2.8			1.0	4.3	3.6	2.6	3.6			4.0	3.5	1.3	1.6	3.3
Plant effluent		1.0			3.0	2.7	2.3	0.8	1.5			2.5	2.1	1.2	1.3	1.3
Nitrogen, mg/l N																
Ammonium nitrogen																
Raw wastewater	16.2	3.9			21.6	16.9	20.0	3.9	4.6			16.9	22.3	13.7	15.4	20.8
Primary influent	18.5	3.1			20.0	16.9	13.7	6.9	8.5			17.7				
Primary effluent	16.9	6.2			14.6	15.4	13.1	10.8	10.8			14.6	11.6	13.7	13.7	17.7
Denit influent	0.9	1.2			1.1	1.2	1.2	1.4	1.6			1.6	1.1	0.7	0.7	0.7
Denit effluent - 2	0.8	1.1			1.4	1.5	1.6	2.0	1.9			1.9	0.9	1.2	0.8	0.9
Plant effluent	0.9	0.9			0.7	0.8	0.9	1.2	1.6			0.9	0.4	0.4	0.3	0.4

Total Kjeldahl nitrogen																
Raw wastewater	30.8	27.7			32.3	34.7	25.4	23.9	28.5			34.7	40.0	27.7	31.6	32.3
Primary influent	38.5	27.7			37.7	33.8	31.6	28.5	29.2			46.2				
Primary effluent	35.4	28.5			23.9	26.2	25.4	26.2	25.4			31.6	23.9	24.6	24.6	25.4
Denit influent	3.6	3.4				2.8	2.3	2.6	2.4			3.8	2.2	3.0	2.8	1.5
Denit effluent - 2	3.4	2.3			3.1	2.7	2.7	3.2	3.2			4.2	2.6	2.2	2.0	2.3
Plant effluent	1.5	2.0			1.5	1.9	1.5	2.2	2.3			2.4	1.1	1.2	1.1	1.5
Nitrate nitrogen																
Denit influent	10.6	8.9			11.9	13.2	10.6	10.6	18.0			12.6	14.7	12.1	13.3	13.8
Denit effluent - 2	2.2	1.5			0.4	0.4	0.4	2.0	0.7			0.1	0.1	0.7	0.2	0.4
Plant effluent	0.1	1.2			0.0	0.1	0.1	1.3	1.0			0.0	0.0	0.1	0.0	0.1
COD, mg/l																
Raw wastewater	178	190			184	261	296	217	183			307	261	269	269	321
Primary influent	352	253			332	376	365	334	186			396				
Primary effluent	158	329			150	157	188	171	132			211	166	154	150	189
Denit influent	75	63			207	134	96	74	116			115	127	95	83	87
Denit effluent - 2	63	32			46	31	58	23	50			73	182	47	40	31
Plant effluent	55	24			31	38	42	27	47			38	40	63	36	39
BOD_5, mg/l																
Raw wastewater	88						260								230	
Primary influent	138						243									
Primary effluent	86						122									
Denit influent	27						57								28	
Denit effluent - 2	14						8.6								9.2	
Plant effluent	14						7.1								1.6	
Methanol doseage, mg/l	46	26	33	33	21	24	24	18	30	41	26	41	40	36	40	34

<u>OPERATIONAL DATA - EL LAGO AWTF</u> <u>SEPTEMBER 1974</u>

	DATE														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Rainfall, inches								0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plant flow, MG								0.2494	0.3236	0.2426	0.3200	0.2700	0.2930	0.2597	0.2604
Denit flow, MG								0.3469	0.4186	0.3237	0.3714	0.3458	0.3410	0.2958	0.3108
pH															
Primary influent								6.4		6.9		7.5			6.8
Primary effluent								6.4		6.9		7.3			6.9
Denit influent								7.0		7.4		7.7			7.6
Denit effluent - 1								7.2		7.7		7.9			7.7
Denit effluent - 2								7.2		7.7		8.0			7.8
Plant effluent								6.8		7.4		7.6			7.5
Suspended solids, mg/l															
Primary influent								201		276		285			312
Primary effluent								25		41		158			78
Denit influent								49		75		107			33
Denit effluent - 1								32		48		83			17
Denit effluent - 2								13		63		34			4
Plant effluent								<1		<1		7			<1
Phosphorus, mg/l P															
Total															
Primary influent								11		11		10			8.1
Primary effluent								1.3		2.1		2.5			3.8
Denit effluent - 2								1.9		2.7		3.3			1.0
Plant effluent								0.19		0.15		0.21			0.18
Filterable															
Primary influent								0.01		0.11		5.7			0.36
Primary effluent								0.01		0.06		0.82			0.81
Denit effluent - 2								0.01		0.08		0.13			0.26
Plant effluent								0.13		0.15		0.16			0.18
Nitrogen, mg/l N															
Ammonium nitrogen															
Primary effluent								17		15		18			18
Denit influent								0.3		0.2		0.4			0.8
Denit effluent - 2								0.4		0.2		0.5			0.5
Plant effluent								0.1		0.1		0.4			0.5

Total Kjeldahl nitrogen								
Primary effluent	22		20		26			27
Denit influent	0.9		1.9		1.7			2.0
Denit effluent - 2	1.2		1.6		1.1			1.2
Plant effluent	0.6		0.8		1.0			1.1
Nitrate nitrogen								
Denit influent	15		16		16			16
Denit effluent - 1	2.7		3.2		3.0			3.2
Denit effluent - 2	0.2		3.8		0.4			0.3
Plant effluent	2.2		0.1		2.1			1.7
COD, mg/l								
Denit influent	94		88		125			100
Denit effluent - 1	35		46		66			32
Denit effluent - 2	23		42		28			16
Plant effluent	12		13		15			16
BOD_5, mg/l								
Plant effluent	3.0		<1.0		3.0			<1.0
Methanol doseage, mg/l	41	41	41	41	41	42	41	40
Ferric iron doseage, mg/l	79	57	58	60	61	57	59	62
Polymer doseage, mg/l	0.41	0.32	0.35	0.33	0.35	0.36	0.32	0.49

OPERATIONAL DATA - EL LAGO AWTF OCTOBER 1974

	DATE														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rainfall, inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55
Plant flow, MG	0.2687	0.2274	0.2242	0.2352	0.2209	0.2420	0.2615	0.2403	0.2213	0.2015	0.2213	0.2458	0.2565	0.2702	0.2977
Denit flow, MG	0.2927	0.2874	0.2842	0.3072	0.2929	0.3380	0.3455	0.2802	0.2453	0.2255	0.2693	0.2938	0.2685	0.2944	0.3217
pH															
Primary influent		7.2		7.2			7.2		7.2		7.3			7.3	
Primary effluent		7.2		7.2			7.2		7.2		7.3			7.3	
Denit influent		7.7		7.7			7.6		7.8		7.7			8.0	
Denit effluent - 1		7.9		7.8			7.9		8.0		8.0			8.1	
Denit effluent - 2		8.0		7.8			7.9		7.9		8.0			8.2	
Plant effluent		7.6		7.4			7.6		7.5		7.5			7.7	
Suspended solids															
Primary influent		682		326			258		304		232			190	
Primary effluent		50		50			57		49		61			47	
Denit influent		62		91			104		126		45			26	
Denit effluent - 1		34		73			72		81		25			8	
Denit effluent - 2		18		57			44		52		85			1	
Plant effluent		1		<1			1		<1		4			<1	
Phosphorus, mg/l P															
Total															
Primary influent		13		11			11		13		11			9.9	
Primary effluent		2.7		3.0			4.1		3.0		3.3			2.8	
Denit effluent - 2		2.3		2.9			3.5		4.5		1.7			1.6	
Plant effluent		0.21		0.20			0.28		0.33		0.29			0.34	
Filterable															
Primary influent		1.6		0.49			1.3		1.0		0.98			0.89	
Primary effluent		0.38		0.61			1.2		0.60		0.86			0.82	
Denit effluent - 2		0.20		0.19			0.23		0.27		0.24			0.38	
Plant effluent		0.20		0.20			0.26		0.30		0.27			0.33	
Nitrogen, mg/l N															
Ammonium nitrogen															
Primary effluent		19		18			18		19		16			19	
Denit influent		0.3		0.2			0.5		0.8		0.3			0.3	
Denit effluent - 2		0.6		0.4			0.4		0.6		0.6			0.4	
Plant effluent		0.5		0.3			0.3		0.2		0.3			0.4	

Total Kjeldahl nitrogen															
Primary effluent		27		25			27		26		22			21	
Denit influent		2.6		2.4			3.1		3.6		2.2			1.7	
Denit effluent - 2		1.3		1.9			1.9		1.8		1.6			0.9	
Plant effluent		1.3		0.7			0.7		1.0		1.1			0.8	
Nitrate nitrogen															
Denit influent		16		15			16		14		15			14	
Denit effluent - 1		1.5		5.2			1.4		0.8		1.4			1.2	
Denit effluent - 2		1.2		2.7			0.2		0.1		0.5			1.1	
Plant effluent		2.0		1.1			0.7		0.1		0.4			0.7	
COD, mg/l															
Denit influent		96		140			130		109		94			110	
Denit effluent - 1		35		53			48		51		27			25	
Denit effluent - 2		30		37			34		39		27			22	
Plant effluent		18		14			20		16		16			22	
BOD_5, mg/l															
Denit influent				83			78		38		46				
Denit effluent - 1				27			16		12		10				
Denit effluent - 2				20			10		10		10				
Plant effluent		1.4		3.0			2.6		2.9		2.7			<1.0	
Methanol doseage, mg/l	39	38	39	38	41	41	40	40	37	47	37	39	40	41	41
Ferric iron doseage, mg/l	51	45	50	43	52	40	41	36	46	48	56	20	53	33	41
Polymer doseage, mg/l	0.52	0.53	0.59	0.51	0.53	0.46	0.45	0.49	0.38	0.25	0.63	0.49	0.49	0.31	0.26

OPERATIONAL DATA - EL LAGO AWTF OCTOBER 1974

	DATE															
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Rainfall, inches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.45	0.00	0.00
Plant flow, MG	0.2430	0.2369	0.2466	0.2403	0.2406	0.2437	0.2172	0.2462	0.2305	0.2992	0.2401	0.2441	0.3043	0.3860	0.2653	0.2455
Denit flow, MG	0.2910	0.2969	0.2826	0.3003	0.2888	0.0835	0.2652	0.2702	0.2905	0.3592	0.2881	0.2801	0.1742	0.3078	0.3133	0.2935
pH																
Primary influent	7.2		7.2			7.5		7.4		7.4			7.5		7.4	
Primary effluent	7.1		7.2			7.3		7.4		7.4			7.4		7.4	
Denit influent	7.6		7.5			7.7		8.0		7.8			7.8		7.8	
Denit effluent - 1	7.7		7.7			7.7		8.1		8.0			7.9		8.0	
Denit effluent - 2	7.7		7.7			7.9		8.1		8.0			8.0		8.0	
Plant effluent	7.7		7.6			7.9		7.8		7.8			7.6		7.7	
Suspended solids																
Primary influent	226		230			334		216		266			294		276	
Primary effluent	49		42			54		43		54			51		51	
Denit influent	84		83			66		63		77			160		72	
Denit effluent - 1	94		54			38		44		33			73		38	
Denit effluent - 2	54		36			41		29		27			106		20	
Plant effluent	1		<1			1		<1		<1			1		<1	
Phosphorus, mg/l P																
Total																
Primary influent	12		12			16		12		13			13		11	
Primary effluent	3.8		4.5			3.6		4.2		3.7			4.0		4.3	
Denit effluent - 2	3.2		3.7			2.9		3.6		3.3			3.2		3.6	
Plant effluent	0.25		0.33			0.58		0.77		0.49			0.69		0.58	
Filterable																
Primary influent	2.2		1.4			3.8		2.7		2.2			2.5		2.8	
Primary effluent	0.61		0.60			1.2		2.2		0.98			1.6		1.7	
Denit effluent - 2	0.31		0.31			0.56		0.90		0.52			0.71		0.53	
Plant effluent	0.25		0.33			0.55		0.74		0.49			0.69		0.56	
Nitrogen, mg/l N																
Ammonium nitrogen																
Primary effluent	18		18			15		20		18			18		17	
Denit influent	0.5		0.6			0.4		0.6		0.2			0.6		0.5	
Denit effluent - 2	0.3		0.2			0.4		0.2		0.2			0.7		0.4	
Plant effluent	0.3		0.4			0.4		0.4		<0.1			0.3		0.2	

Total Kjeldahl nitrogen																
Primary effluent	23		25			20		24		24			26		21	
Denit influent	2.5		3.9			2.0		2.2		2.0			3.4		2.8	
Denit effluent - 2	1.7		1.0			1.8		0.6		2.2					1.0	
Plant effluent	1.2		0.8			1.3		0.5		0.6					0.8	
Nitrate nitrogen																
Denit influent	15		14			11		14		16			15		14	
Denit effluent - 1	2.5		2.7			0.7		1.6		2.0			2.8		0.6	
Denit effluent - 2	1.6		0.5					0.2		1.6					0.6	
Plant effluent	0.5		0.1					< 0.1		1.0					< 0.1	
COD, mg/l																
Denit influent	130		140			79		100		120			110		110	
Denit effluent - 1	67		47			48		40		33			55		37	
Denit effluent - 2	44		35			32		28		33			82		27	
Plant effluent	30		16			20		16		14			24		23	
BOD_5, mg/l																
Denit influent										69					60	
Denit effluent - 1										17					12	
Denit effluent - 2										15					7	
Plant effluent	1.2		3.4			2.8		2.3		3.3			< 1.0		6.0	
Methanol doseage, mg/l	41	40	41	39	42	36	43	41	41	40	40	41	43	41	42	41
Ferric iron doseage, mg/l	34	34	30	31	32	31	32	28	30	32	28	38	30	28	37	31
Polymer doseage, mg/l	0.39	0.32	0.34	0.37	0.42	0.32	0.28	0.19	0.34	0.36	0.37	0.41	0.36	0.31	0.39	0.56

OPERATIONAL DATA - EL LAGO AWTF NOVEMBER 1974

	DATE														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rainfall, inches	0.23	0.38	0.00	0.03	0.16	0.00	0.03	0.18							
Plant flow, MG	0.3275	0.4380	0.3292	0.3876	0.3791	0.3078	0.2820	0.3205							
Denit flow, MG	0.2625	0.3019	0.3292	0.3279	0.3339	0.2510	0.2518	0.3205							
pH															
Primary influent	7.4			7.4		7.5									
Primary effluent	7.3			7.3		7.4									
Denit influent	7.8			7.9		7.9									
Denit effluent - 1	7.9			8.0		7.9									
Denit effluent - 2	7.9			8.0		7.9									
Plant effluent	7.7			7.6		7.6		7.7							
Suspended solids, mg/l															
Primary influent	264			200		212									
Primary effluent	49			41		64									
Denit influent	84			77		83									
Denit effluent - 1	55			48		45									
Denit effluent - 2	19			94		21									
Plant effluent	1			<1		1		<1							
Phosphorus, mg/l P															
Total															
Primary influent	15			12		14									
Primary effluent	3.6			4.2		4.3									
Denit effluent - 2	4.0			3.9		3.9									
Plant effluent	0.60			0.65		0.54		0.41							
Filterable															
Primary influent	5.4			2.9		4.0									
Primary effluent	1.1			1.8		1.6									
Denit effluent - 2	0.59			0.66		0.74									
Plant effluent	0.59			0.64		0.53		0.38							
Nitrogen, mg/l N															
Ammonium nitrogen															
Primary effluent	20			17		20									
Denit influent	0.5			0.3		0.7									
Denit effluent - 2	0.4			0.4		0.6									
Plant effluent	0.3			0.5		0.4		0.6							

Total Kjeldahl nitrogen								
Primary effluent	23			22		26		
Denit influent	2.8			3.4		3.9		
Denit effluent - 2	1.2			3.4		2.0		
Plant effluent	1.0			0.9		1.1		1.5
Nitrate nitrogen								
Denit influent	14			12		12		
Denit effluent - 1	4.2			1.4		0.5		
Denit effluent - 2	3.3			0.6		1.1		
Plant effluent	1.6			<0.1		0.6		2.0
COD, mg/l								
Denit influent	120			96		100		
Denit effluent - 1	44			34		33		
Denit effluent - 2	30			54		25		
Plant effluent	24			12		10		16
BOD_5, mg/l								
Denit influent				48				
Denit effluent - 1				13				
Denit effluent - 2				14				
Plant effluent	3.3			8.3		1.6		7.0
Methanol doseage, mg/l	42	35	40	41	38	39	40	38
Ferric iron doseage, mg/l	33	23	33	28	26	39	35	36
Polymer doseage, mg/l	0.34	0.28	0.24	0.26	0.26	0.31	0.40	0.32

OPERATIONAL DATA - EL LAGO AWTF   NOVEMBER 1974

	DATE														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Rainfall, inches	1.01	0.25	0.01	0.03	0.11	0.00	0.00	0.00	1.43	0.24	0.00	0.00	0.00	0.00	0.03
Plant flow, MG	0.2974	0.6870	0.4206	0.3376	0.3427	0.2898	0.2776	0.2908	0.3201	0.8351	0.4855	0.3611	0.3263	0.3171	0.2763
Denit flow, MG	0.3574	0.5552	0.4806	0.4536	0.3907	0.3138	0.3016	0.3148	0.3681	0.0374	0.3536	0.4451	0.3983	0.3771	0.3483
pH															
Primary influent			7.4		7.3		7.5					7.5			
Primary effluent			7.3		7.3		7.4					7.4			
Denit influent			7.6		7.7		7.8					7.7			
Denit effluent - 1			7.6		7.7		7.8					7.7			
Denit effluent - 2			7.5		7.7		7.9					7.7			
Plant effluent			7.3		7.4		7.6					7.6			
Suspended solids, mg/l															
Primary influent			236		196		152					270			
Primary effluent			69		51		54					70			
Denit influent			37		31		29					35			
Denit effluent - 1			31		20		21					28			
Denit effluent - 2			14		5		9					12			
Plant effluent			3		6		<1					<1			
Phosphorus, mg/l P															
Total															
Primary influent			9.0		11		12					11			
Primary effluent			2.6		4.1		4.5					4.9			
Denit effluent - 2			1.8		1.7		1.7					1.8			
Plant effluent			0.28		0.46		0.54					0.54			
Filterable															
Primary influent			2.2		1.9		4.1					2.9			
Primary effluent			0.96		1.5		1.6					1.6			
Denit effluent - 2			0.27		0.41		0.45					0.30			
Plant effluent			0.25		0.42		0.42					0.41			
Nitrogen, mg/l N															
Ammonium nitrogen															
Primary effluent			10		16		21					14			
Denit influent			0.3		0.5		0.8					1.0			
Denit effluent - 2			0.3		0.6		0.4					0.8			
Plant effluent			0.5		0.4		0.3					0.5			

Total Kjeldahl nitrogen															
Primary effluent			15		19		27					18			
Denit influent			2.8		3.6		1.7					3.4			
Denit effluent - 2			1.0		1.3		1.4					2.0			
Plant effluent			0.9		1.0		0.8					1.2			
Nitrate nitrogen															
Denit influent			9.0		9.7		14					8.2			
Denit effluent - 1			7.9		5.3		5.7					4.5			
Denit effluent - 2			4.1		1.1		0.9					2.1			
Plant effluent			5.4		2.6		<0.1					2.2			
COD, mg/l															
Denit influent			62		57		81					71			
Denit effluent - 1			43		34		53					63			
Denit effluent - 2			23		23		24					48			
Plant effluent			15		19		24					40			
BOD_5, mg/l															
Denit influent			38				39					41			
Denit effluent - 1			20				22					38			
Denit effluent - 2			12				5.3					24			
Plant effluent			5.8		4.5		2.4					10			
Methanol doseage, mg/l	20	21	21	22	23	37	38	29	42	45	44	27	34	33	34
Ferric iron doseage, mg/l*	40	14	25	28	26	43	30	30	30	30	30	30	30	30	30
Polymer doseage, mg/l	0.47	0.17	0.23	0.32	0.38	0.44	0.36	0.39	0.31	0.18	0.17	0.42	0.44	0.42	0.39

*** Average ferric iron doseage is shown for each of the days from 11-22-74 through 11-30-74.**

OPERATIONAL DATA - EL LAGO AWTF DECEMBER 1974

DATE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Rainfall, inches	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.96	0.00	0.00	0.01	0.62	0.00
Plant flow, MG	0.2758	0.2809	0.2676	0.2478	0.2617	0.2791	0.2740	0.2898	0.2905	0.2973	0.4860	0.5989	0.4180	0.3746	0.5010	0.4845
Denit flow, MG	0.3478	0.3649	0.3516	0.3318	0.3217	0.3151	0.2980	0.3018	0.3265	0.3213	0.4484	0.3117	0.4216	0.3770	0.4626	0.4690
pH																
Primary influent		7.7		8.0		7.4			7.4		7.3		7.3			7.4
Primary effluent		7.3		7.8		7.3			7.3		7.4		7.3			7.3
Denit influent		7.9		7.9		7.9			7.9		7.8		7.6			7.5
Denit effluent - 1		7.7		7.8		7.8			7.8		7.7		7.6			7.6
Denit effluent - 2		7.8		7.8		7.8			7.8		7.7		7.7			7.6
Plant effluent		7.4		7.5		7.4			7.4				7.3			7.4
Suspended solids, mg/l																
Primary influent		304		98		232			142		272		204			176
Primary effluent		58		67		61			58		59		71			88
Denit influent		43		48		29			22		33		23			63
Denit effluent - 1		27		31		15			7		16		18			91
Denit effluent - 2		12		15		2			5		7		9			57
Plant effluent		1		<1		<1			<1				2			<1
Phosphorus, mg/l P																
Total																
Primary influent		13		14					12		10		10			6.0
Primary effluent		4.9		10					5.5		4.1		4.8			3.9
Denit effluent - 2		2.4		4.4					2.9		2.7		1.6			3.3
Plant effluent		0.41		1.3					1.3				0.53			0.59
Filterable																
Primary influent		4.1		10					2.6		2.5		1.5			1.2
Primary effluent		2.0		6.5					2.6		0.71		1.0			0.84
Denit effluent - 2		0.41		1.5					1.5		0.91		0.36			0.33
Plant effluent		0.36		1.3					1.3				0.46			0.37
Nitrogen, mg/l N																
Ammonium nitrogen																
Primary effluent		20		21		20			17		18		11			3.4
Denit influent		1.4		1.7		0.5			0.5		0.4		0.3			0.3
Denit effluent - 2		1.9		0.5		0.4			0.3		<0.1		0.2			0.4
Plant effluent		1.7		0.2		0.4			0.2				0.3			0.2

Total Kjeldahl nitrogen																
Primary effluent		25		24		25			22		24		16			11
Denit influent		3.4		2.8		2.8			2.0		2.8		1.7			3.1
Denit effluent - 2		3.6		1.6		0.8			1.2		0.9		1.0			3.4
Plant effluent		2.8		1.2		0.5			1.4				0.6			0.6
Nitrate nitrogen																
Denit influent		12		11		13			15		11		10			6.7
Denit effluent - 1		6.6		8.1		4.7			8.8		3.9		3.5			2.1
Denit effluent - 2		3.7		7.0		1.6			5.5		1.3		0.6			0.6
Plant effluent		3.6		7.0		3.4			5.3				0.6			0.2
COD, mg/l																
Denit influent		43		55		84			63		87		63			97
Denit effluent - 1		28		31		42			28		38		55			97
Denit effluent - 2		16		31		30			20		24		39			70
Plant effluent		8		23		26			26				31			39
BOD_5, mg/l																
Denit influent				16		42			32		35					
Denit effluent - 1				14		20			8.5		17					
Denit effluent - 2				12		8.8			2.7		9.5					
Plant effluent		1.3		1.8		2.8			1.4				2.9			11
Methanol doseage, mg/l	32	33	35	38	39	49	38	38	38	38	43	45	44	44	44	40
Ferric iron doseage, mg/l*	30	30	30	30	30	30	28	31	31	31	23	17	14	14	14	14
Polymer doseage, mg/l	0.50	0.50	0.45	0.40	0.33	0.45	0.45	0.49	0.38	0.20	0.28	0.29	0.32	0.34	0.37	0.36

*Ferric iron doseages for periods 12-1-74 through 12-6-74, 12-8-74 through 12-10-74, and 12-13-74 through 12-16-74 are averages over the respective periods.

OPERATIONAL DATA - EL LAGO AWTP JANUARY 1975

	DATE														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rainfall, inches					0.00	0.00	0.00	0.52	0.00	0.56	0.00	0.27	0.00	0.00	0.00
Plant flow, MG					0.5364	0.5448	0.3683	0.5604	0.4459	0.5200	0.6958	0.5094	0.4623	0.4001	0.3469
Denit flow, MG					0.5019	0.4993	0.4643	0.3481	0.4478	0.5175	0.2185	0.1944	0.2150	0.1595	0.3772
pH															
Primary influent						7.3		7.1		7.1			7.5		7.4
Primary effluent						7.2		7.1		7.3			7.5		7.3
Denit influent						7.7		7.6		7.7			7.8		7.8
Denit effluent - 1						7.7		7.6		7.6			7.9		7.8
Denit effluent - 2						7.7		7.7		7.7			7.9		7.8
Plant effluent						7.4		7.4		7.5			7.5		7.6
Suspended solids, mg/l															
Primary influent						228		170		426			146		188
Primary effluent						50		134		89			62		67
Denit influent						64		65		26			45		30
Denit effluent - 1						70		34		28			15		22
Denit effluent - 2						79		10		22			8		12
Plant effluent						<1		1		<1			2		1
Phosphorus, mg/l P															
Total															
Primary influent						9.9				10			5.9		11
Primary effluent						3.4									
Denit effluent - 2						3.9									
Plant effluent						0.52				1.2			0.78		0.76
Filterable															
Primary influent						1.1				0.84			2.0		0.41
Primary effluent						0.70									
Denit effluent						0.44									
Plant effluent						0.42				0.91			0.63		0.57
Nitrogen, mg/l N															
Ammonium nitrogen															
Primary effluent						11				13			10		16
Denit influent						0.5				0.4			0.6		0.5
Denit effluent - 2						0.3				0.1			0.5		0.3
Plant effluent						0.5				0.5			0.7		0.2

Total Kjeldahl nitrogen											
Primary effluent		18				18			15		20
Denit influent		16				3.1			3.4		2.8
Denit effluent - 2		3.4				1.7			2.0		1.7
Plant effluent		0.9				2.2					1.1
Nitrate nitrogen											
Denit influent		12				11			9.7		13
Denit effluent - 1		8.1				7.2			5.1		7.7
Denit effluent - 2		7.2				3.8			1.0		3.0
Plant effluent		3.4				3.3					3.2
COD, mg/l											
Denit influent		110				96			150		70
Denit effluent - 1		110				56			75		83
Denit effluent - 2		99				56			44		47
Plant effluent		61				52			36		47
BOD_5, mg/l											
Denit influent		52							74		23
Denit effluent - 1		50							36		27
Denit effluent - 2		47							18		26
Plant effluent		29							7.2		21
Methanol doseage, mg/l	47	46	46	46	46	45	47	55	52	55	54
Ferric iron doseage, mg/l	14	14	14	14	14	14	19	19	19	19	19
Polymer doseage, mg/l	0.31	0.31	0.39	0.26	0.30	0.32	0.33	0.41	0.36	0.30	0.40

OPERATIONAL DATA - EL LAGO AWTF JANUARY 1975

DATE

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Rainfall, inches	0.00	0.00	0.18	0.07	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plant flow, MG	0.3052	0.3164	0.3695	0.4621	0.3624	0.3600	0.3208	0.2935	0.2667	0.2788	0.3113	0.3042	0.3197	0.2995	0.2725	0.3327
Denit flow, MG	0.3532	0.3524	0.4175	0.4512	0.4344	0.3293	0.3328	0.3175	0.2907	0.2908	0.3353	0.3522	0.3677	0.3235	0.2965	0.3447
pH																
Primary influent		7.3			7.4		7.3		7.4			7.4		7.4		7.5
Primary effluent		7.3			7.3		7.3		7.5			7.4		7.3		7.5
Denit influent		7.7			7.7		7.7		7.9			7.7		7.7		7.8
Denit effluent - 1		7.8			7.8		7.8		7.9			7.7		7.7		7.8
Denit effluent - 2		7.8			7.9		7.7		8.0			7.8		7.8		8.0
Plant effluent		7.6			7.6		7.7		7.9			7.5		7.2		7.5
Suspended solids, mg/l																
Primary influent		250			252		226									
Primary effluent		73			48		61									
Denit influent		33			23		17									
Denit effluent - 1		22			18		3									
Denit effluent - 2		11			8		2		<1			2		3		5
Plant effluent		3			2		<1		<1			<1		2		2
Phosphorus, mg/l P																
Total																
Primary influent		12			9.1		11		9.9			11		11		12
Primary effluent		5.4			2.8		4.3									
Denit effluent - 2		2.1			1.9		1.7									
Plant effluent		0.92			1.2		0.56		0.46			0.29		0.59		0.59
Filterable																
Primary influent		0.59			0.39		1.1		1.4			0.79		1.9		
Primary effluent		0.47			0.52		0.33									
Denit effluent - 2		0.58			0.58		0.40									
Plant effluent		0.61			0.53		0.43		0.41			0.27		0.51		
Nitrogen, mg/l N																
Ammonium nitrogen																
Primary effluent		16			16		19		18			19		20		18
Denit influent		0.4			0.9		0.5		1.4			1.2		0.7		1.1
Denit effluent - 2		0.4			0.6		0.4		0.8			1.2		0.4		
Plant effluent		0.2			0.2		0.5		0.3			0.5		0.6		0.6

Total Kjeldahl nitrogen																
Primary effluent		21			19		26		26			24		26		25
Denit influent		2.5			2.8		2.8		3.9			3.4		2.8		
Denit effluent - 2		2.0			2.2		1.7		2.8			2.8		2.2		
Plant effluent		1.0			1.4		1.5		1.7			2.8		2.2		2.2
Nitrate nitrogen																
Denit influent		15			14		18		16			15		14		16
Denit effluent - 1		8.8			7.3		6.1		6.4			4.7		4.6		4.1
Denit effluent - 2		3.2			1.0		1.2		0.4			0.2		0.4		0.2
Plant effluent		2.0			1.4		2.7		2.3			2.2		0.2		0.1
COD, mg/l																
Denit influent		140			120		115		110			78		100		90
Denit effluent - 1		73			88		48		47			39		39		31
Denit effluent - 2		37			60		20		27			16		23		12
Plant effluent		29			48		16		24			12		17		16
BOD_5, mg/l																
Denit influent		87			66		68		62			58		64		44
Denit effluent - 1		42			42		14		24			15		18		14
Denit effluent - 2		18			15		5.1		6.0			1.8		6.7		2.4
Plant effluent		16			14		3.8		3.2			2.2		5.4		2.5
Methanol doseage, mg/l	54	54	53	53	53	42	43	42	33	42	40	41	41	43	45	39
Ferric iron doseage, mg/l	31	31	31	31	31	27	31	31	30	57	47	43	32	38	37	32
Polymer doseage, mg/l	0.49	0.45	0.41	0.38	0.41	0.41	0.24	0.47	0.41	0.38	0.37	0.40	0.44	0.31	0.45	0.37

OPERATIONAL DATA - EL LAGO AWTF FEBRUARY 1975

	DATE														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rainfall, inches	0.45	0.00	0.02	0.30	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.93	0.00	0.00	
Plant flow, MG	0.5300	0.7895	0.5868	0.4141	0.4662	0.3538	0.3340	0.3161	0.3129	0.3099	0.3097	0.7225	0.4388	0.3591	
Denit flow, MG	0.4250	0.3288	0.3998	0.4501	0.5382	0.3784	0.3820	0.3401	0.3489	0.3339	0.3337	0.4283	0.3893	0.4161	
pH															
Primary influent			7.6		7.4		7.4			7.6		7.5		7.3	
Primary effluent														7.4	
Denit influent			7.7		7.6		7.6			7.6		8.0		7.8	
Denit effluent - 1			7.7		7.7		7.7			7.7		8.0		7.8	
Denit effluent - 2			7.8		7.7		7.7			7.8		8.0		7.9	
Plant effluent			7.3		7.4		7.3			7.1		7.6		7.6	
Suspended solids, mg/l															
Primary influent			208		170		286			180		378		404	
Primary effluent														68	
Denit influent			25		33		49			26		43		26	
Denit effluent - 1			14		15		57			8		21		8	
Denit effluent - 2			15		6		43			2		10		3	
Plant effluent			<1		3		5			1		3		<1	
Phosphorus, mg/l P															
Total															
Primary influent			11		6.8		10			9.5		9.4		10	
Plant effluent			0.40		0.39		0.31			0.52		0.78		0.46	
Nitrogen, mg/l N															
Ammonium nitrogen															
Primary effluent														13	
Denit influent			1.0		0.2		0.6			0.5		0.2		0.2	
Denit effluent - 2										0.4		0.3		0.4	
Plant effluent			1.1		0.2		0.3			0.5		0.3		0.5	
Total Kjeldahl nitrogen															
Primary effluent														18	
Denit influent			2.8		2.5		2.8			2.2		2.5		2.2	
Denit effluent - 2														1.7	
Plant effluent			2.0		1.7		1.7			1.7		1.7		2.0	

Nitrate nitrogen														
Denit influent			15		12		17			17		16		12
Denit effluent - 1			4.5		4.5		6.6			3.0		4.1		2.9
Denit effluent - 2			1.6		0.8		1.2			0.9		0.8		0.4
Plant effluent			3.7		0.4		1.6			0.8		0.3		0.2
COD, mg/l														
Denit influent			56		87		67			98		100		106
Denit effluent - 1			40		43		67			31		39		59
Denit effluent - 2			28		24		61			23		27		47
Plant effluent			12		24		22			20		21		35
BOD_5, mg/l														
Denit influent			35		52		27			66		58		44
Denit effluent - 1			24		15		20			13		20		18
Denit effluent - 2			14		10		9.6			3.0		4.5		14
Plant effluent			7.9		4.9		4.2			2.9		2.8		12
Methanol doseage, mg/l	41	40	40	35	38	40	38	39	39	38	38	43	44	49
Ferric iron doseage, mg/l	20	20	20	20	23	24	24	24	24	24	18	15	15	23
Polymer doseage, mg/l	0.24	0.21	0.22	0.31	0.23	0.30	0.22	0.31	0.31	0.32	0.31	0.22	0.34	0.30

APPENDIX B

CONVERSION FACTORS

English Unit	*Multiplier*	*Metric Unit*
cfm	0.028	cu m/min
cfs	1.7	cu m/min
cfs/acre	4.2	cu m/min/ha
cfs/sq mile	0.657	cu m/min/sq km
cu ft	0.028	cu m
cu ft	28.32	l
cu in.	16.39	cu cm
cu yd	0.75	cu m
cu yd/mile	0.475	cu m/km
cu yd/sq mile	0.29	cu m/sq km
°F	0.555 (°F − 32)	°C
fathom	1.8	m
ft	0.3048	m
ft-c	10.764	lumen/sq m
gal	0.003785	cu m
gal	3.785	l
gpd/sq ft	0.0408	cu m/day/sq m
gpm	0.0631	l/sec
gpm/sq ft	40.7	l/min/sq m
hp	0.7457	kw
in.	2.54	cm
lb	0.454	kg
lb/day/acre	11.2	kg/day/ha
lb/day/acre-ft	3.68	g/day/cu m
lb/1,000 cu ft	16.0	g/cu m
lb/acre/day	0.112	g/day/sq m
lb/day/cu ft	16	kg/day/cu m
lb/day/cu yd	0.6	kg/day/cu m
lb/day/cu yd	0.6	kg/day/cu m
lb/day/sq ft	4,880	g/day/sq m
lb/ft	1.51	km
lb/mil gal	0.12	g/cu m
mgd	3,785	cu m/day
mgd/acre	9,360	cu m/day/ha
mile	1.61	km
ppb	10^{-3}	mg/l
pcf	16.02	kg/cu m
psf	4.88	kg/sq m
psi	0.0703	kg/sq cm
sq ft	0.0929	sq m
sq ft/cu ft	3.29	sq m/cu m
sq in.	6.452	sq cm
sq miles	2.590	sq km

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-76-104	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Nutrient Control by Plant Modification at El Lago, Texas		5. REPORT DATE July 1976 (Issuing Date)
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) B. W. Ryan * and E. F. Barth **		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS *Harris County WCID No. 50 1122 Cedar Lane Seabrook, Texas 77586		10. PROGRAM ELEMENT NO. 1BC611
		11. CONTRACT/GRANT NO. (11010 GNM) S803099
12. SPONSORING AGENCY NAME AND ADDRESS **Municipal Environmental Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 9/15/70-8/15/75
		14. SPONSORING AGENCY CODE EPA-ORD

15. SUPPLEMENTARY NOTES
E. F. Barth, Project Officer
684-7641

16. ABSTRACT

A project was conducted to demonstrate the feasibility of modifying an existing small trickling filter plant to control nutrients in wastewater discharge. All existing facilities of the nominal 0.3 mgd plant were utilized in the advanced waste treatment design. The processes control phosphorus by metallic salt addition to the primary settler, carbonaceous oxygen demand by trickling filters, and nitrogenous oxygen demand by suspended growth second stage activated sludge. Nitrogen is removed via attached growth column denitrification, and tertiary solids removal is accomplished by granular media filtration. These processes are operated in series.

Process evaluation shows that an effluent with the following residual concentrations can be obtained at the design flow of 0.3 mgd.

Biochemical oxygen demand, 5 day	4 mg/l
Chemical oxygen demand	25 mg/l
Suspended solids	2 mg/l
Total phosphorus	1 mg/l
Total nitrogenous content	2 mg/l

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste water*, Activated sludge process, Nitrification*, Phosphorus*, Chemical removal (sewage treatment), Sludge digestion	Denitrification*, Clear Lake (Texas), Effluent standards, Tertiary treatment, Suspended solids, Chemical dosing system	13B

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