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Supplementary Aeration of Lagoons in Rigorous Climate Areas

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SUPPLEMENTARY AERATION OF LAGOONS IN RIGOROUS CLIMATE AREAS

by

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for the

ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

A field investigation, using a pilot scale unit, was carried out to determine the effects of supplementary aeration on Waste Stabilization Lagoon performance. The tests were conducted at Laramie, Wyoming during the winter and spring months. The climate can be considered rigorous and lagoon performance indicative of low temperatures and high altitudes.

Both complete mix and batch experiments were conducted. Air flow was constant, but loading rates, both hydraulic and process were changed from 160 lbs. five-day BOD/acre/day (0.725 lbs./1,000 ft ^{3}/day) to 900 lbs. five-day BOD/acre/day (4.08 lbs./1,000 ft ^{3}/day). Loading below about 8 lbs./1,000 ft ^{3}/day can be considered as supplementary aeration. The air supplied by the INKA system performed the two functions of mixing and aerating the sewage.

The BOD reduction varied from 72% to 85% under three different loadings. The temperature of the aerated sewage was below 12°C. Solids removal was significant. No settleable solids resulted from the system, indicating no bioflocculation. The change in total bacterial counts were roughly proportioned to the change in loading.

Tests on a second cell, functioning as a batch process, indicated increase of oxygen levels to saturation values. Significant algae production also occurred at temperatures of 6°C. Coliform bacteria were reducted to about 10 per ml in the second cell. Total bacteria counts remained about the same as indicated in first cell tests.

This report was submitted in fulfillment of Project No. 17050 DVO, under the partial sponsorship of the Environmental Protection Agency.

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FIGURES

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SECTION I

CONCLUSIONS

1. Modification of existing lagoon systems can be accomplished in order to exert more positive control.
2. Supplementary aeration loading indicated high efficiencies of BOD removal even at low temperatures.
3. Aeration provided both mixing and oxygen in order to increase metabolism rates.
4. No settleable solids were found in the effluent from the aerated system.
5. Series operation will dampen variations in quality parameters, provide for shock loading and reduce coliform count to minimum levels.
6. Loading below 320 lbs./Acre/Day and secondary cell operation produced significant algal growth even at temperatures around 6^{o}C.
7. Short detention periods take advantage of the warmer influent temperatures in order to satisfy easily oxidized organic material.

SECTION II

RECOMMENDATIONS

Algae production seems to occur in many environs of treatment and after-growth. More research should be extended into removal methods and growth factors.

Present aeration equipment is designed to both mix and aerate the sewage. In order to perform both functions neither is maximized. Separation of functions and maximizing of separate efficiencies needs development.

A standarized test procedure or test location, preferably under severe conditions, for evaluation of aeration equipment is needed.

SECTION III

INTRODUCTION

One of the most popular sewage treatment units in the western and midwestern United States is the sewage lagoon. The number of these units increased from about 1,400 in 1960 to 3,500 in 1968 (1). There are several reasons why the lagoon is a popular treatment unit, especially with the smaller communities. First, the capital expense for construction is very low compared with other forms of treatment. It does require, however, a large land area near the community. Second, little supervision of the process is required. Daily inspection checks generally include water levels, lagoon color, odor, weed control, and hydraulic units. Third, supervisory personnel require little training. There is a critical lack of trained sewage treatment operators, especially in small communities. Because of this shortage of trained operators, state and city officials have promoted use of a treatment system requiring little technical knowledge - the sewage lagoon.

There are several overlapping classification systems for lagoons. A flow-through Waste Stabilization Lagoon, classified as a lagoon that treats raw sewage (2), was used for comparison purposes in this project. A Waste Stabilization Lagoon can operate in three different or combined ways. This is illustrated in Figure 1.

Under the best operating conditions (sufficient oxygen = aerobic, Figure 1a), a quasi-steady state symbiotic condition exists between heterotrophs and autotrophs. It is not a true steady state condition because at night or during reduced sunlight periods the autotrophs (algae) are reduced to a heterotrophic cycle increasing the demand for oxygen. In fact an excess of oxygen must be gained during the afternoon in order that the increased oxygen demand of the night can be met. If sufficient oxygen is not present the system approaches anaerobic conditions in the early morning hours. With this condition it is possible that a reduction in autotrophic activity will occur during the daylight hours and recovery to full aerobic conditions during daylight hours will be retarded.

Under the least acceptable conditions (no oxygen = anaerobic, Figure 1c), there is insufficient physical or autotrophic activity to maintain or satisfy the oxygen demand. Under these conditions obnoxious odors are given off, a poor effluent is produced, and public reaction is rapid.

Under conditions of varying load or varying sunlight an intermediate state (variable oxygen = facultative - Figure 1b) can exist. This condition can produce biochemical reactions of both an aerobic and anaerobic nature.

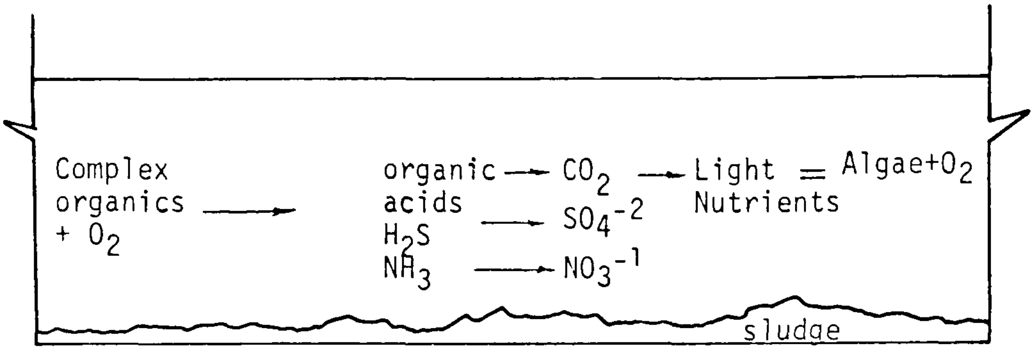


Figure 1a Aerobic Lagoon

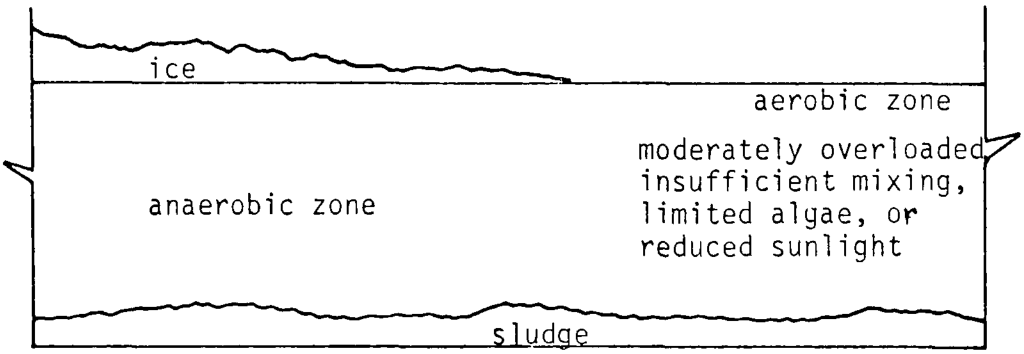


Figure 1b Facultative Lagoon

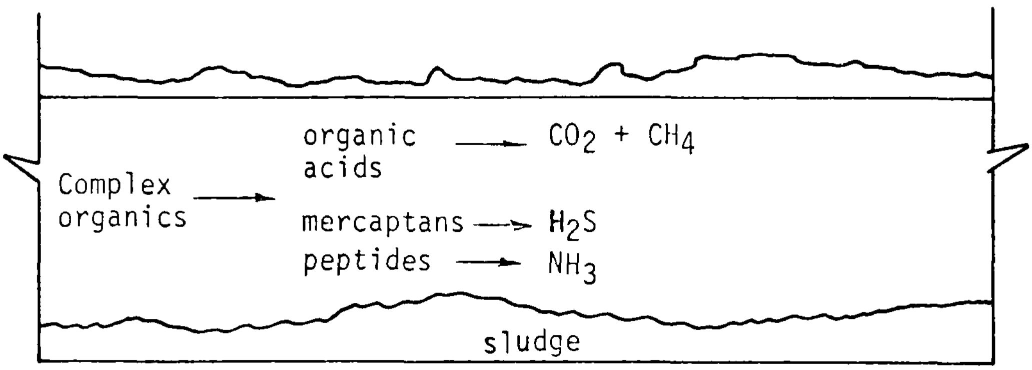


Figure 1c Anaerobic Lagoon

Figure 1 Waste Stabilization Lagoon - Reactions

At the present time design loading criteria for flow-through Waste Stabilization Lagoons varies from 50 lbs. of five-day BOD per acre in the southern states to about 15 lbs. of five-day BOD per acre in the northern states. This reduced loading is used in order to minimize problems of odor due to anaerobic conditions. This minimizing generally results in about one to three weeks of odor after ice break-up in the spring. In the past, public reaction to this odor was unsatisfactory but not sufficient to finance a better treatment system.

This public apathy has changed. Now there is public demand for water quality in our streams and lakes, a push by hundreds of groups for better sewage treatment and a realization among ourselves as design engineers that better positive-control treatment systems are necessary.

If we consider all indices of water quality, in addition to odor, there are some decided drawbacks to lagoon-type treatment. First, under the best operating conditions (balance of heterotrophs and autotrophs), few Waste Stabilization Lagoons (except holding ponds = percolation and evaporation) remove the algal biomass from the effluent. This biomass is approximately equivalent to the influent organic mass. The algal biomass is a more stable organic form and records a lower five-day BOD value but ultimately an equal or greater total demand for oxygen is recorded. This demand occurs at a slower rate and over a long stretch of the river, but it does occur. In effect a rapid demand waste has not been treated - we simply changed it to a slower demand waste and passed it on down the river.

Many people test the BOD of the effluent after filtering out the algae and record this as the efficiency of the treatment. This is a delusion. There have been suggestions of using the algae as a treatment technique for removal of nutrients from the sewage (3). Algae, in effect, do remove the excess phosphate from sewage but at present no effective, economical algae removal method has been found.

Considering all the indices of quality, there is a decided pollution of the river downstream from the lagoon. The river is green, sludge banks form, decomposition occurs, poisoning of livestock can occur from some toxic algae forms, and a section of the river is lost for community aesthetic enjoyment.

Second, if the balanced aerobic system could be considered sufficient treatment, its state is indeed a fragile one. Its existence depends entirely on climatic and atmospheric conditions. This lack of positive control produces other conditions over the year, especially in the northern states, that are far from acceptable.

Testing and evaluation of a flow-through Waste Stabilization Lagoon were conducted at Laramie, Wyoming (Figure 2). These ponds operate in parallel and series as shown. The ponds were loaded at an average rate of 35 lbs. of five-day BOD per acre. These ponds have since been modified with addition of supplementary aeration equipment.

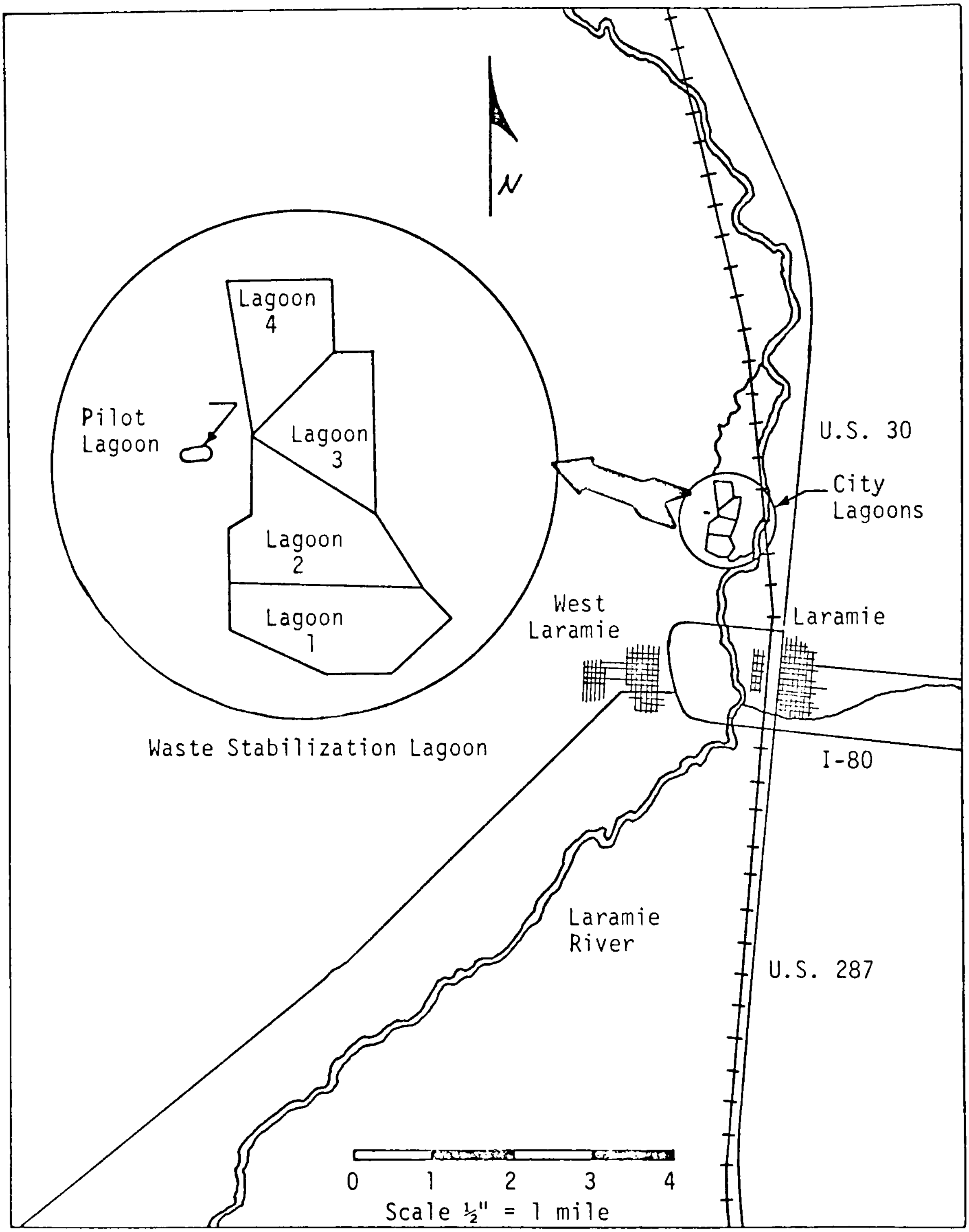


Figure 2 Location Map

In the Laramie area, a northern climate, lagoons become thickly covered with ice during the winter. Photosyntheses and reaeration are insufficient to maintain aerobic conditions (sufficient oxygen) and the slower anaerobic process becomes predominant (Figure 3). The colder temperatures during the period further reduce the microorganisms' activity. Since the loading rate is fairly constant during the year, the lagoon is overloaded in the winter. This results in the formation of a sludge blanket of only partially treated sewage deposited on the lagoon floor and only about 50% BOD removal efficiency in the effluent (Figure 4).

In the spring after the ice breaks up, the more active aerobic conditions prevail at the surface but the benthal deposits as well as the normal loading must be metabolized. Strong winds, lagoon overturn or obnoxious gas release can resuspend the benthal deposits causing an excess demand for oxygen and the lagoon will again turn anaerobic. This is reflected in the dissolved oxygen values during March on Figure 3. This phenomena can occur for several weeks until the oxygen production is greater or equal to the demand. In effect the summer period is used to treat part of the winter load. The lagoon changes from completely aerobic in late summer to completely anaerobic in winter with facultative processes in intermediate times.

Effluent variables from this type of Waste Stabilization Lagoon vary from color = bright green, five-day BOD = 40 ppm (80% efficiency), and saturated with oxygen in summer to color = brown, five-day BOD = 100 ppm (50% efficiency), and no oxygen in winter. The winter effluent carries an additional problem in the western states. During the winter, minimum stream flow occurs in our streams. This also is the period where the quality of lagoon effluent is the poorest. In some cases the entire stream flow consists of effluent from the lagoon. Significant degradation of the stream occurs with fish death, organic deposits on the river bed and the odor nuisance spread downstream.

In order to partially counteract the effects of ice cover and low temperature, to maintain aerobic conditions throughout the winter months, and to exert some positive control on the system, the technique of supplementary mechanical aeration was investigated. Although mechanical aeration devices of many kinds have been used as methods for supplying additional oxygen to overloaded treatment units, little research has been done on their efficiency in rigorous climates. The research presented here identifies several variables that affect performance of an aerated lagoon in a rigorous climate. The research was conducted on a pilot scale aerated lagoon located near Laramie, Wyoming, adjacent to the city sewage lagoon system (Figure 2).

Laramie, Wyoming, is a small college town (23,000 population) located in southeastern Wyoming at an elevation of 7,200 feet. Air temperatures range from -20°F to 90°F during the year. The high altitude and variable climate are ideal for pilot scale studies of biological treatment systems.

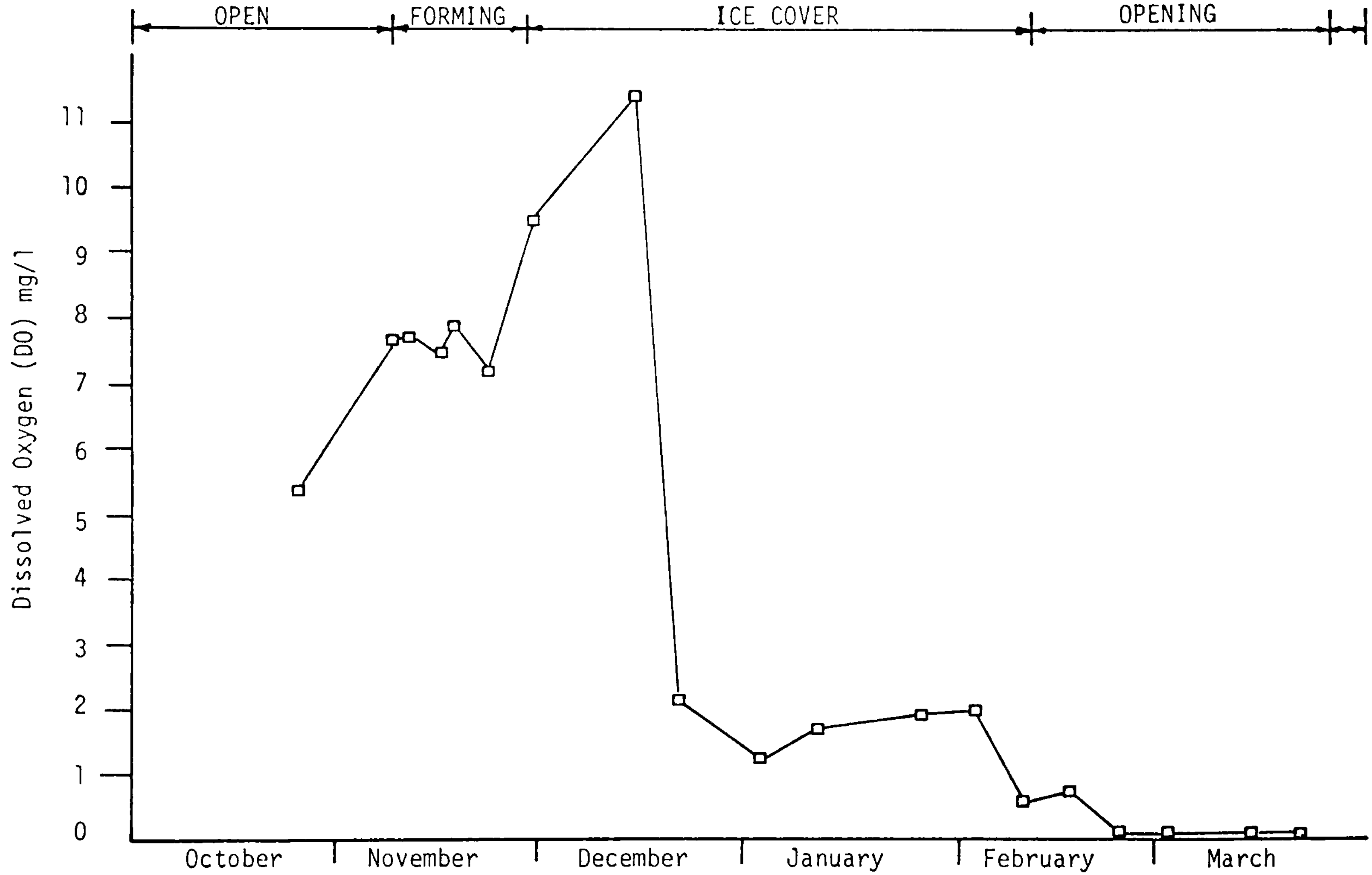


Figure 3 - Dissolved Oxygen in Laramie Lagoon's Effluent

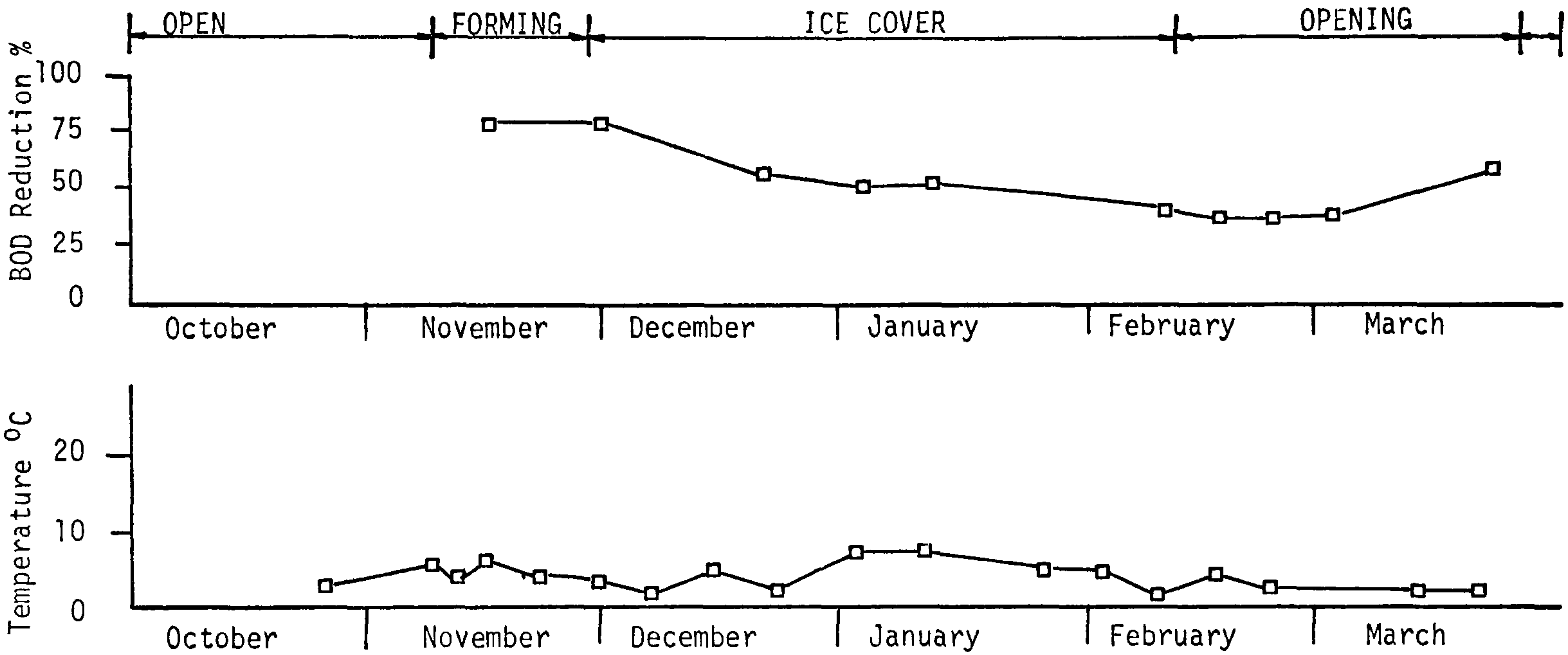


Figure 4 - BOD Reduction and Temperature in the Laramie Lagoon's Effluent

SECTION IV

THE PILOT AERATED LAGOON

This project was initiated to indicate possible modifications of present Waste Stabilization Lagoon design in order to improve treatment efficiency. This required incorporation of several operational features in the design of the pilot lagoon. First, the system must treat average raw sewage from the city collection system. Second, in order to vary loading rates over the supplementary aeration range and still secure a representative sample over the total time period, a variable timing device was required on the influent pump. Third, the severe icing condition required an aeration system which introduced the air under the ice and was not affected by the ice. Fourth, the unit must be large enough to reduce or eliminate possible scale-up effects.

Construction of the pilot lagoon began in June of 1968 and was substantially complete by the following October. The pilot unit was located adjacent to the City of Laramie's lagoon system (Figure 2). The pilot lagoon used in this study consists of four major components. They are the detention structure, the hydraulic system, the aeration system, and the baffle system.

The Detention Structure

The lagoon was formed by a rectangular, earth-fill dike with a berm of five feet, face slopes of three to one and backslopes of two to one. The bottom dimensions of the lagoon were 150 feet by 75 feet. The lagoon was designed to operate at a water level of about five feet. The aeration system required a depth of five feet for proper operation. A schematic diagram of the completed pilot lagoon is shown in Figure 5.

After construction of the dike, attempts were made to fill it with sewage. However, due to the high permeability of the earth fill and lagoon floor, seepage rates were unacceptably high. In order to seal the lagoon, a vinyl plastic membrane lining was used. This covered the bottom, sides and berm. No further seepage problems were encountered.

The Hydraulic System

The hydraulic system consists of influent piping, a centrifugal sewage pump, a discharge line to the lagoon through a measuring weir and outlet structure, an effluent weir and discharge piping (see Figure 6). An 18-inch city sewer line was used as a source of raw sewage. This 18-inch city sewer line conducts sewage to the city lagoon system. This line

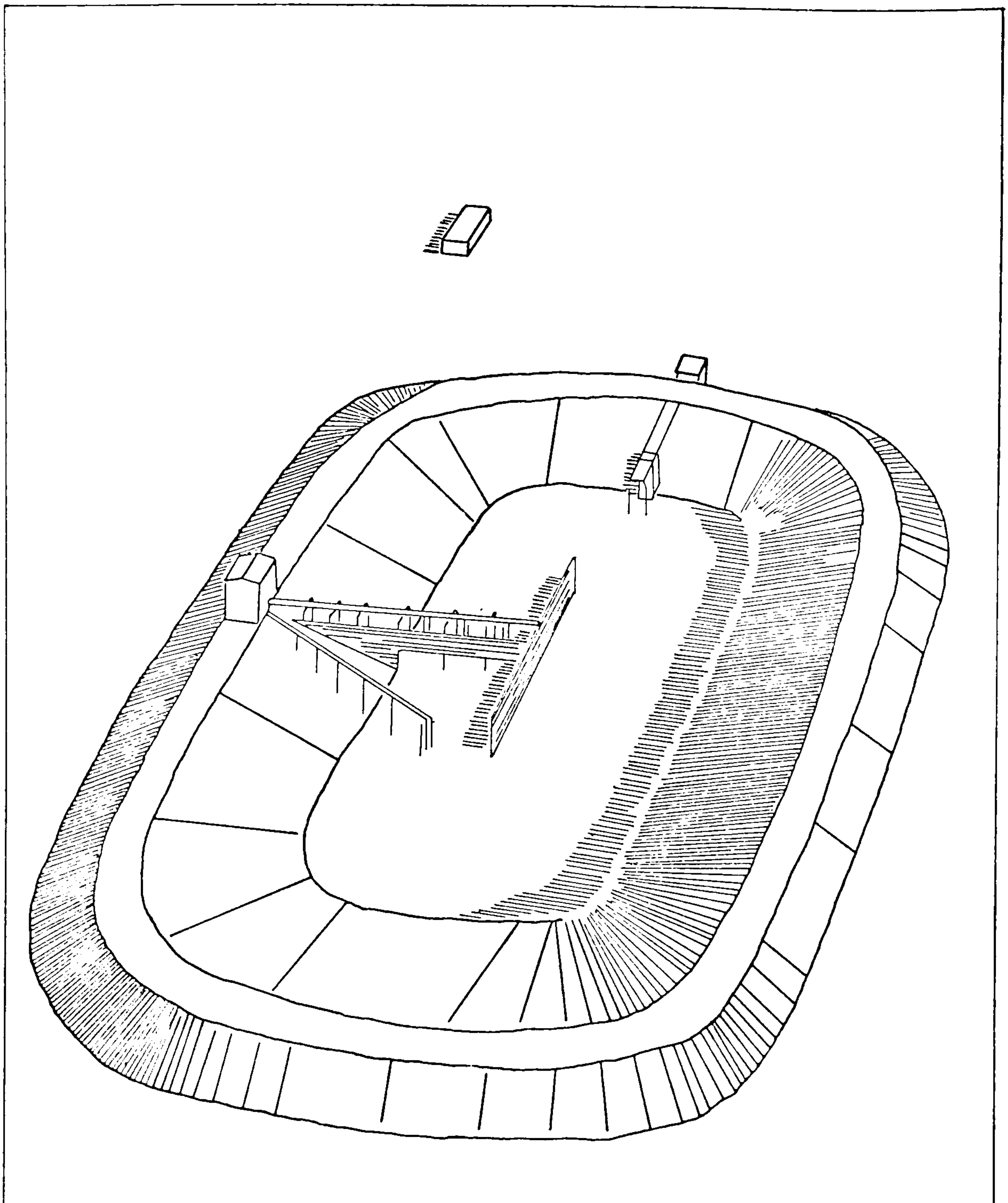


Figure 5 Detention Structure

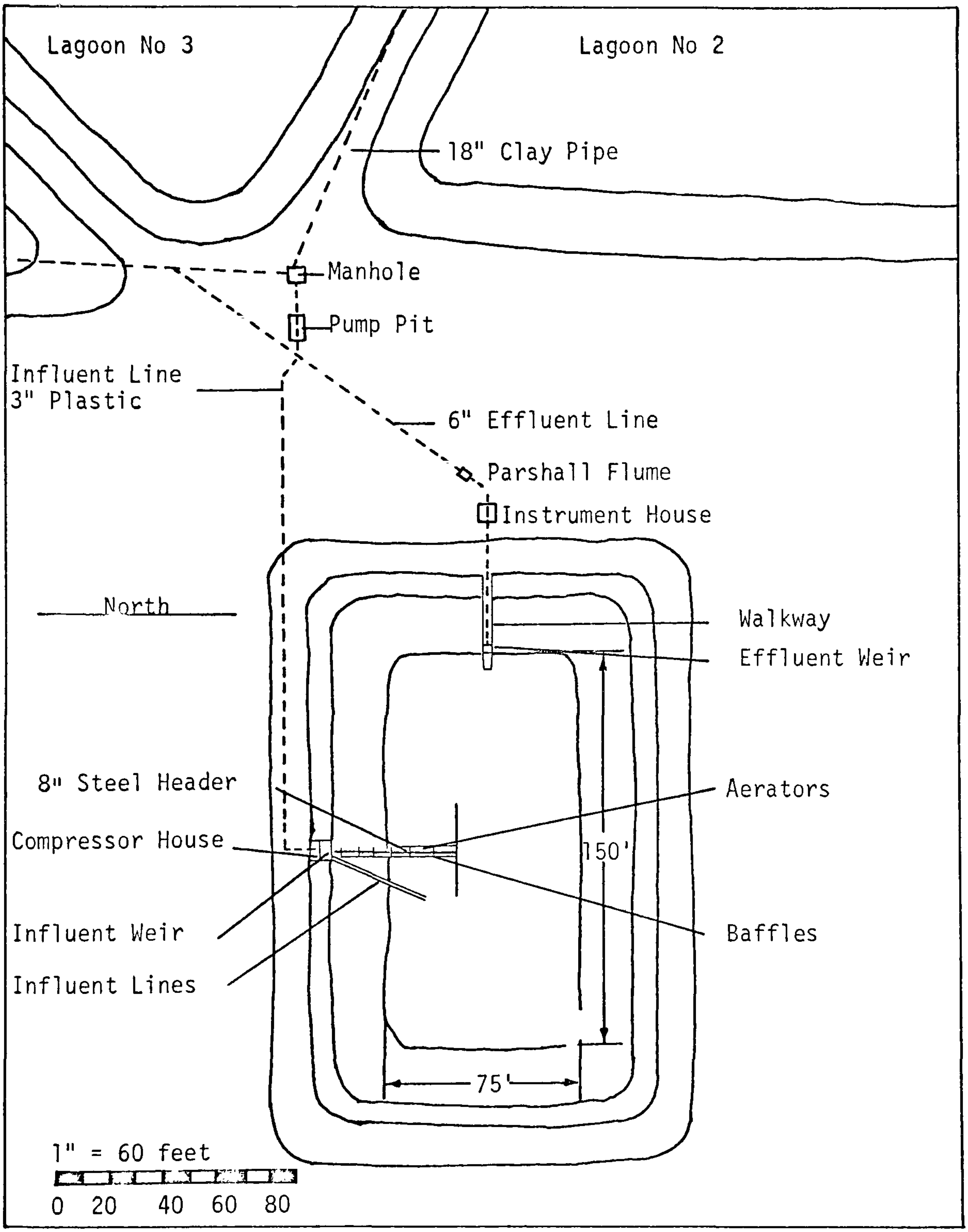


Figure 6 Hydraulic System

makes a sharp turn at a manhole near the pilot lagoon. A three-inch steel pipe was tapped into the bottom of the line at the manhole and connected to the centrifugal pump. This allowed a constant static head on the pump. An automatic shutoff device was installed which shuts the pump off if the pressure on the discharge side falls below a preset value.

In order to vary the loading applied to the lagoon and still maintain a representative sample from the city sewage system, a timing system was connected to the centrifugal pump. This allowed the pump to operate at periods of varying times and then shut off. By changing the time of pumping, the rate of hydraulic loading was changed. The pumping time varied from five minutes per hour to 50 minutes per hour. Since the pumping times operated 24 hours a day, an incremental representative process organic load was applied to the lagoon.

Since raw sewage (not comminuted) was used, clogging of the pump was expected. In order to provide some cleaning, the three-inch discharge lines were installed at a positive slope from the pump. This line discharged into an outlet tank and weir assembly. At times when the pump shut off, enough static head was present in this discharge line to back-flush the line and clean out the pump.

The discharge line from the centrifugal pump was a three-inch diameter plastic pipe. It was buried 30 inches below ground level. This line discharged into a stilling basin and flowed over a V-notch weir into two four-inch diamater plastic discharge lines (Figure 6). Flow rates were determined by use of a float type gauge height recorder mounted above the V-notch weir. Effluent from the lagoon discharged over a V-notch weir mounted on the outlet structure. The effluent discharged back to the city lagoon system through a six-inch vitrified clay effluent line. A walkway was constructed to provide access to the effluent weir so that samples could be collected and the discharge monitored.

The Aeration System

The mechanical aeration system used for the pilot lagoon was of the INKA type as designed by Industrikemiska Aktiebologet of Stockholm, Sweden. Major components of the system are a 10 horsepower radial air compressor, an eight-inch diameter air header and support frames, and three stainless steel INKA type air diffusors (Figure 7). The support frames were fabricated of two-inch steel pipe and set in concrete about two feet deep. Five sections of eight-inch diameter ¼ inch steel pipe were welded together to make a continuous air header. Three-inch diameter holes were cut in the header and short pieces of three-inch pipe were welded to the header to facilitate connection of the aeration units. A concrete platform was poured and the air compressor was attached to it by anchor bolts. A five-foot pipe transition section was used to connect the five-inch discharge head of the compressor to the eight-inch diameter air header

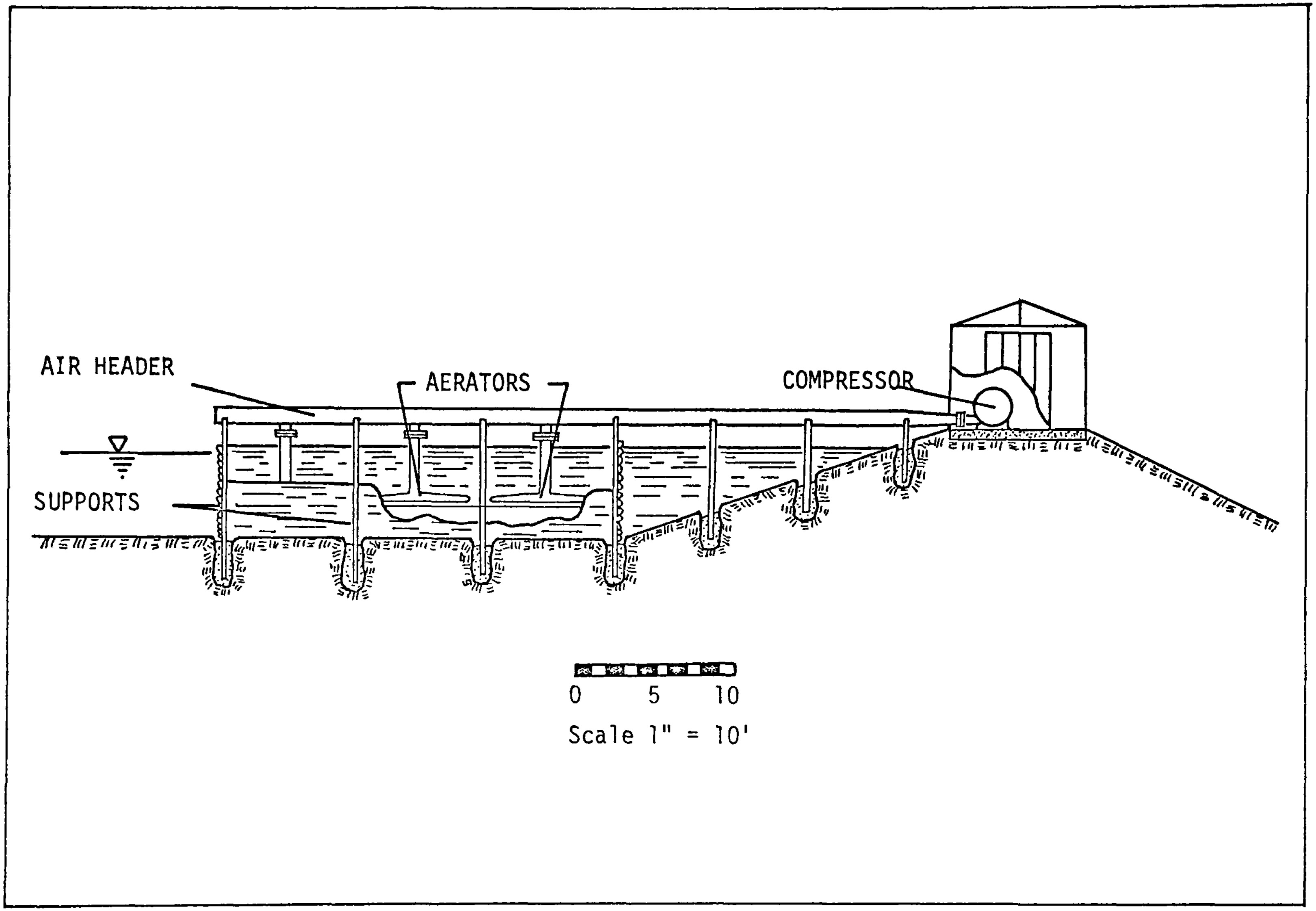


Figure 7 Profile of the Aeration System

line. The compressor was placed in a prefabricated steel shelter house for protection from the weather. A differential pilot tube was inserted into the header and connected to a U-tube monometer inside the compressor house for monitoring of air quantities.

The diffused aeration grids are approximately three by eight feet with 3/16 inch orifices located on the bottom of the grill. Three of these units were used in the pilot lagoon. The grids were placed at a depth of 2.67 feet below the water. Since the aerator units were under the water, they were not affected by icing (Figure 8).

The Baffle System

A baffle system consisting of corregated plastic sheets was attached to the two-inch structural pipes. In order to give the sheets longitudinal flexural strength they were supported by chainlink fence. The purpose of the baffling along the sides of the aerator created a flow pattern that insured mixing and immediate aeration of the incoming sewage. The aeration grids and baffling form a type of air pump (Figure 9). The longitudinal baffling promotes a clockwise circulation pattern in the lagoon. The aeration units perform two operations - mixing of the sewage and aeration of the sewage.

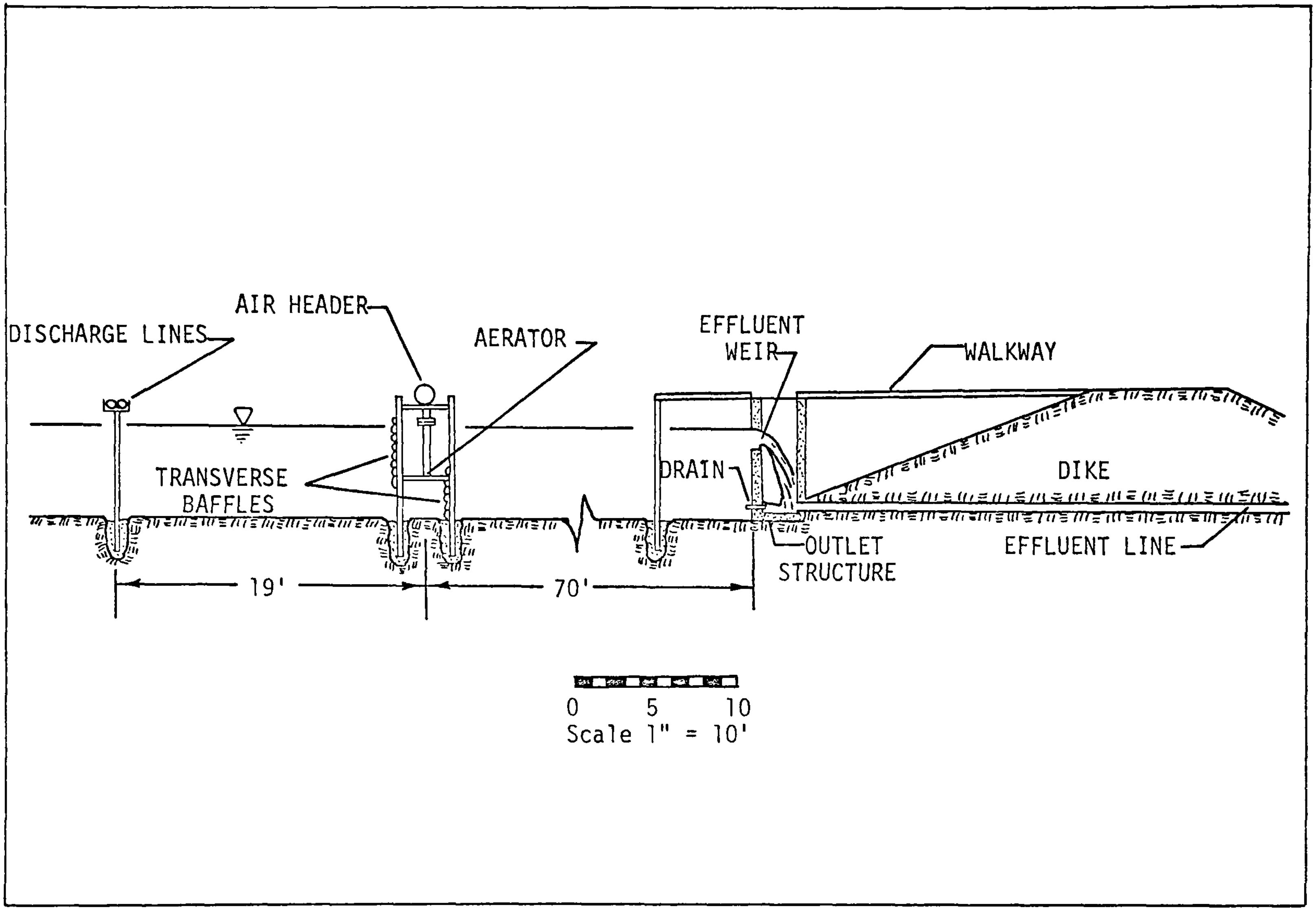


Figure 8 Longitudinal Cross-Section of the Lagoon

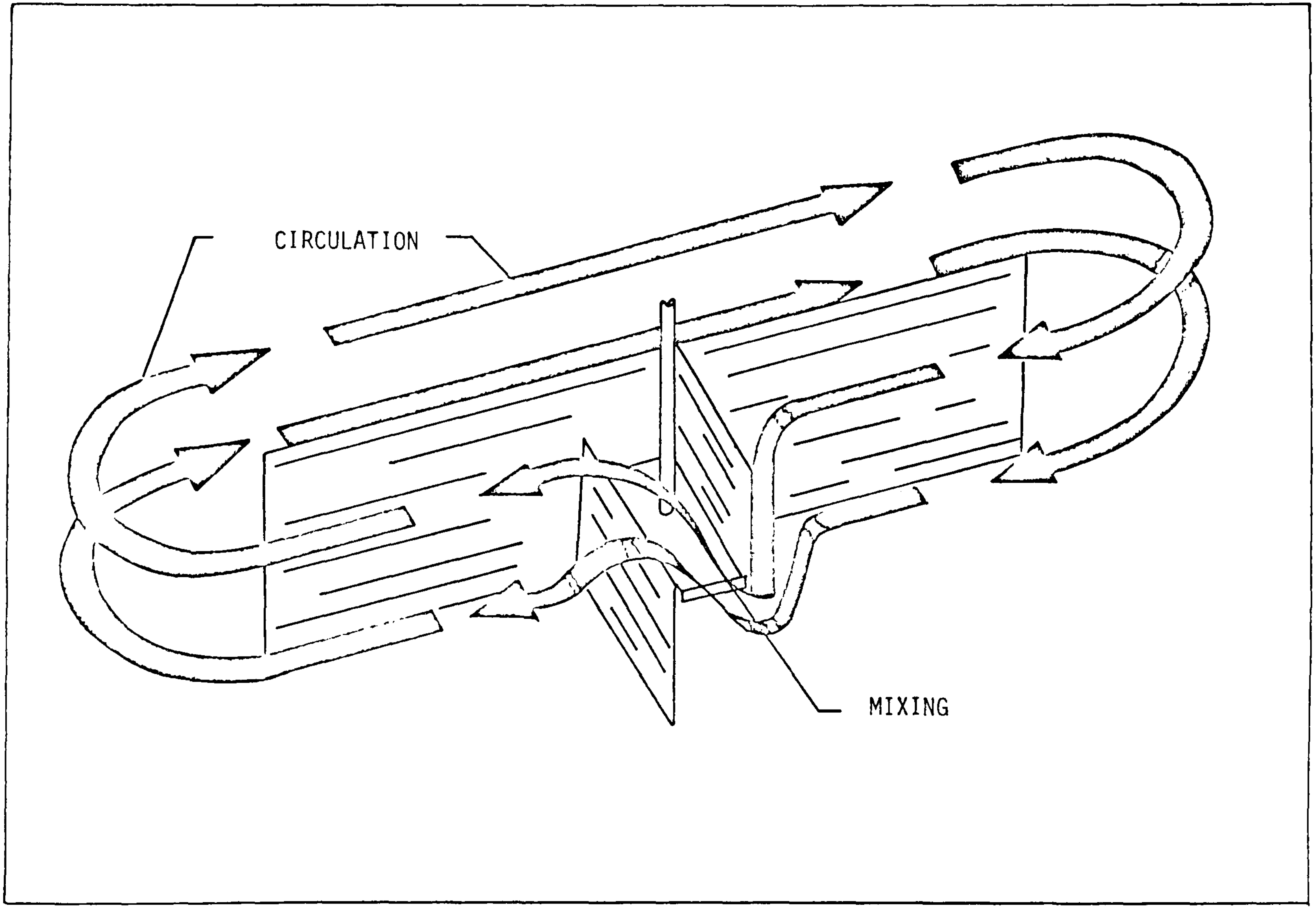


Figure 9 Hydraulic Flow

SECTION V

OPERATIONAL FEATURES OF THE PILOT LAGOON

With the installation of the diffused aeration device and considering the baffling and shape of the lagoon, it was hoped that the pilot lagoon would approach a complete mixed system. In order to evaluate the mixing characteristics of the lagoon and the rate constants of the raw sewage, several tests were conducted.

Tracer Study

In order to test the hydraulic characteristics of the lagoon, a dye test was used and a flow-through curve was plotted. To obtain a flow-through curve, a slug of tracer is injected in the influent and the concentration of tracer is monitored in the effluent at timed intervals. From this data a flow-through curve (concentration of dye in the effluent vs. time after injection) is plotted.

The flow-through curve indicates the statistical distribution of the flow times of individual water molecules as they pass through the system. In reality, the curve only approximates this distribution as tracers do not necessarily follow the path lines taken by the water or waste water molecules. Even with this imperfection, a flow-through curve obtained with a good tracer and measuring device will yield valuable information about the hydraulic characteristics of the detention structure.

All ideal flow-through curves have two fundamental characteristics: 1) the average concentration of the dye in the effluent as computed from the curve is equal to the average concentration applied and 2) the centroid of the curve with respect to time occurs at the theoretical detention time. The theoretical detention time is equal to the volume of the tank divided by the flow rate.

Observed curves generally never fully satisfy these characteristics. The tracer recovery ratio, defined as the ratio of the observed average concentration to the average applied concentration is generally less than one. Any sorption, fading of dye, or decay of radioactivity (radioisotope tracer) will cause the ratio to be less than one.

Several features of the flow-through curve indicate the hydraulic characteristics of the system. High peaks close to the injection time indicate short-circuiting. Long tails on the curve at low concentrations, seemingly asymptotic to the zero concentration line, indicate zones or spaces which are hydraulically stagnant with little fluid exchange. Sharp peaks near the theoretical detention time indicate plug flow or flow with little longitudinal mixing. Curves which are flat with little peaking indicate good mixing characteristics. Good mixing, which brings food, oxygen, nutrients and bacteria together, is essential to proper, efficient treatment.

Rhodamine WT, a fluorescent dye, was selected for use in this study. This dye is easy to detect, has a low sorptive tendency and good diffusion properties. A detailed explanation of fluorescent dye and their relative merits has been presented by Wilson (4). The detection device used was a Turner Model III Fluorometer.

The dye was injected through the influent line of the lagoon. Sampling of the effluent began immediately with samples taken at approximately one minute intervals. The one minute interval was continued for about one hour and was changed only after the curve was defined.

All samples were tested in the field with temperature corrections made according to Wilson (4).

The flow-through curve for a hydraulic loading of 210,000 gallons per day is shown in Figure 10. The theoretical detention time is 2.5 days with a tested detention time of 1.94 days. The tracer recovery ratio is 0.90.

The first peak, occurring only minutes after dye injection, indicates some short-circuiting directly to the effluent weir (samples were collected at effluent weir). The effluent weir should be located at the opposite end of the lagoon which would allow more mixing time before exit. The second slight peak indicates a return of the general flow from the clockwise pattern of the lagoon. The height of the peak also indicates that after only one pass the influent dye is about completely mixed in the lagoon. If the first peak is neglected the actual detention time will be closer to the theoretical time. Also with the extrapolation of concentration values to infinite time, a recovery ratio approaching one will occur.

Considering the computed values and the general shape of the flow-through curve, the tank can be seen to approach a complete mixed unit.

DO and BOD Values in the Lagoon

From the tracer studies it appears that the lagoon functions hydraulically as a complete mix tank. In order to investigate the mixing properties in a chemical and biological sense, Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) values were tested at several locations in the pilot lagoon.

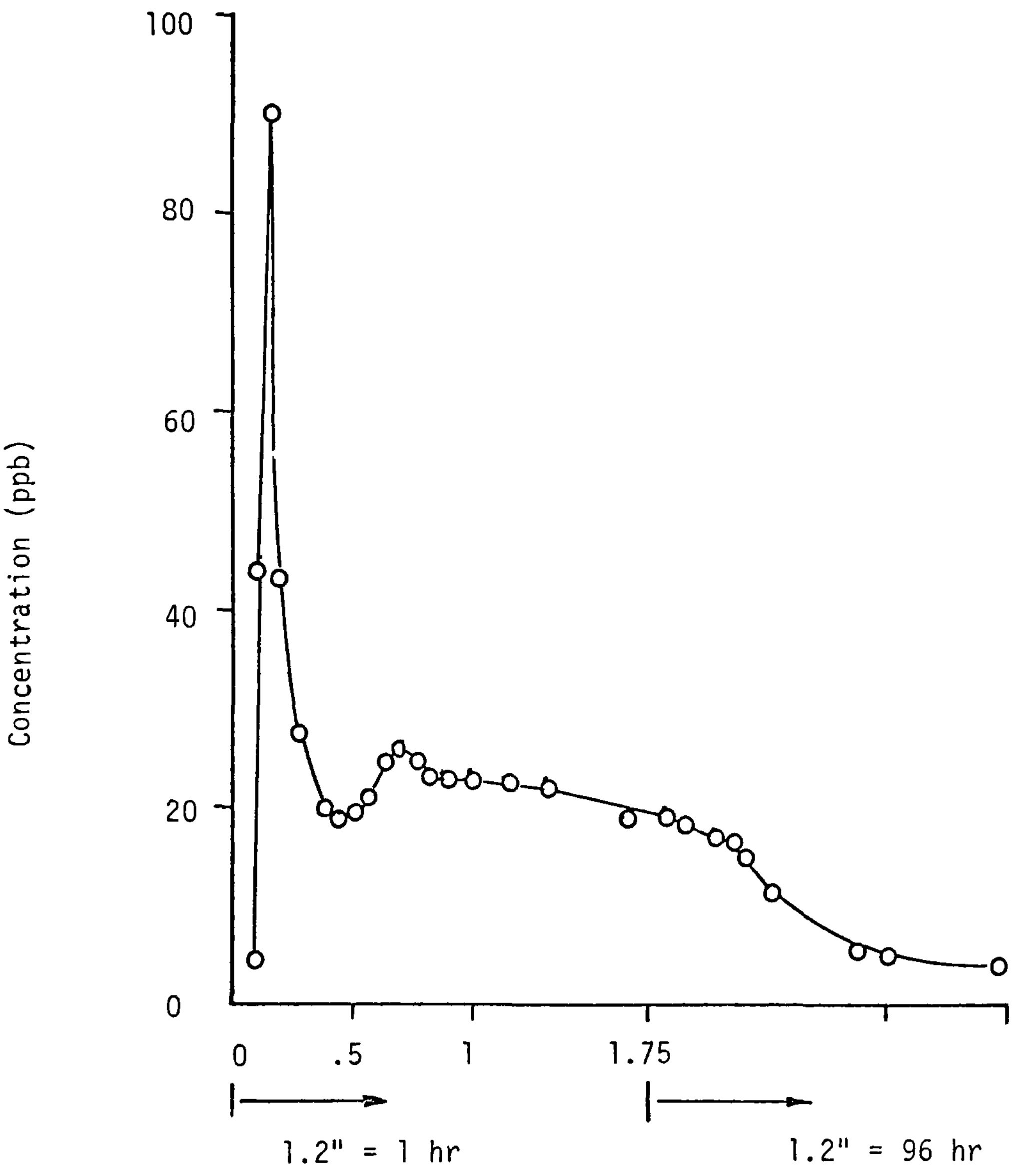


Figure 10 Flow-Through Curve
Dye Test

Initial testing showed no variation in DO and BOD values as a function of depth at any of the sampling stations. Therefore, samples were secured from a depth of about 18 inches below the surface in all further testing. A two-man rubber raft was used as a platform to secure the samples. A rope system was used to stabilize the position of the raft at each site. All samples were tested according to approved methods outlined in "Standard Methods" (5).

Dissolved Oxygen and Biochemical Oxygen Demand tests were carried out under two different process loads (320 and 990 lbs. of five-day BOD per acre/day). Samples were taken in 300 ml BOD bottles and tested in the laboratory. No difference between field and laboratory testing was noted and therefore the more convenient laboratory procedures were used.

Figure 11 shows a plan view of the pilot lagoon with the numbered sampling sites. Flow is generally clockwise as viewed in Figure 11. Figures 12 and 13 give the Dissolved Oxygen (DO) values in mg/liter and Biochemical Oxygen Demand (BOD values (five-day 20°C) in mg/liter for the process loads respectively of 320 and 990 lbs. of five-day BOD per acre/day.

The test process loading of 320 lbs. of five-day BOD per acre/day, as shown in Figure 12, indicates several features. The average DO is 7.3 mg/liter with little significant deviation from this value. A slight increase is noted passing the influent line.

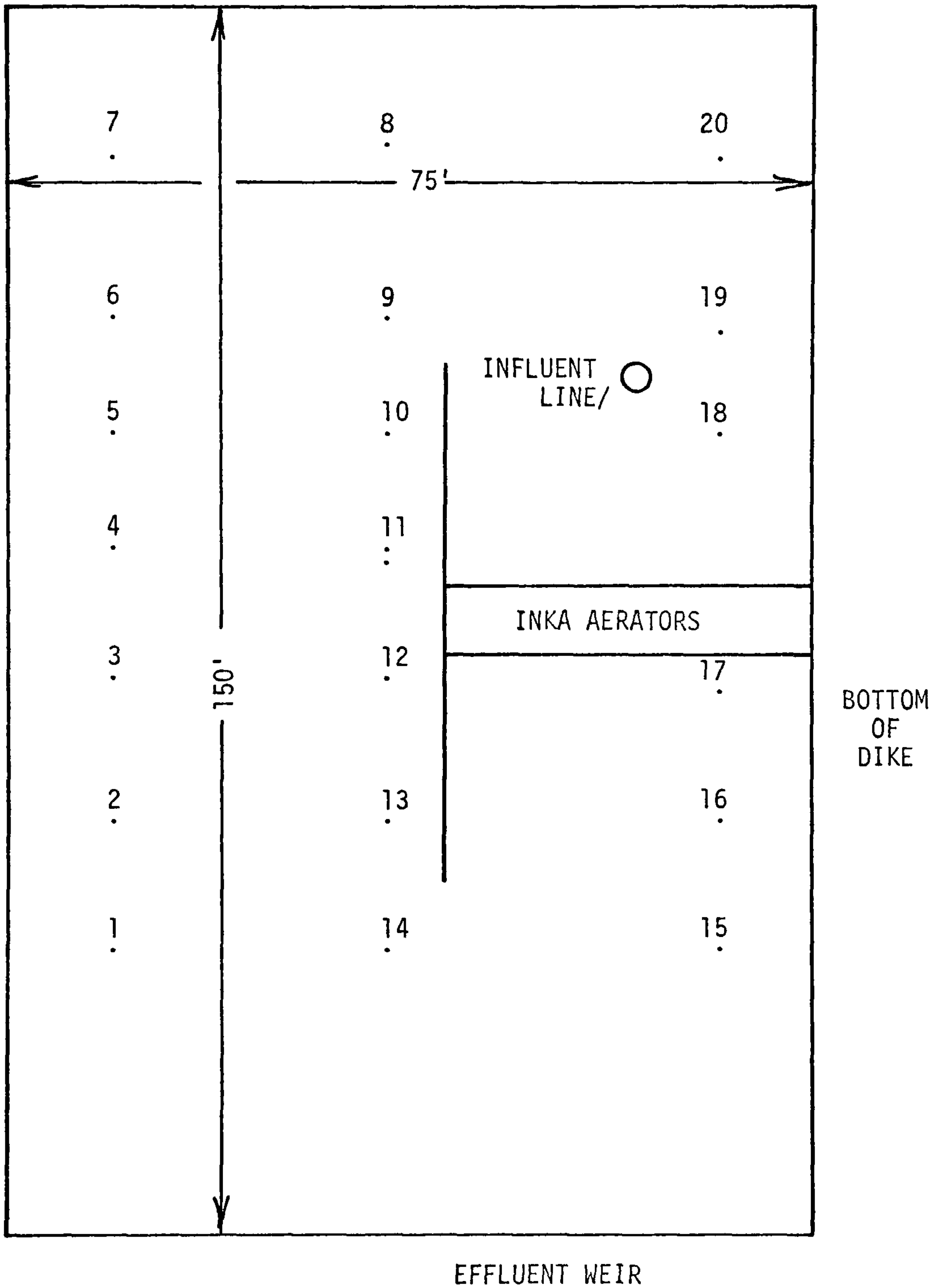
The test process loading of 990 lbs. of five-day BOD per acre/day, as shown in Figure 13, indicates features different from the 320 lb. loading. The average DO value is 2.0 mg/liter. There is little significant deviation from this value except below the point where the sewage influent line is placed. Here the DO value drops to 0.0 mg/liter. After the aerators the value is again 2.3 mg/liter. The average BOD value is 47 mg/liter. Again little variation is shown except at the point below the influent line. The values change from 45 mg/liter above to 77 mg/liter below the influent line to 67 mg/liter below the aerators.

Considering the values of DO and BOD under the two process loadings, it is apparent that the pilot lagoon approaches a complete mixed unit chemically and biologically.

An attempt was made to determine how the oxygen was utilized around the clockwise pattern. The differences appear to be random and no pattern except across the aerators could be established.

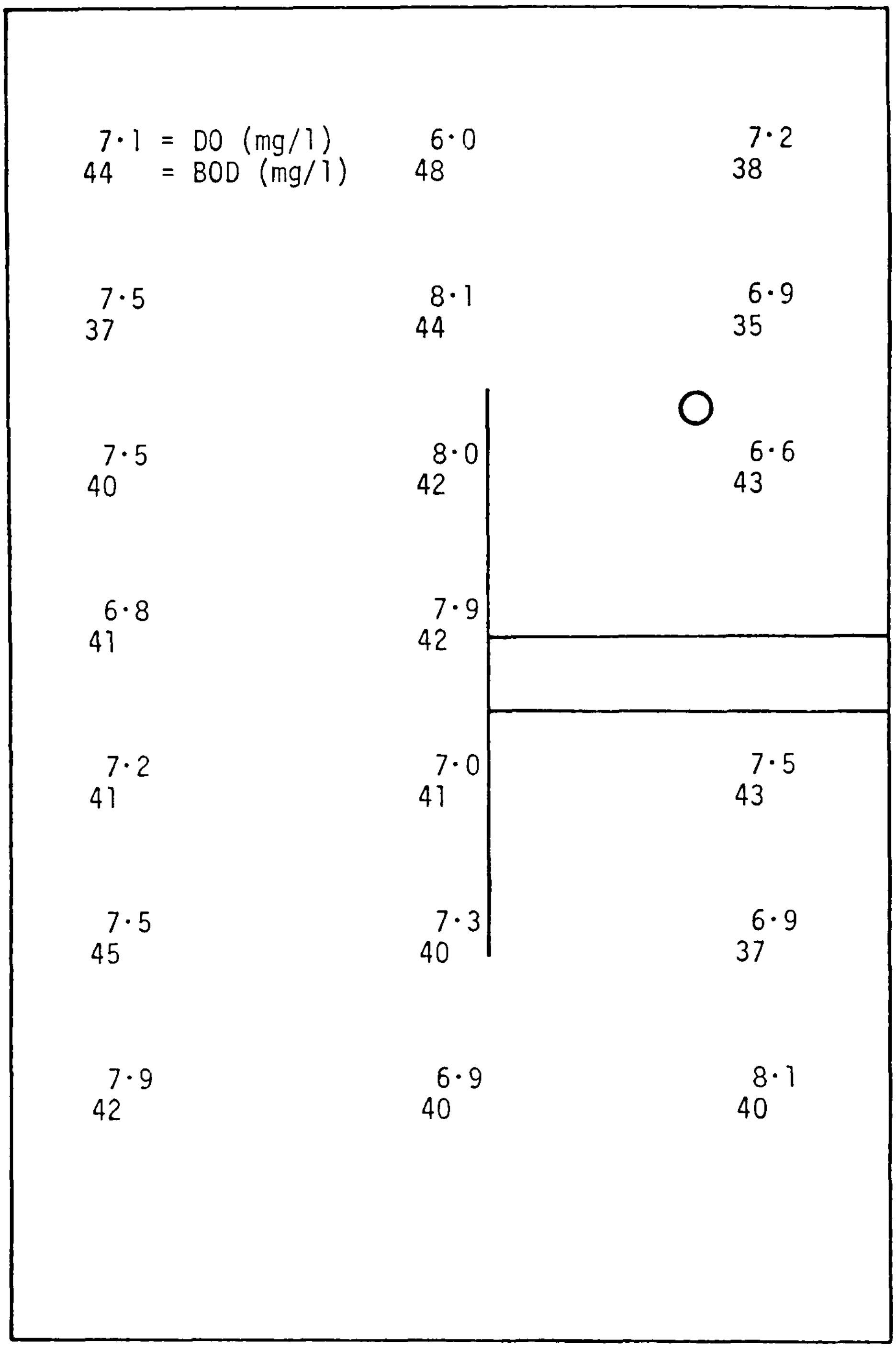
BOD Constants

In order to evaluate the sewage used in the test periods, the BOD constants were computed. The BOD test as set forth in "Standard Methods" (5) was



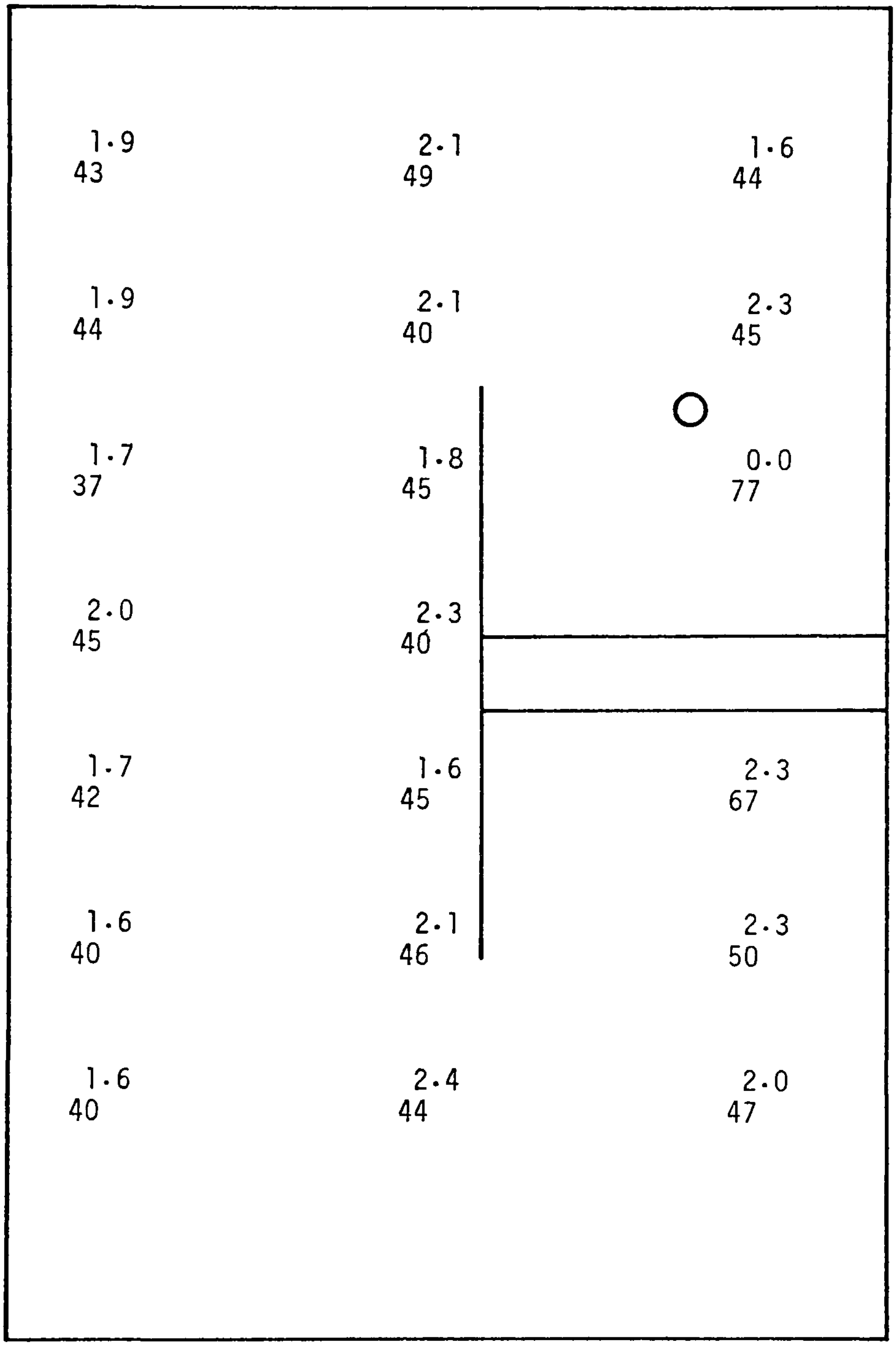
SAMPLING STATIONS IN PILOT LAGOON

Figure 11



DO AND BOD LEVELS IN PILOT LAGOON AT
320 Lbs./Acre/Day Loading

Figure 12



DO and BOD Levels in Pilot Lagoon at
990 Lbs./Acre/Day Loading

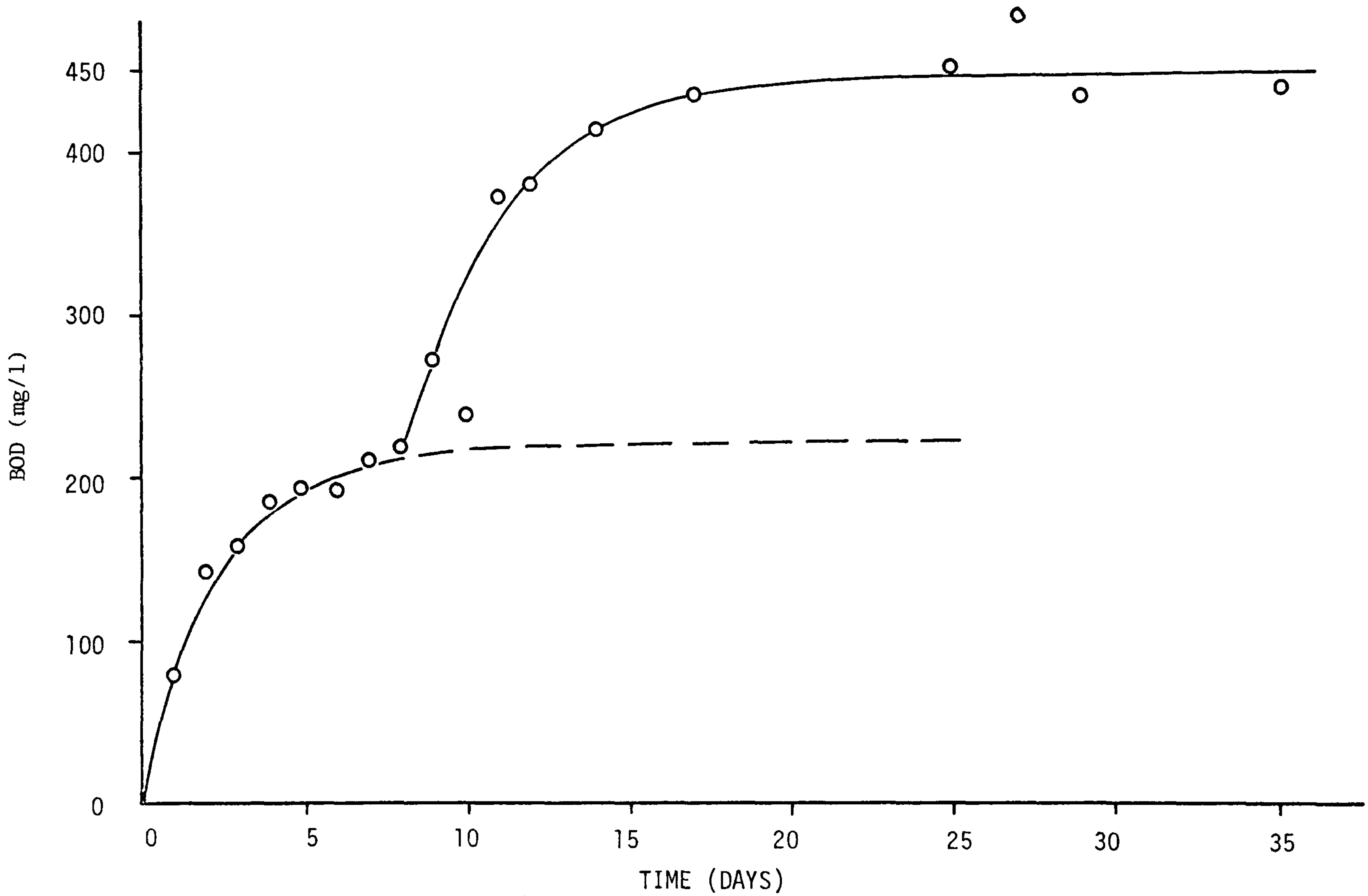
Figure 13

used with the following modification. The raw sewage was diluted to a 10% concentration with normal dilution water. This solution was thoroughly mixed to insure homogeneity. All dilutions for testing were taken from the 10% solution. The test was conducted for a 36-day period with four dilutions used for each test day. The "method of moments" developed by Moore, Thomas and Snow was used to determine the first stage constants (6).

Figure 14 shows the results of the 36-day BOD tests. It shows that the first stage BOD is the controlling reaction until the eighth day. From the eighth day nitrification plays the dominant role. The figure shows a five-day BOD value of 190 mg/liter and an ultimate oxygen demand of 450 mg/liter.

Evaluation of the first stage constants using the "method of moments" gave values of $k_{10} = 0.19$ ($k_e = 0.44$) days $^{-1}$ and L (initial demand) equal to 207 mg/liter. Assuming the second stage demand follows the same sort of curve as the first stage with BOD = 0 and t = 0 for t = 8 days on the first stage curve, and using the "method of moments" as before yields $k_{10} = 0.13$ ($k_e = 0.3$) day $^{-1}$ and L of 240 mg/liter for nitrification. The total ultimate (36-day) oxygen demand (207 + 240 = 447 mg/liter) is in close agreement with the laboratory testing.

Considering the first stage demand of 207 mg/liter, the rate constant of $k_{10} = 0.19$ ($k_e = 0.44$) days $^{-1}$ and a five-day BOD value of 190 mg/liter, it appears the sewage is of average type.



36 Day BOD Curve for Laramie Municipal Sewage

Figure 14

SECTION VI

RESULTS - THE AERATED PILOT LAGOON

The pilot lagoon was operated during two winter periods. The operation of the pilot lagoon during these two periods was considerably different. In order to understand the results and reasons for the testing and operational procedures each test period is considered separately. A final summary is included in order to collate all the results but each set of data must be considered in light of operational conditions.

Test Period One

Although the pilot lagoon was put into operation in October of 1968, the sewage pump did not operate reliably enough to obtain meaningful data until the latter part of January, 1969. Period one presented here was from February 2 to April 21, 1969. By February 2 the lagoon was considered to have attained biological steady state and the pump was giving satisfactory performance. The lagoon was operated at high (800 lbs. of five-day BOD per acre/day = 3.625 lbs./1,000 ft^3/day), intermediate (320 lbs. per acre/day = 1.450 lbs./1,000 ft^3/day), and low loadings (160 lbs. per acre/day = 0.725 lbs./1,000 ft^3/day) during the study. Since the aerated pilot lagoon was a complete mix tank, a loading intensity based on volume and not surface area is probably more appropriate. However, a comparison to normal lagoon loadings is necessary and important for engineering evaluation. Samples were taken four days per week. The parameters selected for testing were: influent BOD and temperature, hydraulic loading, effluent BOD, temperature and dissolved oxygen (DO). All tests were conducted in accordance with "Standard Methods," 12th Edition.

Average Influent BOD and Rate Constant

Several composite, influent samples were taken over a three-week period. The maximum BOD value observed was 226 mg/l, and the minimum was 154 mg/l. The average value for influent BOD was computed to be 190 mg/l, and this value was used in computations for period one. The composite samples were obtained by a gravity feed device that fed 40 ml/hour of influent sewage, twenty-four hours per day, into a container held at 4°C to retard bacterial activity. Composite samples were required to obtain an average because of the variability in composition of the sewage over a twenty-four hour period. The temperature of the influent sewage varied from 10° to 12°C during the period of study.

A value at the rate constant (k) was computed by the "method of moments" on the basis of results from a three-day series of BOD tests run at 20°C.

The value was $k_{10} = 0.19$ ($k_e = 0.44$) days $^{-1}$. This is in agreement with the mean value reported by Fair and Geyer (7).

These loading rates on the lagoon were held constant by use of an automatic timer on the pump to regulate the pumping time to a specific number of minutes on each hour's flow. For a given pump discharge rate, lagoon area and influent BOD, the surface intensity loading is established by:

$$i = \frac{Q(Y_1)\ 8.34}{A}$$

where
- i = loading intensity in lb. BOD/acre/day
- Q = influent flow in million gallons per day (mgd),
- Y_1 = five-day 20°C BOD of the influent sewage in mg/l, and
- A = surface area of the lagoon in acres.

For a typical example, surface loading intensity is illustrated by:

- Y_1 = BOD_5 of 200 mg/l,
- Q = 0.108 mgd (150 gpm pumped for 30 minutes/hour for 24 hours),
- A = 0.32 acres, and
- $i = \frac{0.108\ (200)8.34}{0.32}$ = 565 lbs.BOD/Acre/day

Since the aerated lagoon is a complete mix basin from a physical mixing standpoint, the volume factor can be utilized to determine a volume intensity loading from the formula:

$$i = \frac{QT(24)Y_1\ 8.34}{V \times 10^3}$$

where
- i - loading intensity in lb. BOD/1,000 ft^3/day,
- Q = influent flow in gallons per minute,
- T = time of pump operation (minutes) per hour,
- Y_1 = five-day 20°C BOD of the influent sewage in mg/l, and
- V = volume of lagoon in cubic feet

For a typical example, volume loading intensity is illustrated by:

- Y_1 = five-day 20°C BOD of 200 mg/l
- Q = 160 gal./min.
- V = 71,125 ft^3
- T = 16 min./hr. (pump period during day)
- $i = \frac{(160)\ (16)\ (24)\ (200)\ (8.34)}{71{,}125 \times 10^3} = \frac{1.450 \text{ lbs. BOD}}{1{,}000\ ft^3/\text{day}}$

Air Quantities

The quantity of air introduced through the diffusors was essentially constant throughout the period of study. Air velocity was measured with a differential pilot tube and manometer, and from this air flow was calculated. Six different measurements were made and the average flow was determined to be 900 cfm.

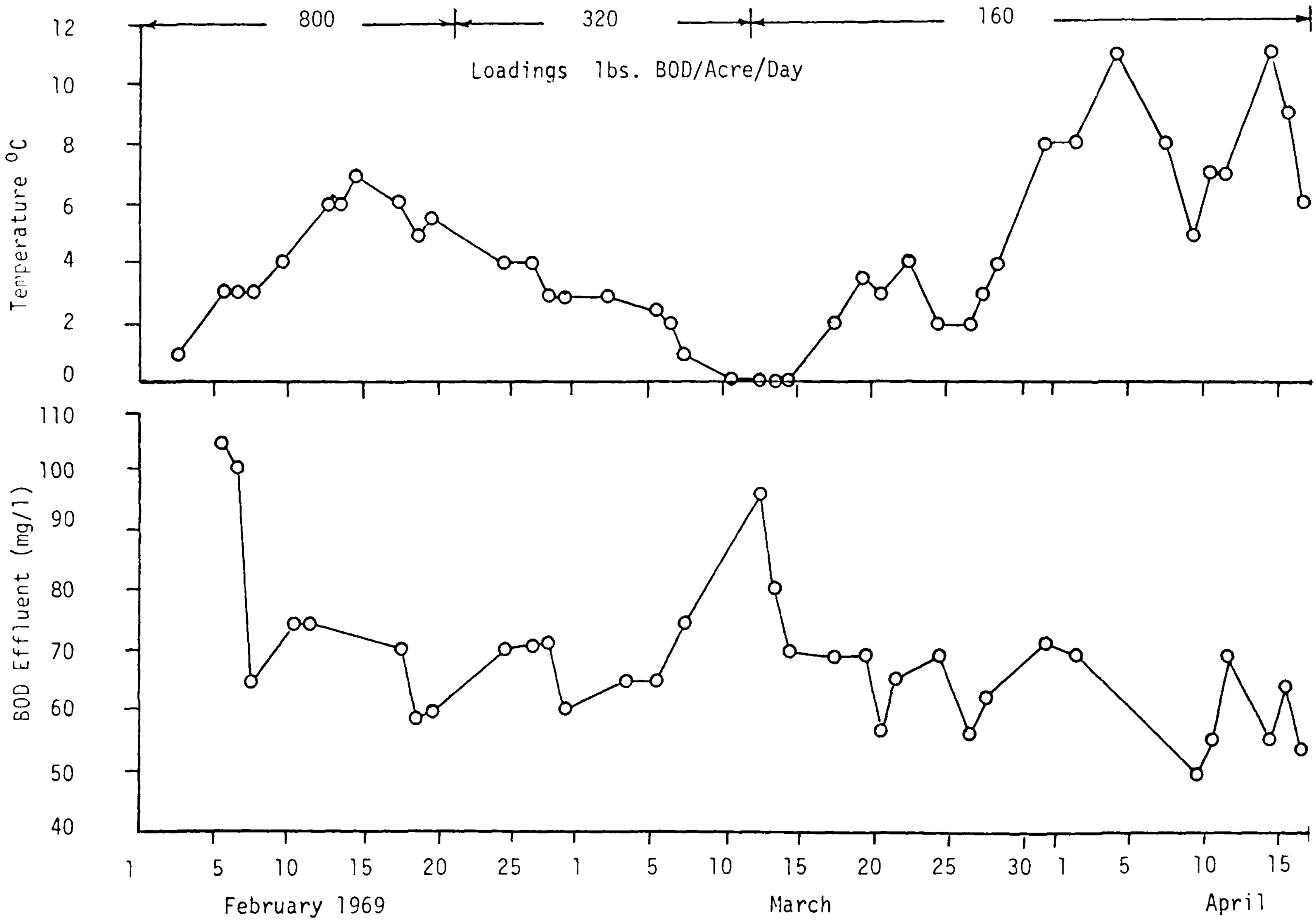
Sludge Deposition

In the second week of May, 1969, the lagoon was drained in order to examine sludge deposits. Estimation of sludge quantities were difficult. The lagoon bottom was not allowed to dry to any extent, because of time considerations for other studies being conducted. However, it was estimated that the sludge blanket was three to four inches in depth. The sludge was fairly uniformly distributed over the lagoon bottom, except the northeast quadrant of the lagoon. This area is hydraulically behind the aeration units, and the higher velocities here prevented the deposition of significant amounts of sludge (see Figure 9).

Discussion of Results

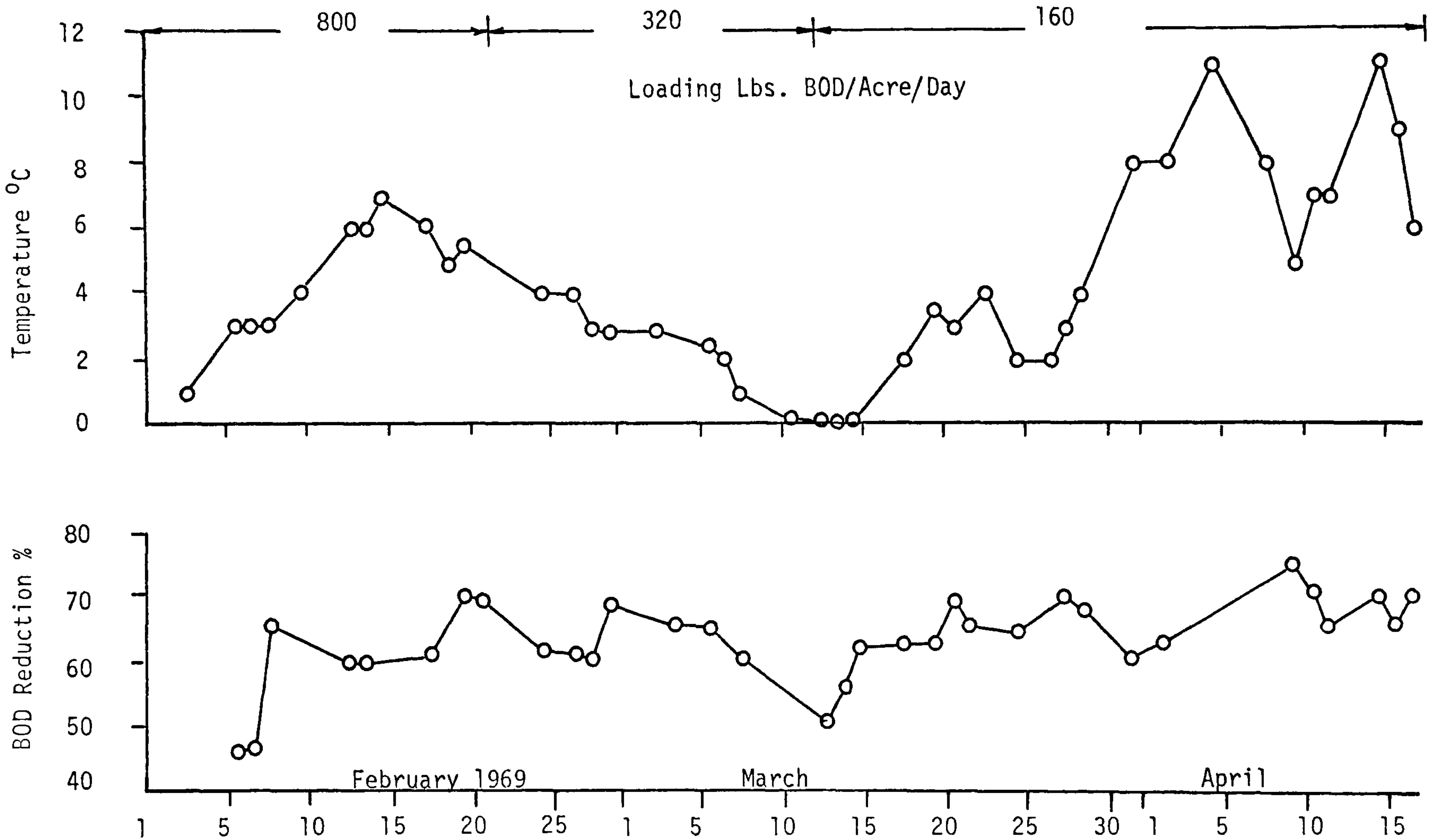
Field data taken during the study are presented in graphical form in Figures 15 through 17. The parameters are plotted in pairs for ease of comparison.

Some interesting effects can be noted upon examination of Figures 15 through 17. Although no consistant relationship is apparent between temperature and effluent BOD, Figure 15 shows that three BOD values in the vicinity of 100 mg/l occurred at low temperatures ranging from 0^o to 3^oC. Since influent BOD was taken as a constant for the period of study loading intensity and detention time were both functions of hydraulic loading. Examination of Figures 15 and 16 shows that there was no correlation between detention time and effluent BOD (or percentage BOD reduction), and correspondingly no correlation between loading intensity and effluent BOD reduction). With few exceptions, effluent BOD values, and corresponding percentage BOD reduction values, were consistently in the range of 55 to 75 mg/l, and 70 to 55 percent respectively. Figures 15 and 16 indicate that a five to six fold increase of detention time, from three up to 17 days, does not produce an appreciable change in lagoon performance with regard to BOD reduction in the effluent. Figures 15 and 16 indicate a corollary to the above statement; that is, an 80 percent reduction in loading intensity, from 800 lbs. BOD/acre/day to 160 lbs. BOD/acre/day does not produce an appreciable change in lagoon performance with regard to BOD reduction in the effluent. These facts suggest that the bacteria are able to oxidize some constituents of the sewage within three days, but



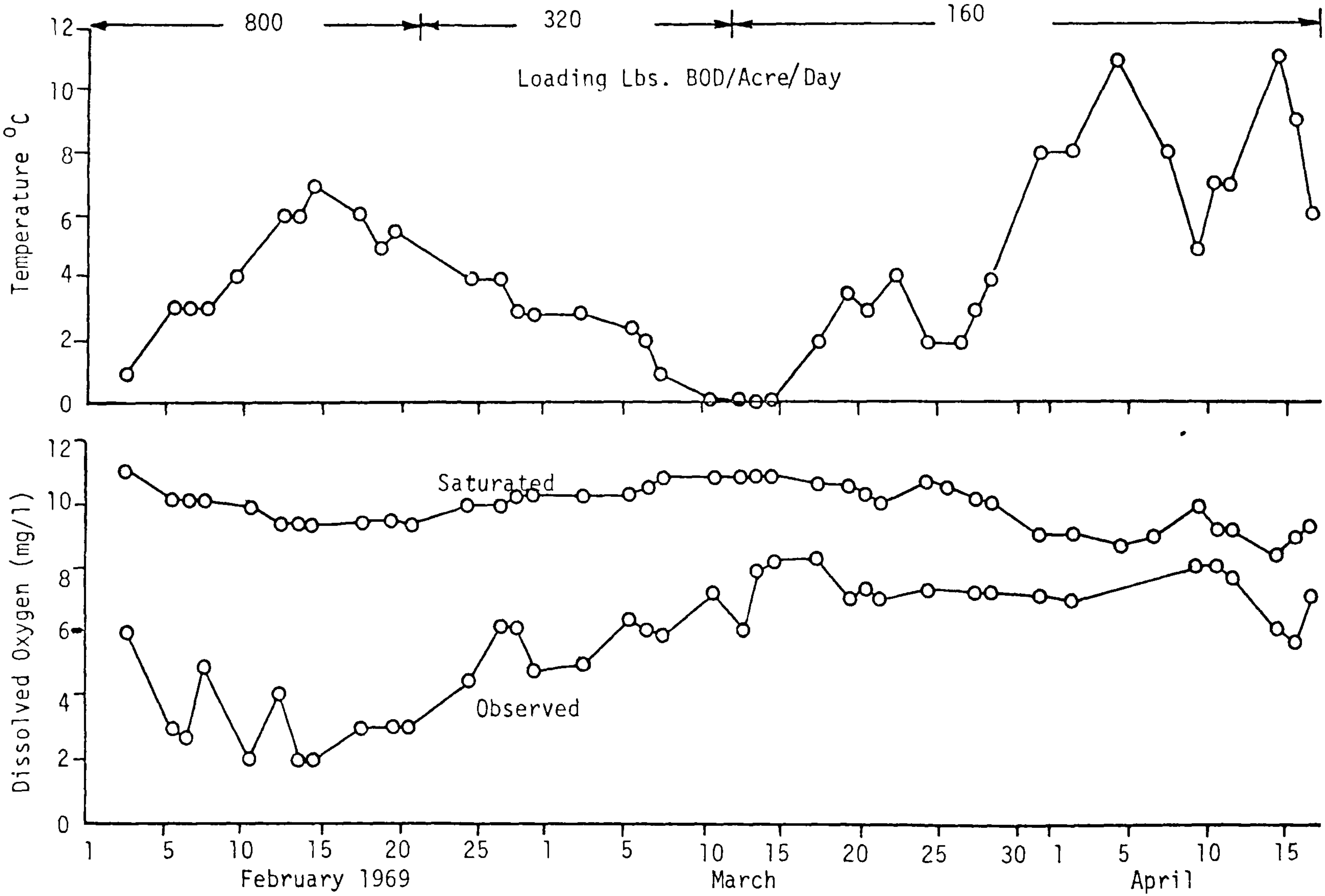
Effluent BOD and Temperature in the Pilot Lagoon

Figure 15



Effluent BOD Reduction and Temperature in the Pilot Lagoon

Figure 16



Effluent DO and Temperature in the Pilot Lagoon

Figure 17

that remaining organic matter requires detention times in excess of 17 days for stabilization at temperatures observed during the study. Operating temperatures in the range of 20°C should produce considerably lower effluent BOD values. Another possible explanation of the lack of correlation between loading and efficiency is that possibly large amounts of sludge were deposited at the high loading intensities at the beginning of the study, producing a secondary load on the lagoon throughout the remainder of the study.

Figure 17 shows that at no time during the study did the dissolved oxygen content fall to zero. This implies that oxygen for bacteria was never a limiting factor and that aerobic conditions were maintained in the system throughout the period. Figure 17 also suggests that there is a correlation between loading intensity and dissolved oxygen content. Figure 18 shows the correlation, as a plot of dissolved oxygen deficiency (saturation DO value minus observed DO value) versus loading intensity. Assuming a requirement of 6 mg/l DO in the effluent, and assuming a critical temperature of 20°C (saturation = 7.1 mg/l at Laramie), the curve indicates that a loading of about 100 lbs. BOD/acre/day would meet the DO requirements.

Tests on effluent samples showed that settleable solids were consistently less than 1/2 ml/l. The pH values are not included here because they were essentially constant and had no apparent variation. The pH values of the influent sewage varied from 8.0 to 7.4 and values of the effluent ranged from 8.2 to 7.1.

The samples and temperature measurements taken at the effluent weir are felt to be representative of conditions in the lagoon because of the mixing provided by the aerators. The lagoon was probably operating in a bacterial log growth phase. Two facts lead to this conjecture. First, mixing by the aerators provides a system in which bacteria and substrate are dispersed, and secondly the absence of significant settleable solids in effluent samples indicates that no flocs were formed by bioflocculation. The reason for the absence of bioflocculation could be due to either shearing effects caused by the violent mixing at the aerators or the absence of endogenous growth.

The foaming of detergents present in the sewage was observed on several occasions. Agitation of the incoming sewage by the aerators caused foam, which at times was two feet above the water surface behind the aerators. The foaming does not appear to be a serious operational problem. The flow pattern in the lagoon, illustrated in Figure 19, was borne out by observing the pattern formed by foam on the lagoon surface. The aerators showed no appreciable physical deterioration at the conclusion of the study. Some trash accumulated on them, but the trash build-up was not large enough to affect operation.

Some icing occurred during the period March 10 to March 15. This was the only time that ice was formed and even during this period the ice covered

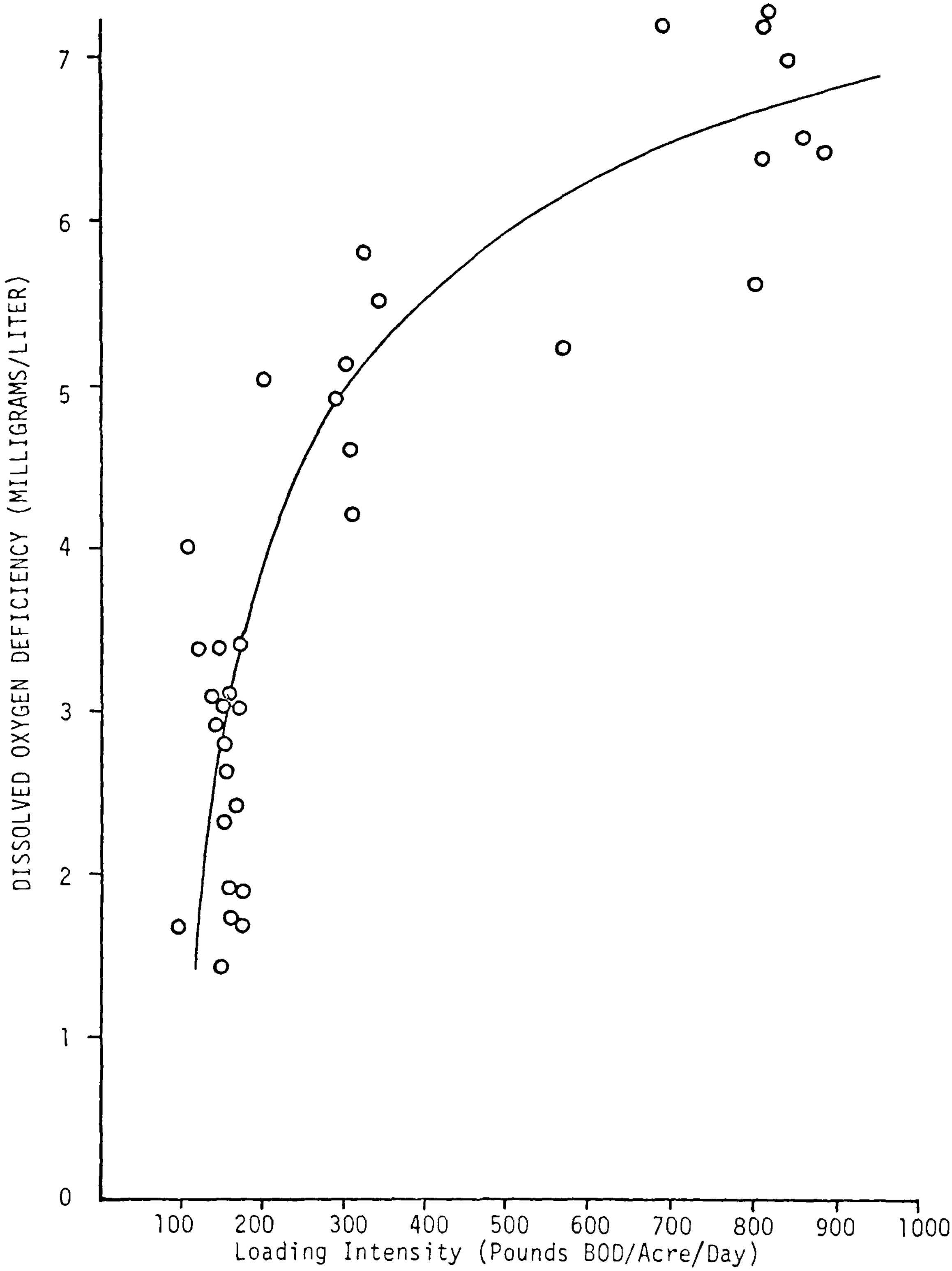


Figure 18 Dissolved Oxygen Deficiency vs. Loading Intensity

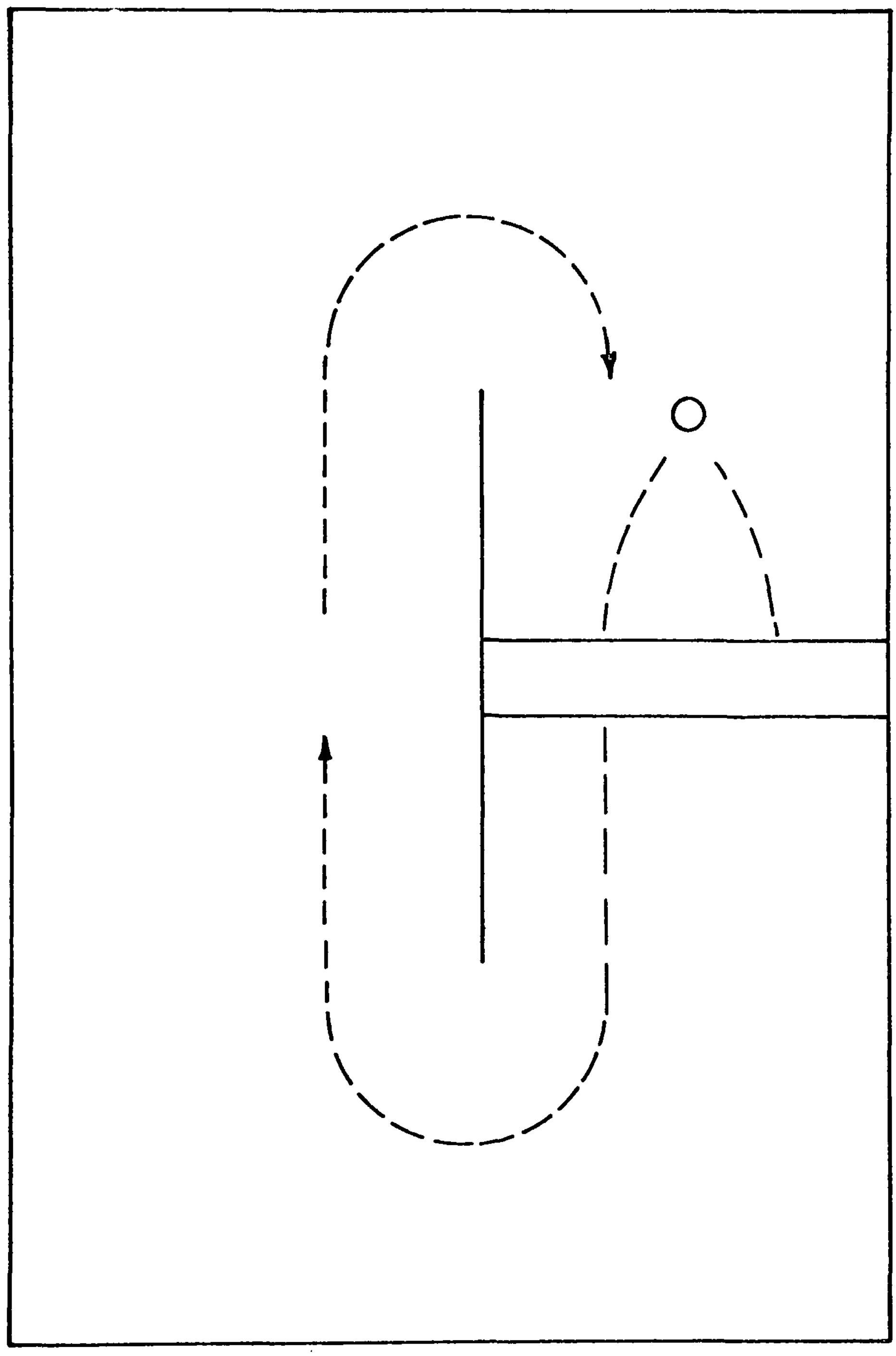


Figure 19 Flow Pattern

only about 75 percent of the lagoon surface and was less than an inch thick. The area behind the aerators remained open during this period. The mean air temperature during this period was 3°F. The average daily low temperature for the period was -15°F.

Test Period Two

Several questions concerning operation and data occurred during the first test period. Since the initial process load for period one was 800 lbs./acre/day (the highest loading), it was possible a sludge deposit was formed. This deposit could have been metabolized during the two lower loadings and masked the effect of load and detention time variation. Therefore, the pond was operated starting at the lower loadings (160 lbs./acre/day) for Test Period Two.

A second question regards the bacterial concentration. If the rate of loading varies and no appreciable sludge build-up occurs and the final BOD is comparable, then organic material must be metabolized at a faster rate. Since temperatures were not significantly changed, the bacterial population or kind must change. Bacterial counts therefore were secured during Test Period Two.

A third question was the possibility of improvement of effluent quality by the use of aerated cells operated in series. Since only one pilot lagoon was constructed, a second cell was simulated by shutting off the influent and monitoring the change in several parameters with time. The aeration system remained constant (900 cfm) during this period. This type of test obviously is not a true picture of series operation. The second cell actually operates as a batch or slug type flow cell. However, the results from the testing indicates some significant operational problems associated with series operation.

All physical, chemical and biological testing was performed at the Environmental Engineering Laboratory, Civil Engineering Department, University of Wyoming. Testing and sampling procedures were in accord with the Thirteenth Edition of "Standard Methods" for the Examination of Water and Waste-Water. Tests to determine total bacteria and coliform bacteria were performed in the laboratory of the Veterinary Medicine and Microbiology Department of the University of Wyoming.

In addition to testing procedures from "Standard Methods," analytical determinations for nitrate nitrogen, nitrite nitrogen, orthophosphate and sulfate were made using the Hach DR-EL "Direct Reading" Portable Laboratory as manufactured by the Hach Chemical Company.

Samples were routinely collected and tested from the influent and effluent of the pilot lagoon. Samples were collected four times a week. Additional testing was performed when the loading was changed in order to determine steady state conditions.

Operation Test Period Two

The test series in the first cell was conducted with loadings of 160 lbs./acre/day (.725 lbs. BOD/1,000 ft^3/day), 320 lbs. BOD/acre/day (1.450 lbs. BOD/1,000 ft^3/day), 700 lbs. BOD/acre/day (3.15 lbs. BOD/1,000 ft^3/day), and 900 lbs. BOD/acre/day (4.08 lbs. BOD/1,000 ft^3/day), a maximum loading rate. The 160 lbs./acre/day and 320 lbs./acre/day test functioned as planned; however, the maximum loading varied considerably from a low 700 lbs./acre/day to a maximum of 900 lbs./acre/day due to the large fluctuation of the influent BOD. At the time that the final test series was started, infiltration from the flooded Laramie River was at a peak and the influent BOD dropped from an average value of 200 mg/l to an average value of 160 mg/l. Using the loading intensity equation, the hydraulic loading was adjusted in an attempt to hold the planned maximum load of 900 lbs./acre/day. This attempt was not successful since the increased head of water above the aeration grid reduced the flow of air supplied to the lagoon which in turn reduced the dissolved oxygen level. A maximum rate of 700 lbs./acre/day was then established and continued for seven days until the loading could be increased.

Detention time in the first cell based on the loading rates is as listed in Table 1 below.

TABLE 1

LOADING INTENSITY AND DETENTION TIME (FIRST CELL)

Loading Lbs. BOD/acre/day	Calculated Detention Time Days
160	17.0
320	8.5
700	3.9
900	3.0

After changing the intensity loading, the test series was of a duration of at least twice the detention time. This allowed establishment of steady state conditions. It is difficult to determine the ecological steady conditions. It was assumed that when the values for several variables (including biological variables) remained constant a steady state condition was attained.

The efficiency of lagoon treatment at the test loading conditions is based on percentage BOD reduction as computed from the equation:

$$E = \left(\frac{Y_1 - Y_2}{Y_1} \right) 100$$

where E = efficiency or % BOD reduction,
Y_1 = five-day 20°C BOD of influent sewage, and
Y_2 = five-day 20°C BOD of effluent

Physical and chemical changes at various test loadings are compared using a similar percentage calculation as the BOD reduction equation above. The general percent reduction equation is:

$$R = \left(\frac{S_1 - S_2}{S_1} \right) 100$$

where R = percent reduction, and
S_1 and S_2 = concentrations in influent and effluent, respectively.

160 Lbs. BOD/Acre/Day Loading

A loading intensity of 160 lbs. BOD/acre/day (.725 lbs. BOD/1,000 ft^3/day) was initiated in February 1970. The theoretical detention period for this loading is 17 days. Aeration was a constant of 900 cfm for the period. After the onset of steady state conditions, the system was operated for a period of about four weeks.

Toward the end of March the influent loading to the aerated lagoon was stopped. This was done in order to assess the performance of a second cell in series. Since the second cell received no constant influent, a series operation was only simulated. This batch process however did indicate several operational features. Aeration was continued at 900 cfm during second cell operation.

A summary of data acquired during cell one and cell two testing is shown in Tables 2 and 3. Four values are shown for each parameter. Each of these values represents an average of several samples. Those of cell two (the batch process) also indicate testing on a three or four day subsequent time period.

TABLE 2

STEADY STATE TEST RESULTS
AERATED LAGOON LOADING
160 Lbs./Acre/Day

TESTS	FIRST CELL Influent	FIRST CELL Effluent	SECOND CELL Effluent
Temperature (°C)	12	2	0
	12	3	0
	12	0	3
	12	1	5
TS (mg/l)	1198	1065	1027
	1534	1039	1081
	1264	1068	1053
	1164	1071	1041
TVS (mg/l)	407	268	226
	465	197	206
	425	251	202
	356	267	208
TSS (mg/l)	304	46	43
	422	57	36
	- -	- -	48
	- -	- -	61
VSS (mg/l)	223	42	28
	262	32	38
	- -	- -	47
Settleable Solids (ml/l)	9	0	0
	9	0	0
	9	0	0
	9	0	0
Alkalinity (mg/l) as $CaCO_3$	340	306	314
	337	317	334
	340	318	316
	337	314	311
Hardness (mg/l) as $CaCO_3$	610	690	564
	516	572	572
	500	568	568
pH	7.6	7.8	8.0
	7.5	7.8	8.1
	7.3	7.6	8.4
	7.5	7.6	8.2

TABLE 3

STEADY STATE TEST RESULTS
AERATED LAGOON LOADING
160 Lbs./Acre/Day

TESTS	FIRST CELL Influent	FIRST CELL Effluent	SECOND CELL Effluent
SO_4^{-2} (mg/l)	460	450	500
	300	400	400
	500	500	400
	400	400	- -
NO_3^{-1} (mg/l)	8.0	8.0	6.0
	8.0	8.0	0.0
	6.0	5.0	0.0
	10.0	10.0	8.0
PO_4^{-3} (mg/l)	22	12	15
	30	12	22
	35	25	25
	15	18	- -
DO (mg/l)	0	7	9
	0	7	11
	0	7	11
	0	7	12
COD (mg/l)	506	119	128
	560	70	44
	500	85	54
	399	133	111
Biochemical Oxygen Demand (BOD) (mg/l)	217	32	23
	214	38	33
	202	44	38
	183	20	39
Coliform Bacteria (Number/ml)	5×10^5	7.5×10^3	10
Total Bacteria/ml Henrici's Agar*	- -	1.2×10^7	7.2×10^6
TSA**	- -	1.9×10^6	1.8×10^6

*Henrici's Agar incubated at 30°C (dilute medium with a wide variety of carbon and energy sources).
**TSA incubated at 30°C (rich nutrient medium), Trypticase Soy Agar-BBL Division of Bioguest, Cockeysville, Maryland.

Several features are apparent from the data of Tables 2 and 3. The temperature of the influent, which was true for all test periods, averaged 12°C. The temperature of the effluent was modified by detention time and ambient air temperature.

Even at temperatures close to 0°C, significant BOD, COD, and volatile solids reduction is experienced for the 160 lbs. BOD/acre/day loading. BOD reduction averaged about 85% reduction in cell one and no change in cell two. Apparently further biological reduction in BOD would require larger periods of time or warmer temperatures.

At a loading of 160 lbs. BOD/acre/day no settleable solids were produced in the effluent from cell one or cell two. The biological process would not be improved by the introduction of a sedimentation tank in series operation.

The dissolved oxygen level varied from 6.7 to 7.5 with an average of 7 mg/l during the loading of cell one. When the influent loading was stopped, the dissolved oxygen increased and approached saturation levels.

Both coliform and total bacteria counts were secured for cell one and cell two. The total count as determined on Henrici's Agar should be considered the base count with the TSA count used as a check of magnitude. The second cell bacteria values reported in Table 3 were from a sample taken two weeks after the beginning of cell two operation. The total count apparently does not change significantly from cell one to cell two during this period. The coliforms, however, were reduced to a value of about 10/ml after two weeks in cell two. This value apparently was a minimum since additional detention time (greater than two weeks) did not reduce it.

Changes in hardness and sulfate are due to the ionization of $CaSO_4$ (gypsum) dissolved from the berm by wind and wave action. Toward the end of the test period for cell two significant algae were produced in the aerated pond. This became a significant parameter in the next test series.

320 Lbs. BOD/Acre/Day Loading

A loading intensity of 320 lbs. BOD/acre/day (1.450 lbs. BOD/1,000 ft^3/day) was initiated following the test on cell two (160 lbs. BOD/acre/day) in early April. The theoretical detention period for this loading is 8.5 days. Aeration was a constant of 900 cfm for the period. After the onset of steady state conditions, the system was operated for about two weeks.

Toward the end of April the influent loading was stopped. A batch process resulted. This indicated possible operational features of a cell in series but since it received no influent from cell one it is only a simulation.

A summary of the data acquired during cell one and cell two operation is shown in Tables 4 and 5. Four values are reported for each parameter. Each of these values represents an average of several samples. The data of cell two (the batch process) also indicates testing on a three or four day subsequent time period.

Several features are apparent from the data of Tables 4 and 5. The temperature of the influent averaged about 12°C. The temperature of the effluent from cell one or two is modified by the ambient air temperature. The shorter the detention time the closer the effluent temperature will be to the influent temperature.

During this test period an increase in algae concentration was noted. The increase was significant during cell two operation. The BOD data indicates a reduction to about 37 mg/l (filtered) but about 60 with the algae. During cell two operation a further increase in BOD to around 75-80 is noted. The filtered also increased to 51 perhaps due to non-filterable algae waste.

At the loading intensity of 320 lbs. BOD/acre/day no settleable solids were produced in the effluent from cell one or cell two. Sedimentation would not improve efficiency.

The dissolved oxygen level remained at about 7 mg/l during this loading. When the influent flow was stopped again the dissolved oxygen approached the saturation levels. Dissolved oxygen samples were taken at 12 noon. Under cell one operation the dissolved oxygen level varied from about 2 mg/l at daylight to about 10 mg/l in middle afternoon. A noon sample was selected as representative of the average value.

Both coliform and total bacteria count were secured for cell one and cell two. The total count was determined on Henrici's Agar should be considered the base count with the TSA method used to check reliability.

The second cell bacteria values in Table 5 were from a sample taken two weeks after the beginning of cell two operation. The total count appears to be in the same magnitude range in cell one and cell two. The coliform count is reduced to 5/ml in test two. Under the environmental conditions of cell two, coliforms are unable to compete and die-off is rapid.

900 Lbs. BOD/Acre/Day Loading

A loading intensity of 900 lbs. BOD/acre/day (4.08 lbs. BOD/1,000 ft^3/day) was initiated in late May. Due to infiltration from snow melt a loading of 700 lbs. BOD/acre/day was the maximum attainable until June 5. At that time a uniform loading intensity of 900 lbs. BOD/acre/day was achieved and maintained. The system was operated at this level for about four weeks. The detention time was 3.0 days.

TABLE 4

STEADY STATE TEST RESULTS
AERATED LAGOON LOADING
320 Lbs./Acre/Day

TESTS	FIRST CELL		SECOND CELL
	Influent	Effluent	Effluent
Temperature (°C)	12	5	7
	12	6	10
	12	7	11
	12	6	9
TS (mg/l)	1430	1264	- -
	1504	1337	1195
	1859	1325	1372
	1486	1279	1440
TVS (mg/l)	409	298	- -
	355	350	317
	- -	- -	288
	364	312	251
TSS (mg/l)	606	87	- -
	- -	- -	288
	1327	136	188
	575	100	208
VSS (mg/l)	324	87	- -
	- -	- -	152
	- -	- -	144
	305	98	142
Settleable Solids (ml/l)	9	0	0
	10	0	0
	8	0	0
	7	0	0
Alkalinity (mg/l) as $CaCO_3$	304	296	- -
	360	279	268
	282	287	280
	346	300	- -
Hardness (mg/l)	632	772	- -
	612	752	732
	624	780	780
	628	784	- -
pH	7.5	8.0	8.6
	7.9	8.0	8.7
	7.5	8.2	8.8
	7.5	8.2	8.4

TABLE 5

STEADY STATE TEST RESULTS
AERATED LAGOON LOADING
320 Lbs./Acre/Day

TESTS	FIRST CELL Influent	FIRST CELL Effluent	SECOND CELL Effluent
SO_4^{-2} (mg/l)	800	1200	1250
	600	800	1000
	500	700	750
	600	800	750
NO_3^{-1} (mg/l)	0.0	5.0	3.0
	8.0	8.0	0.0
	6.0	2.0	0.0
	0.0	0.0	0.3
PO_4^{-3} (mg/l)	3	10	25
	8	12	23
	18	28	9
	18	12	7
DO (mg/l)	0	6.6	8.6
	0	6.6	8.0
	0	7.0	7.6
	0	7.0	8.2
COD (mg/l)	313	156	- -
	339	131	200
	338	202	185
	- -	- -	173
Biochemical Oxygen	223	56(filtered)	72(filtered)
	203	69 (37)	76 (51)
	224	63	91
	165	50	75
Coliform Bacteria	5 X 10^5	9 X 10^3	5
Total Bacteria Henrici's Agar*	- -	2.2 X 10^7	4 X 10^7
TSA**	- -	1.1 X 10^7	1.1 X 10^7

*Henrici's Agar incubated at 30°C (dilute medium with a wide variety of carbon and energy sources).
**TSA incubated at 30°C (rich nutrient medium), Trypticase Soy Agar-BBL Division of Bioguest, Cockeysville, Maryland.

At the end of this period the influent loading to the aerated lagoon was stopped. This provided a means for assessing the performance of a second cell in series.

Since the second cell received no loading the second cell operated under batch type conditions and only simulated series operation. This batch process did indicate several operational conditions. Aeration was continued at 900 cfm during both cell operations.

A summary of data acquired during cell one and cell two testing is shown in Tables 6 and 7. Four values are shown for each parameter. Each of these values represents an average of several samples. The data of cell two (batch process) also indicates testing on a three or four day subsequent time period.

Several features are apparent from the data of Tables 6 and 7. The temperature of the influent remains, as in the other test periods, at 12°C. The effluent temperatures however are now equal to or greater than the effluent because of high ambient temperatures.

Significant BOD and COD reduction was experienced for the 900 lbs. BOD/acre/day loading. BOD reduction averaged about 80% to 88% in cell one.

At this loading intensity the algae produced in cell two from the 320 lbs. BOD/acre/day load were rapidly reduced and they did not significantly reappear until the 900 lbs. BOD/acre/day loading was stopped and cell two operation was begun.

At a loading of 900 lbs. BOD/acre/day no settleable solids were produced in the effluent from cell one or cell two. The biological process would not be improved by sedimentation tank in series operation.

The dissolved oxygen level varied from about .5 mg/l at daybreak to about 4.4 mg/l during the rest of the day under cell one operation. Under cell two operation the dissolved oxygen varied from zero at daybreak to about 6.8 mg/l in late afternoon. A noon sample gave an average value for this variation. The influence of heavy loading and algae is apparent.

Both coliforms and total bacteria count were secured for cell one and cell two. The total count as determined on Henrici's Agar should be considered the base count with TSA count used for magnitude check. The second cell bacteria reported in Table 7 were from a sample taken two weeks after the beginning of cell two operation. The total count indicates the total bacteria population remains constant for cell one and cell two operations. However, coliforms are not competitive in this environment and are reduced to about 15/ml after two weeks.

Increase in VSS, BOD, COD and average pH in cell two indicate algae production. Increase in TS, hardness and SO_4 indicates solution of gypsum from berm of lagoon.

TABLE 6

STEADY STATE TEST RESULTS
AERATED LAGOON LOADING
900 Lbs./Acre/Day

TESTS	FIRST CELL Influent	FIRST CELL Effluent	SECOND CELL Effluent
Temperature (°C)	12	11	19
	12	11	18
	12	12	20
	12	14	--
TS (mg/l)	1991	1022	1751
	1918	1366	1812
	1833	1469	2134
	1910	1540	- -
TVS (mg/l)	331	325	335
	365	267	411
	386	300	676
	361	286	- -
TSS (mg/l)	255	65	104
	200	59	127
	269	71	296
	241	74	340
VSS (mg/l)	158	60	130
	108	50	132
	159	71	172
	142	68	120
Settleable Solids (ml/l)	9	0	0
	8	0	0
	7	0	0
	9	0	-
Alkalinity (mg/l) as $CaCO_3$	248	240	228
	254	220	220
	268	240	246
	280	244	224
Hardness (mg/l) as $CaCO_3$	1240	820	1140
	900	800	1160
	1040	880	1160
	1068	980	1150
pH	7.7	7.7	7.7
	7.4	7.7	8.6
	7.3	7.6	8.3
	7.5	7.7	8.6

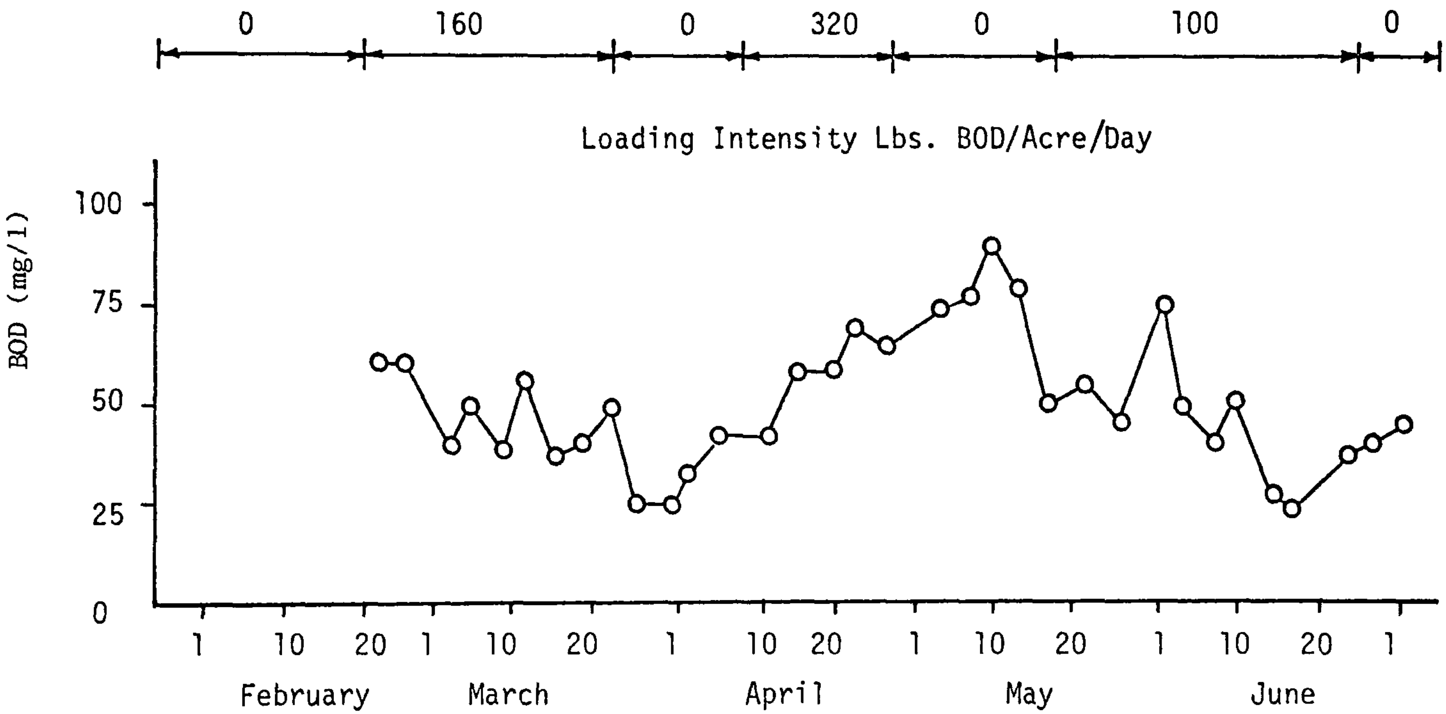
TABLE 7

STEADY STATE TEST RESULTS
AERATED LAGOON LOADING
900 Lbs./Acre/Day

TESTS	FIRST CELL Influent	FIRST CELL Effluent	SECOND CELL Effluent
SO_4^{-2} (mg/l)	1500	1000	1000
	850	750	1500
	1250	1250	1500
	1000	1000	1500
NO_3^{-1} (mg/l)	0.0	0.5	0.0
	0.5	0.0	0.0
	0.0	0.0	1.0
	0.0	0.0	0.0
PO_4^{-3} (mg/l)	5	15	10.0
	10	7.5	10.0
	7.5	5.0	10.0
	10	6.0	- -
DO (mg/l)	0.5	1.5	5.5
	0.0	4.4	5.5
	0.0	3.5	5.5
	0.0	3.0	- -
COD (mg/l)	164	40	163
	300	80	259
	279	65	269
	368	98	- -
Biochemical Oxygen Demand (BOD) (mg/l)	225	51	40(filtered)
	175	54	45 (40)
	199	30	90
	200	25	125
Coliform Bacteria (Number/ml)	5×10^5	1.7×10^4	15
Total Bacteria (Number/ml)			
Henrici's Agar*	- -	5×10^7	2.8×10^7
TSA**	- -	8.6×10^6	2.1×10^7

*Henrici's Agar incubated at 30°C (dilute medium with a wide variety of carbon and energy sources).
**TSA incubated at 30°C (rich nutrient medium), Trypticase Soy Agar-BBL Division of Bioguest, Cockeysville, Maryland.

A summary of curves indicating values of several parameters identified under the various loadings and conditions is illustrated in Figure 20 through 24.



Effluent BOD (five-day 20°C) vs. Loading Intensity

Figure 20

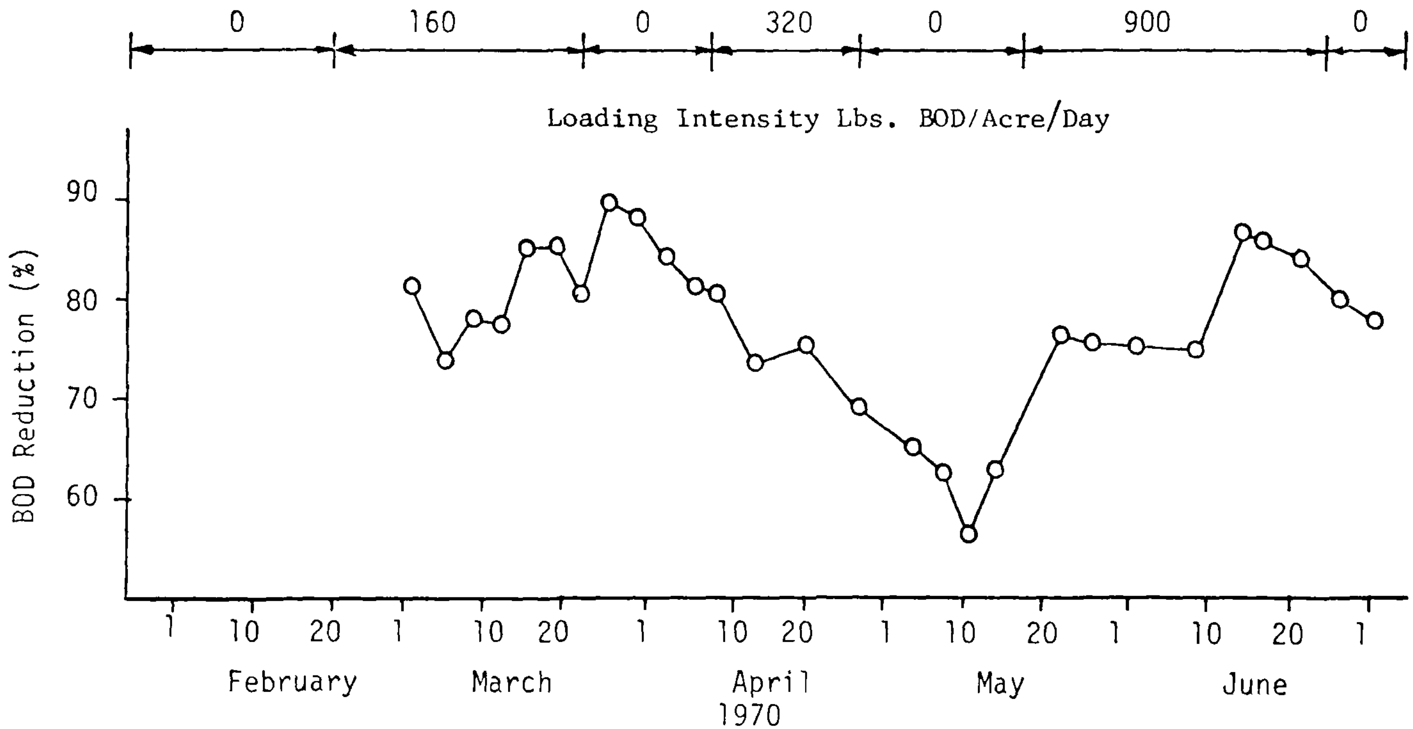
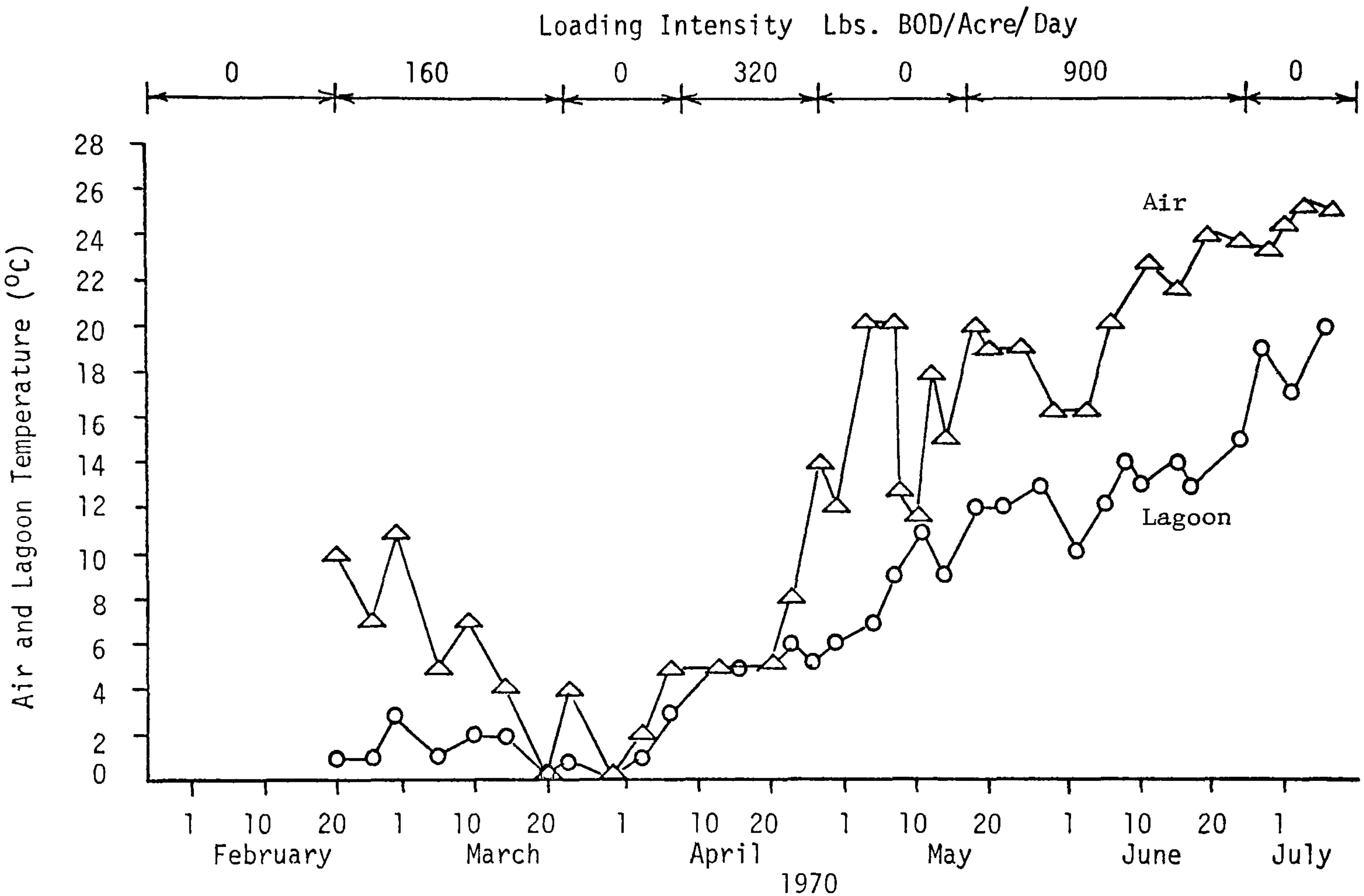
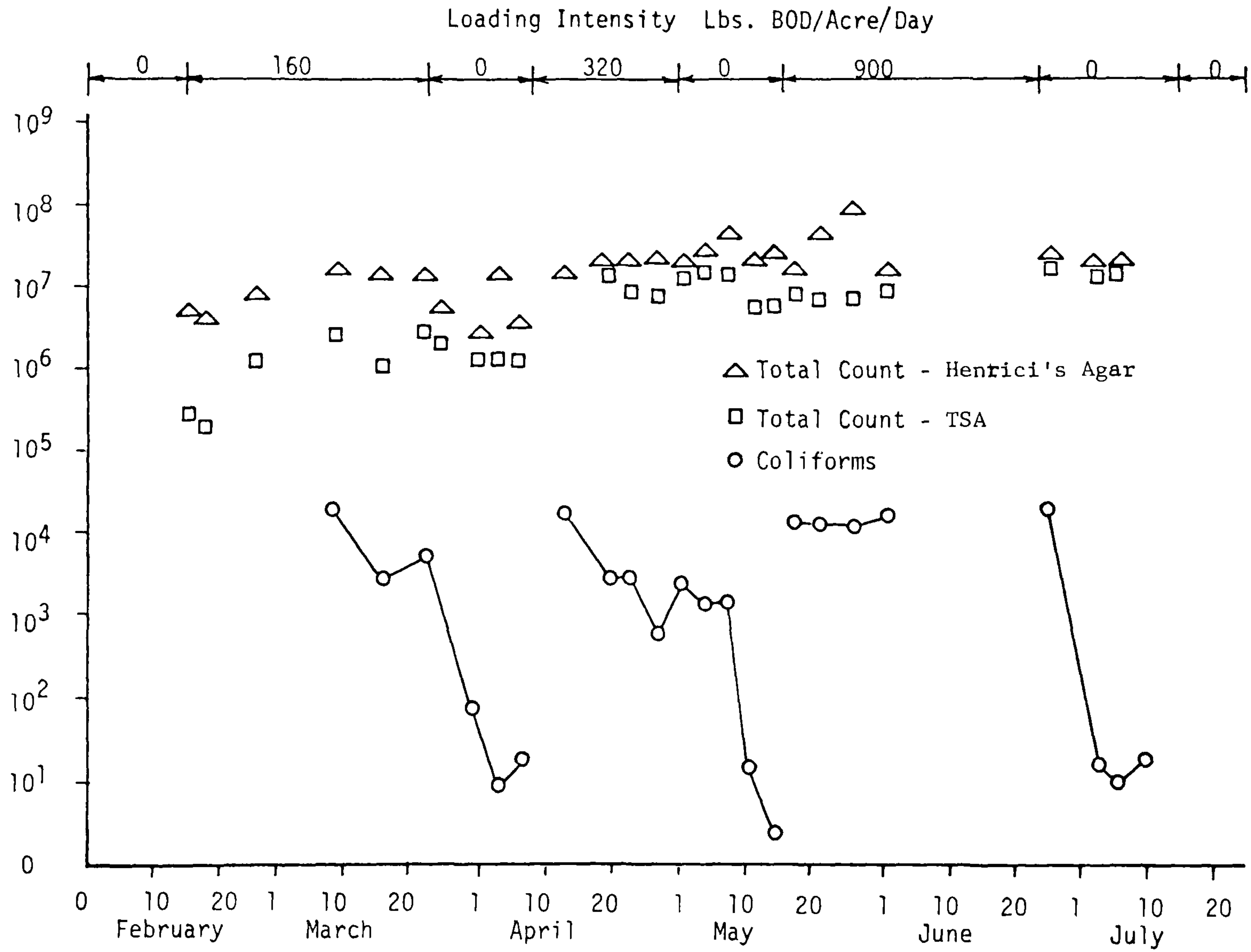


Figure 21 Percent Reduction of BOD



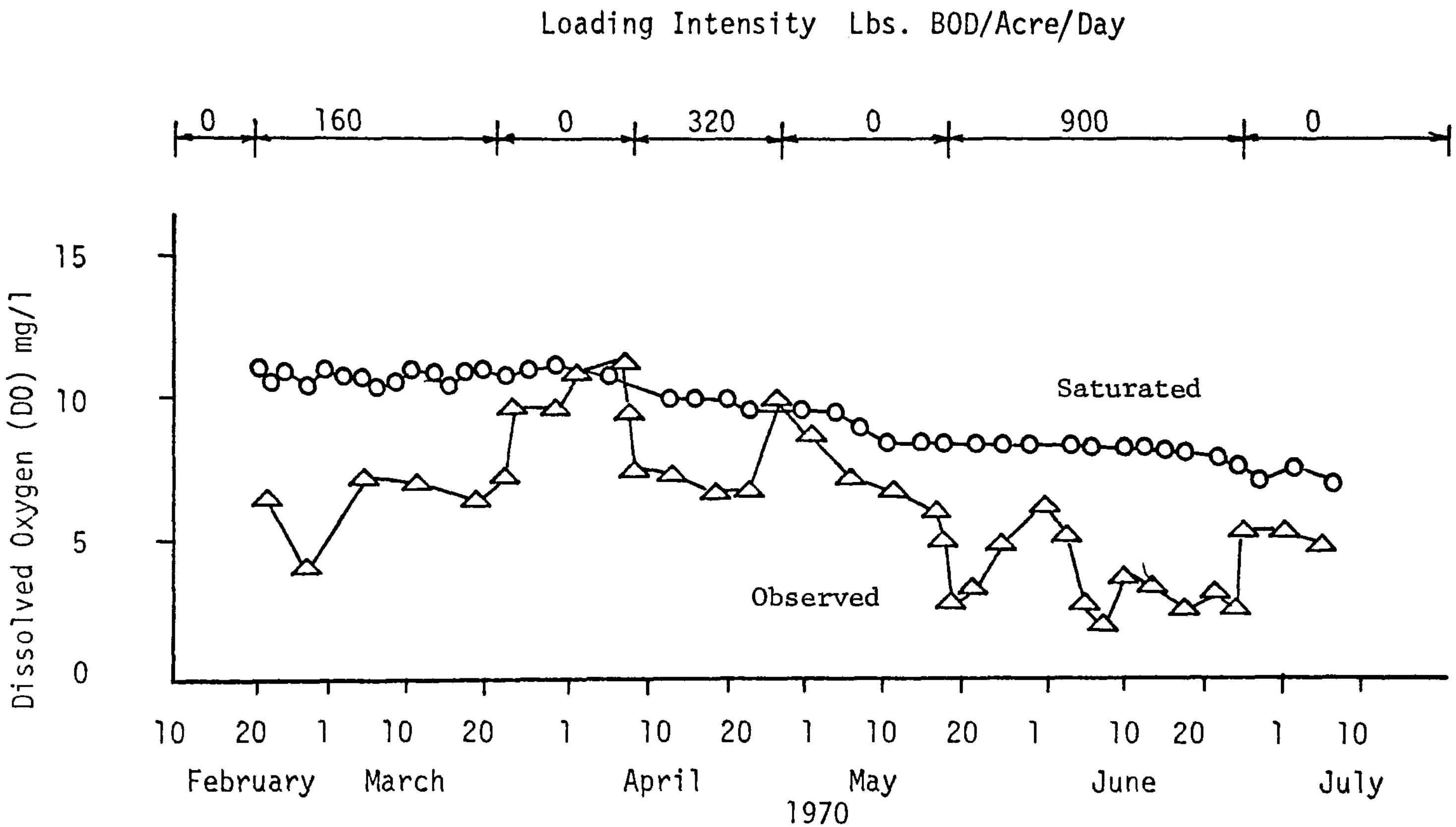
Air and Lagoon Temperatures (°C) vs. Loading Intensity

Figure 22



Total Bacteria and Coliform Counts vs. Loading Intensity

Figure 23



Dissolved Oxygen and Saturation Values vs. Loading Intensity

Figure 24

SECTION VII

SUMMARY AND CONCLUSIONS

First Cell Summary

The data summarized in this section refers to loadings of 160, 320 and 900 pounds per acre/day used in the 1970 tests. Table 8 shows the percent reduction in BOD between the influent of raw sewage and the effluent from cell one. The influent five-day 20°C BOD was determined from a composite sample. At the 160 lbs./acre/day loading the effluent had a BOD of 34 mg/l for an efficiency of 85% with no algae present. The average temperature was approximately 2°C. At the 320 lbs. per acre/day loading the temperature increased to about 6°C and an algae bloom developed. Tests with algae shows an average BOD of 57. Tests after filtering the algae gave a value of 37. At the 900 lbs./acre/day loading, algae were still present in the effluent but at a greatly reduced concentration. Effluent BOD was 39 mg/l in the filtered sample for an efficiency of 80 percent. The average temperature in this test was 12°C. These values are slightly better than data from 1969 testing. Since testing in 1969 was done in reverse order of loading from high to low, better efficiency at lower loadings in 1970 seems to indicate that some sludge setting in 1969 and delayed metabolism masked lower loading values.

Table 9 shows the change in coliform count and total bacteria count at the three loading conditions of the first cell. Of significance in this table is the smaller increase (2.3 times) of coliform bacteria as compared to a larger increase (4.2 times) in total bacteria as loading increased from the low loadings of 160 lbs./acre/day to the high loading of 900 lbs./acre/day (5.6 times). Apparently as loading increases the coliform group is less able to compete and are reduced. Since Table 8 shows no significant difference in BOD reduction under different loadings, a difference in bacterial population or kind must exist. Table 9 shows an increase proportional to loading. Differences from exact proportion can be rationalized from increased temperature at higher loadings.

Table 10 shows the removal of the physical variables the first cell loadings. It is noted that values from influent samples at various loadings are not consistent even though the values reported were averaged over the period. Over the test period several influent parameter changed in magnitude. This can possibly be explained by: (1) Laramie is a college town resulting in fluctuations in sewage flow depending on student presence, (2) variations in air temperatures resulting in changes in infiltration rates.

TABLE 8

SUMMARY OF AVERAGE BIOCHEMICAL OXYGEN DEMAND
AERATED PILOT LAGOON
FIRST CELL

Loading Conditions	Influent mg/l	Effluent mg/l	reduction (percent)	temperature
160 lbs./acre/day (no algae)	204	34	85	2°C
320 lbs./acre/day (algae)	203	57	72	6°C
320 lbs./acre/day (algae filtered out)	203	37	82	6°C
900 lbs./acre/day (algae)	200	40	80	12°C
900 lbs./acre/day (algae filtered out)	200	39	80	12°C

The reduction of TSS and VSS from influent to effluent samples was either from solids settling in the lagoon or as a result of biological activity. The solids settled were not significant based on deposits remaining in the lagoon after the test program (lagoon drained).

Table 11 indicates the average value of chemical tests performed under the three loading conditions. The table again shows a variation of influent during the three loading periods. Hardness increased due to the change in infiltration rate or ionization of wind-blown gypsum from the berm. The hardness and sulfate concentration at the 900 lbs./acre/day load is indicative of gypsum.

TABLE 9

TOTAL BACTERIA AND COLIFORM COUNTS
(FIRST CELL)

Loading	Coliform Number/ml	Total Number/ml	Temperature Average
160 lbs./acre/day	7.5×10^3 (average)	1.2×10^7 (Henrici's) 1.9×10^6 (TSA)	2^oC
320 lbs./acre/day	9.0×10^3 (average)	2.2×10^7 (Henrici's) 1.0×10^7 (TSA)	6^oC
900 lbs./acre/day	1.7×10^4 (average)	5.0×10^7 (Henrici's) 8.6×10^6 (TSA)	12^oC

TABLE 10

SUMMARY OF AVERAGE PHYSICAL TEST RESULTS
AERATED PILOT LAGOON
FIRST CELL

Aerated Lagoon Loading 160 lbs./acre/day				
TS (mg/l)	Influent	1290.0	% Removal	18
	Effluent	1061.0		
TVS (mg/l)	Influent	413.0	% Removal	35
	Effluent	271.0		
TSS (mg/l)	Influent	363.0	% Removal	86
	Effluent	51.0		
VSS (mg/l)	Influent	242.0	% Removal	85
	Effluent	37.0		

Aerated Lagoon Loading 320 Lbs./acre/day				
TS (mg/l)	Influent	1570.0	% Removal	17
	Effluent	1301.0		
TVS (mg/l)	Influent	376.0	% Removal	15
	Effluent	320.0		
TSS (mg/l)	Influent	836.0	% Removal	87
	Effluent	107.0		
VSS (mg/l)	Influent	223.0	% Removal	71
	Effluent	92.0		

Aeraged Lagoon Loading 900 Lbs./acre/day				
TS (mg/l)	Influent	1917.0	% Removal	29
	Effluent	1350.0		
TVS (mg/l)	Influent	361.0	% Removal	18
	Effluent	295.0		
TSS (mg/l)	Influent	241.0	% Removal	72
	Effluent	67.0		
VSS (mg/l)	Influent	142.0	% Removal	56
	Effluent	62.0		

TABLE 11

SUMMARY OF AVERAGE CHEMICAL TEST RESULTS
AERATED PILOT LAGOON
FIRST CELL

Aerated Lagoon Loading		160 lbs./acre/day	320 lbs./acre/day	900 lbs./acre/day
Alkalinity (mg/l)	Influent	338	323	260
	Effluent	314	290	236
Hardness (mg/l)	Influent	542	624	1062
	Effluent	610	772	870
pH	Influent	7.5	7.6	7.5
	Effluent	7.7	8.1	7.7
SO_4^{-2} (mg/l)	Influent	415	625	1150
	Effluent	437	875	1000
NO_3^{-1} (mg/l)	Influent	8.0	3.5	0.0
	Effluent	8.0	3.7	0.0
PO_4^{-3} (mg/l)	Influent	25	12	8.0
	Effluent	17	15	8.4
DO (mg/l)	Influent	0	0	0.0
	Effluent	7	3.5	3.1
COD (mg/l)	Influent	491	263	277
	Effluent	102	163	71

The pH increased to 0.5 units at the 320 lbs./acre/day load. This was due to algal absorption of CO_2. Algal absorption of phosphate also occurred in this loading. In order to evaluate this absorption, samples were filtered and tested. Filtered samples contained no phosphate ions indicating absorption in the algal mass.

Although the BOD test is an indication of biologically oxidizable organic matter, a chemical oxidation test (COD) can also give valuable information as to the effectiveness of treatment technique. Under the 160 lbs./acre/day process loading the BOD removal was 85% in comparison to a COD reduction of 80%. Under the 320 lbs./acre/day process load the BOD removal was 72% (with algae) and only 38% removal of COD. This clearly indicates the inadequate nature of the BOD test as a lone criteria of treatment efficiency. Under the 900 lbs./acre/day process load, very little algae were present and COD reduction of 75% again is significant.

First Cell Conclusions

Operation of the aerated first cell proved very successful both from the stabilization efficiency of BOD removal and percentage reduction of the physical and chemical parameters in the effluent. BOD removal in the range of 75 to 85 percent for these loading rates at temperatures below 12°C was encouraging. At low loading intensities, common in normal lagoon practice, a large surface area is required and an effluent at best of 85 to 90% BOD reduction is produced. Although the algae do not significantly affect the BOD test their effect is dramatic on the COD test. Using the high loading of greater than 900 lbs./acre/day corrects both problems of large surface area and heavy algae production and release.

Second Cell Summary

The data summarized in this section refers to second cell operation after successive process loadings of 160, 320 and 900 lbs./acre/day used in the 1970 tests. These results indicate batch-type operation and not true series operation. However, they do indicate several variations of boundary conditions important for engineering consideration.

Table 12 shows the percent reduction in BOD between the steady state batch condition and the effluent from cell two. It is apparent that as far as BOD is concerned, little or negative results occurred. Again, algae production under the 320 and 900 lbs./acre/day loading increased the effluent BOD.

Table 13 shows the change in coliform and total bacterial count after nine two-week periods in cell two. The average coliform count of cell one (7.5×10^3 to 1.7×10^4) of about 10,000 per ml is reduced to about

TABLE 12

SUMMARY OF AVERAGE BIOCHEMICAL OXYGEN DEMAND
AERATED PILOT LAGOON
SECOND CELL

Aerated Lagoon - No Influent - First Cell Loading Was 160 Lbs./acre/day

BOD			
Influent	34	% BOD Reduction	3
Effluent	33		

Aerated Lagoon - No Influent - First Cell Loading Was 320 Lbs./acre/day

BOD		
Influent	57 with algae	% BOD Reduction
	37 with algae removed	
Effluent	78 with algae	-37 with algae
	51 with algae removed	-28 with algae removed

Aerated Lagoon - No Influent - First Cell Loading Was 900 Lbs./acre/day

BOD		
Influent	40 with algae	% BOD Reduction
	39 with algae removed	
Effluent	80 with algae	-100 with algae
	39 with algae removed	0 with algae removed

TABLE 13

TOTAL BACTERIA AND COLIFORM COUNT
IN SECOND CELL TESTS

Loading Condition*	Coliform Bacteria Count	Total Bacteria Count
160 lbs./acre/day	Die-off to 10/ml in two weeks	7.2×10^6/ml (Henrici's)
		1.8×10^6/ml (TSA)
320 lbs./acre/day	Die-off to 5/ml in two weeks	4.0×10^7/ml (Henrici's)
		1.1×10^7/ml (TSA)
900 lbs./acre/day	Die-off o 15/ml in two weeks	2.8×10^7/ml (Henrici's)
		2.1×10^7/ml (TSA)

*Loading Condition preceded second cell.

10 per ml in cell two. In this environment the coliform organisms obviously fail to compete. A comparison of total bacterial counts from all three loads shows that they tend to level off at around 2×10^7 ml after two weeks.

Table 14 shows average values and percent removal of physical variables in the second cell for the three loadings. Test results under the 160 lbs./acre/day loading indicate no significant change in solids in the second cell. Under the 320 lbs./acre/day loading the percent removal is generally negative indicating an increase in the second cell. The removal is also negative at the 900 lbs./acre/day load. These can be attributed to an abundant growth of algae in the second cell.

The chemical tests shown in Table 15 indicate no significant changes except in pH, DO and COD. The pH in the second cell system tends to increase from 0.5 to 1.0 units as preliminary loading increases. This is indicative of changes in CO_2 concentrations due to algal growth. There is a significant change in DO concentration in the second cell. From all three loading systems of the first cell the DO increased to saturation in cell two. Again the algal cycle produced a variation in DO during the day as shown by testing in cell one. A sample secured at noon was considered average.

The results of the COD test under second cell conditions indicate a reduction of oxidizable organic matter only in the absence of algae. For example, only after the 160 lbs./acre/day loading was there a decrease in COD. During this test loading no algae were produced. However, after the 320 and 900 lbs./acre/day loading the COD increased. Under these loadings significant algae production occurred.

Second Cell Conclusions

Test results from the second cell indicate little increase in efficiency over the first cell performance. In addition, algal growth is not inhibited in this cell; in fact, the rate of algal production was very high. This is indicated by the increase in BOD and COD in this cell. Table 12 indicates the difference in BOD readings with and without algae. The BOD is higher if algae is included. Although the nuisance or pollutional effect of releasing this large algal production into a river is generally not considered serious, the esthetic value of the river is considerably diminished for many miles downstream.

Although at first sight there seems to be little reason for second cell operation, day to day testing indicates that the BOD, COD, DO and pH from the effluent of the first cell vary from the average values given in the Tables. A second cell operation without algae would tend to dampen out this variation. A second and more important feature of the second cell

TABLE 14

SUMMARY OF AVERAGE PHYSICAL TEST RESULTS
AERATED PILOT LAGOON
SECOND CELL

Aerated Lagoon - No Influent - First Cell Loading Was 160 lbs./acre/day				
TS (mg/l)	Influent	1061.0	% Removal	1
	Effluent	1050.0		
TVS (mg/l)	Influent	271.0	% Removal	22
	Effluent	210.0		
TSS (mg/l)	Influent	51.0	% Removal	8
	Effluent	47.0		
VSS (mg/l)	Influent	37.0	% Removal	0
	Effluent	37.0		
Aerated Lagoon - No Influent - First Cell Loading Was 320 lbs./acre/day				
TS (mg/l)	Influent	1301.0	% Removal	-2
	Effluent	1336.0		
TVS (mg/l)	Influent	320.0	% Removal	11
	Effluent	285.0		
TSS (mg/l)	Influent	107.0	% Removal	-110
	Effluent	228.0		
VSS (mg/l)	Influent	92.0	% Removal	-60
	Effluent	146.0		
Aerated Lagoon - No Influent - First Cell Loading Was 900 lbs./acre/day				
TS (mg/l)	Influent	1350.0	% Removal	-30
	Effluent	1751.0		
TVS (mg/l)	Influent	295.0	% Removal	-13
	Effluent	335.0		
TSS (mg/l)	Influent	67.0	% Removal	-110
	Effluent	140.0		
VSS (mg/l)	Influent	62.0	% Removal	-110
	Effluent	130.0		

TABLE 15

SUMMARY OF AVERAGE CHEMICAL TEST RESULTS
AERATED PILOT LAGOON
SECOND CELL

Aerated Lagoon - No Influent - First Cell Loading Was		160 lbs./ acre/day	320 lbs./ acre/day	900 lbs./ acre/day
Alkalinity (mg/l)	Influent	314	290	236
	Effluent	319	274	230
Hardness (mg/l)	Influent	610	772	870
	Effluent	568	756	1150
pH	Influent	7.7	8.1	7.7
	Effluent	8.2	8.6	8.6
SO_4^{-2} (mg/l)	Influent	437	875	1000
	Effluent	430	940	1500
NO_3^{-1} (mg/l)	Influent	8.0	3.7	0.0
	Effluent	4.0	1.0	0.0
PO_4^{-3} (mg/l)	Influent	17	15	8.4
	Effluent	20	16	8.6
DO (mg/l)	Influent	7.0	3.5	3.1
	Effluent	11	8	5.5
COD (mg/l)	Influent	102	163	145
	Effluent	84	186	250

concerns coliform reduction. As indicated in Table 13 the coliform count is significantly reduced by second cell operations. This feature is important assuming pathogenic organisms are reduced at the same or faster rates. A third feature of second cell operation is the trend toward saturated oxygen levels in cell two. Of course this varies in presence of algae.

SECTION VIII

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Mr. Jim Nelson -- City Engineer, and
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SECTION IX

REFERENCE

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16. Abstract

A field investigation, using a pilot scale unit, determined the effects of supplementary aeration on Waste Stabilization Lagoon performance. The climate can be considered rigorous (high altitude - cold temperatures). Both complete mix and batch experiments were conducted. Air flow was constant, and loading rates, both hydraulic and process, were changed from 160 to 900 lbs BOD/acre/day. INKA aeration system performed the two functions.

The BOD reduction varied from 72% to 85% under three different loading conditions. The temperature of the aerated sewage was below 12°C. Solids removal was significant. No settleable solids resulted from the system, indicating no bio-flocculation. Change in total bacterial counts were roughly proportional to the change in loading.

Tests on a second cell, functioning as a batch process, indicated an increase of oxygen levels to saturation level. Significant algae production also occurred at temperatures of 6°C. Coliform bacteria were reduced to about 10/ml in the second cell. Total bacteria counts remained about the same as indicated in first cell tests.

17a. Descriptors

*Oxidation Lagoons, Aeration

17b. Identifiers

*Waste Stabilization Lagoons, *Supplementary Aeration, Biochemical Oxidation Demand removal, Solids removal, Coliform Bacteria removal

17c. COWRR Field & Group

18. Availability

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