EPA-600/2-76-131
June 1976

# OVERLAND FLOW TREATMENT OF RAW WASTEWATER WITH ENHANCED PHOSPHORUS REMOVAL

by

R. E. Thomas, B. Bledsoe, and K. Jackson
Wastewater Management Branch
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
ADA, OKLAHOMA 74820

## DISCLAIMER

This report has been reviewed by the Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

A 36-month pilot study was conducted to evaluate the capability of overland flow to provide complete treatment of raw comminuted wastewater on a year-round basis in mild climates. This second report in a series covers 36 months of performance at a loading of 10 cm/week and a special 15-month adjunct on phosphorus removal by chemical precipitation with aluminum sulfate. Data for 15 parameters are included, and data for suspended solids, biochemical oxygen demand, chemical oxygen demand, total organic carbon, nitrogen, and phosphorus are covered in detail. Data collected over the 36-month period show overland flow to be a simple and reliable treatment process. Pilot studies are continuing at this laboratory, and field projects are underway in two states.

This report was submitted as an in-house project by the Wastewater Management Branch, Robert S. Kerr Environmental Research Laboratory, of the Environmental Protection Agency. Work was completed as of December 1974.

# CONTENTS

# LIST OF FIGURES

## LIST OF TABLES

## SECTION I
## INTRODUCTION

Overland-flow treatment is achieved by allowing a wastewater to trickle slowly over gently sloping ground as sheet flow. Other names including "spray-runoff" and "grass filtration" are also used to indicate this type of treatment. The term overland flow has been used by the authors in a previous report and will also be used throughout this second report in a series on treatment of raw domestic wastewater. The rationale for testing the capability of overland flow to treat raw domestic wastewater was covered in detail by Thomas, Jackson, and Penrod[1] in the initial report of this series, and a brief recapitulation is all that will be given in this report.

Briefly, the development of overland flow in the United States appears to have originated from experiences with a spray disposal system discussed by Luley[2] in 1963. Subsequent reports of other studies such as those by Bendixen, et al.[3], Law, Thomas, and Myers[4], and Kirby[5] provided background information supporting the hypothesis that overland flow could be utilized as a practical system for rural communities in mild climates.

The results of the initial phase of this three-phase study showed that overland-flow treatment can perform satisfactorily with an average load of 10 cm/week under climatic conditions comparable to those in southcentral Oklahoma. A well-operated system should produce an effluent with less than 10 mg/l of suspended solids and biochemical oxygen demand, while removing 70 to 90 percent of the total nitrogen. Phosphorus removal, as expected, averaged about 50 percent for this initial phase of the study project and is a factor deserving further assessment.

The principal objectives for the research period covered in this report were to (1) evaluate the enhancement of phosphorus removal by addition of aluminum sulfate, (2) continue the assessment of treatment capability for other parameters, and (3) verify the reliability of the initial phase design data.

## SECTION II
## SUMMARY

Data have been reported from a 36-month study of overland-flow treatment of raw comminuted wastewater. This report, which is the second in a series, emphasizes a study on phosphorus removal, while summarizing overall performance over two study periods for other parameters. Data for the 36-month period continue to show that overland flow is a simple and economical process, which achieves advanced waste treatment without sludge production. Pretreatment needs only remove solids which cannot be comminuted to pass nozzle orifices and provide for odor control at the point of pickup.

The overland-flow process can produce an effluent of the following chemical quality while treating a typical raw comminuted wastewater at a loading rate of about 10 cm/week in a mild climatic zone. Total suspended solids and biochemical oxygen demand will be less than 10 mg/l throughout the year. Total nitrogen will range from 2 to 10 mg/l with concentrations greater than 5 mg/l limited to a brief period of 2 to 3 months in the winter season, largely as nitrate. Total phosphorus will be about 5 mg/l unless the system is designed especially for phosphorus removal. Use of aluminum to precipitate phosphorus reduces the phosphorus concentration to about 1.0 mg/l. The summer values for phsophorus will be slightly less than winter values, but seasonal differences in phosphorus removal will be minor.

It is noteworthy that the effluent from this 36-month evaluation of the overland-flow process is substantially better than established criteria for secondary treatment. Satisfactory development and demonstration of several operating scale systems employing the overland-flow approach will provide the waste treatment community with a new tool which will have particular value for application in small rural communities.

# SECTION III
# CONCLUSIONS

It is feasible to utilize overland flow to achieve advanced waste treatment of raw comminuted wastewater.

It should be practical to develop simple and economical systems for use at rural communities in mild climates.

Such systems should perform satisfactorily when loaded at an average loading of 10 cm/week when located at a site with climatic conditions comparable to the test site.

A well-operated system should produce an effluent with an average of 10 to 15 mg/l of suspended solids and about 10 mg/l of biochemical oxygen demand.

The system is reliable and the quality of the system effluent is consistent.

A well-operated system should achieve 90 percent nitrogen removal in the summer, but nitrogen removal may drop to 75 percent in the winter.

Phosphorus removal should be about 50 percent with relatively minor seasonal variation but can be improved to 90 percent by precipitation using aluminum sulfate.

## SECTION IV
## RECOMMENDATIONS

Overland flow should be tested and demonstrated at several locations in addition to the two sites already under study.

These communities should be located at places with varying climatic conditions to determine climatic limits.

Capital and operating cost data should be included in all evaluation programs for full-scale operational systems.

Pilot-scale studies should be conducted to evaluate the effect of pretreatment on treatment efficiency and system loading.

Pilot-scale studies should be conducted to evaluate a combination of overland flow followed by high-rate infiltration.

# SECTION V

# EXPERIMENTAL DESIGN AND OPERATION

The study was conducted at the field site of the Robert S. Kerr Environmental Research Laboratory located in Ada, Oklahoma. The climate at this location is suitable for year-round operation with minimal considerations due to severe weather conditions. Annual precipitation averages about 100 cm, and there is an average of 26 days per year with more than 1.25 cm of precipitation. Average minimum temperatures are above freezing for all months except January, when the average minimum dips to -1.0° C. Average daily maximum temperatures are greater than 10° C throughout the year. The experimental system was designed without special considerations for continuing operations during cold weather, and the downtime due to freezing weather was included as a variable for evaluation. The period of operation covered in this report includes two study periods. The first study period from March 1971 through September 1972 was a study of varying loading rates. The second period from November 1972 through March 1974 was a study of phosphorus removal at a constant loading rate selected on the basis of the results of the initial study period.

## SITE PREPARATION AND WASTEWATER DISTRIBUTION

The preparation of the site and the wastewater distribution system were identical for the latter part of the initial study period and throughout the second study period. The subsoil at the selected site is a dense clay that provided the restriction to downward movement of water which is necessary for successful installation and operation of an overland-flow system. Plots measuring 11 meters by 36 meters were smoothed to a uniform slope of 2 to 4 percent and provided with runoff sampling stations at the toe of the slope. Raw domestic wastewater was obtained from the city sewer main, settled for a few minutes to remove grit, skimmed to remove bothersome floatables, and comminuted to a fine particle size before being applied to the plots through a specially designed applicator. This wastewater handling system was fully automated to minimize time required for operation and maintenance. A schematic of the wastewater handling system is shown in Figure 1. The mutrator, pumps, and valves were controlled by a 7-day clock timer, permitting wastewater to be applied for periods of 3 hours or more on any given day of the week.

The applicator was designed to apply the wastewater without creating an aerosol and to operate at relatively low hydraulic pressures. The principal features of the applicator are fixed fan nozzles, a lightweight horizontal boom, and an easily rotatable vertical support. The applicators used to apply the wastewater to the experimental plots are shown in detail in Figure 2. The nozzles used were FF series flooding nozzles manufactured by Bete Fog Nozzle, Inc. They were the wide angle 145 degree nozzles made from PVC plastic. The boom was 2 cm schedule 40 PVC pipe supported by a 2 cm steel channel on the bottom and guy wires as shown in Figure 2. The rotatable vertical support was mounted in roller thrust bearings fastened to a concrete anchored stand. The wastewater transmission line was connected to the bottom of the rotatable vertical support with a standard hose swivel connector. With proper alignment and counterbalancing, the hydraulic pressure from the single fan nozzle with orifices as small as 0.5 cm and operating at a pressure of 1.0 kg/sq cm (15 psi) provided ample thrust to rotate the distributor boom. The variable loading rates for the first period of study were obtained by selection of nozzle orifice size, while the constant loading rate for the second period of study was obtained with a single size of orifice for all three plots. These distributor booms were mounted at a height of 1.2 m and applied the comminuted wastewater over one-third of the plot area on the upper part of the slope.

## FIELD OPERATIONS AND SAMPLE PROCESSING

The principal variable to be evaluated in the first period of study was the effect of loading rate on system performance under the influence of seasonal weather changes. Nozzles with differing orifices were used to obtain average areal loadings of 7.4, 8.6, and 9.8 cm per week. The actual loading rate was seasonally adjusted so that a 3-month-duration winter rate was 85 percent of the average rate, and a 3-month-duration summer rate was 115 percent of the average rate, while the spring and fall rates were equal to the average rate. Summer operation provided for 9 hours of application per day for 6 days a week. Spring and fall operation provided for 8 hours of application per day for 6 days per week, and winter operation provided for 8 hours of application per day for 5 days per week.

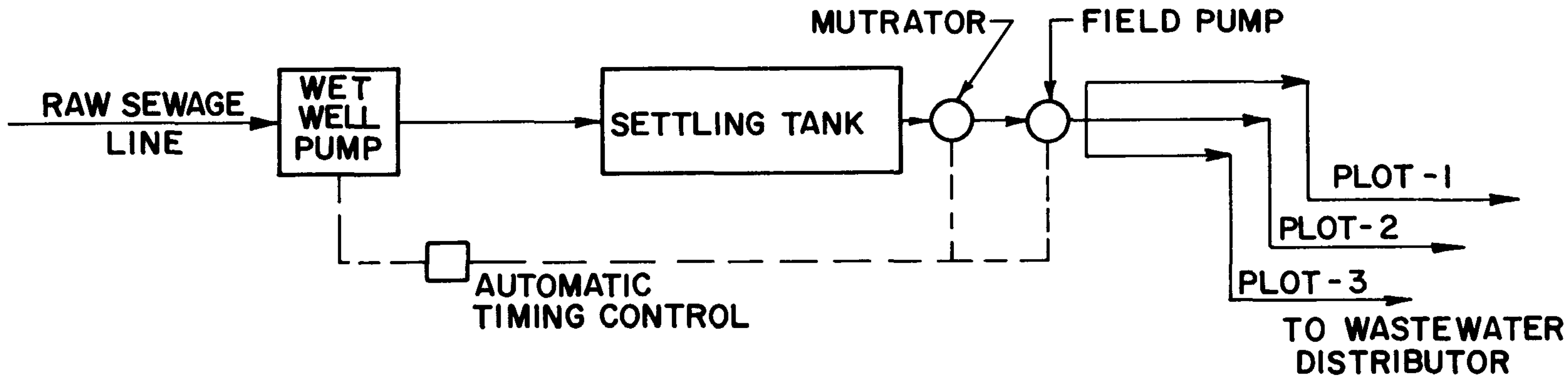


FIGURE 1 - SCHEMATIC OF WASTEWATER HANDLING SYSTEM

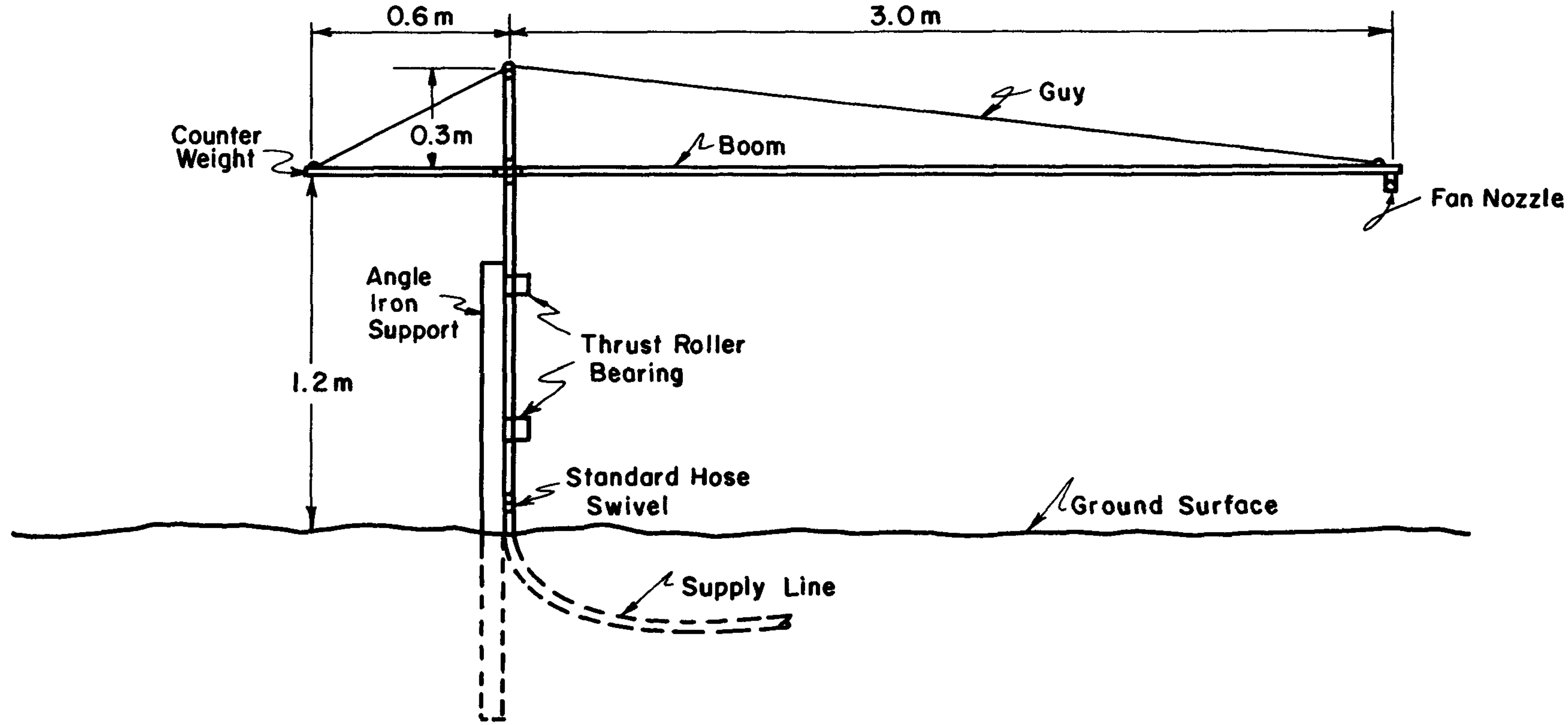


FIGURE 2 - DETAIL OF WASTEWATER DISTRIBUTOR

The principal factors to be evaluated in the second period of study were continuing performance at the high loading of 10 cm per week and enhancement of phosphorus removal. The seasonal adjustments of the loading rate were somewhat different from the first period of study with only a summer and winter level of loading being used. The study of enhanced phosphorus removal included a control plot which received no addition of aluminum sulfate, a plot receiving 20 mg/l of Al, and a plot receiving 15 mg/l of Al. The Al was injected into the raw wastewater lines with a metering pump. The point of injection was several feet beyond the field pump header shown in Figure 1.

The runoff data for determining the water balance were obtained by installing a V-notch weir in the collection ditch receiving the runoff from all three plots. This point was chosen for measuring the runoff in order to increase the area included and to reduce the influence of border effects. Previous attempts to measure runoff from the individual plots indicated that the influence of border effects prevented collection of reliable water-balance data.

Samples of the raw comminuted wastewater and the runoff from each of the three experimental plots were collected at weekly or biweekly intervals throughout the study, except for periods when operations were temporarily interrupted for removal of vegetation, or because of severe freezing conditions. Initially, the raw wastewater samples were collected as a composite of the comminuted wastewater being sprinkled on the plots throughout the 8- or 9-hour application period. This sample was collected into a container packed in ice to reduce compositional changes during sample collection. Collection of composite samples was terminated about halfway through the first study period after it had been determined that grab samples from the sedimentation tank provided comparable information on the quality of the raw wastewater. Runoff samples from the treatment plots were taken as a grab sample obtained while runoff was at its peak flow. Previous experience during the study reported by Law, Thomas, and Myers[4] had shown that grab samples taken this way are comparable in chemical quality to flow proportional composite samples.

All samples collected throughout both study periods were subjected to analysis for 15 chemical parameters frequently employed to characterize the solids content, oxygen demand, and nutrient content of wastewater. Total coliform, fecal coliform, and aluminum analyses were added to the analytical program during the second study period from November 1972 through March 1974. The analytical procedures used were selected from those published in "Methods for Chemical Analysis of Water and Wastes, 1971."[7]

## SECTION VI
## OPERATING RESULTS

Results from operation of the wastewater distribution system will be presented in several sections covering an initial shakedown period of 6 months, the first study period of 18 months, and the second study period of 15 months.

### SHAKEDOWN PERIOD

The initial design of the distribution system provided for the wet well wastewater pump to feed directly to the mutrator rather than the sedimentation and skimming tank shown in Figure 1. Operating with this design led to frequent nozzle plugging due to fragments of plastics, tinfoil, and other materials which were cut into pieces by the mutrator but would not pass through the 0.40 to 0.55 cm orifices being used to apply the comminuted wastewater to the experimental plots. The frequency of nozzle plugging was enough to require a full-time operator to visually inspect the system during the application periods. Attempts to screen the wastewater after comminution appeared to be substantially less practical than providing a presedimentation and skimming tank; therefore, the distribution system was modified to handle the wastewater as shown in Figure 1.

### AFTER ADDING SEDIMENTATION

Inclusion of the sedimentation and skimming tank substantially eliminated the frequent plugging experienced during the shakedown period. The tank used had a working depth of 0.4 m and provided a volume equal to about 10 minutes of the pumping rate of the wet well pump. Since the wet well pump capacity was greater than the capacity of the plot distribution pump, it was possible to utilize excess flow through the sedimentation tank to flush grit back to the sewer line through a return flow line in the bottom of the tank and to return skimmed floatables through an overflow line at the top of the tank.

Operating with this arrangement, maintenance of the system required about one hour per day. Duties performed were a routine checking and servicing of pumps, the mutrator, and the timer control system. Nozzle plugging was reduced to a frequency of one or two per week per nozzle. Most of these plugs were partial plugs, and a daily check of the system was sufficient to maintain the weekly loading to the experimental plots at the scheduled rates. This arrangement for the distribution system was used for the remainder of the first study period and throughout all of the second study period.

WEATHER EFFECTS ON OPERATION

It was projected that climatic conditions at this and other comparable sites would permit continuous operation throughout the winter with a minimum of freeze protection. This experimental system was run without freeze protection to get an estimate of the difficulties which would be encountered for a system operated in this manner. Temperatures for the three winter seasons included in the study period are shown in Table 1 along with the long-term norms. December temperatures have fluctuated about the norm while averaging 1° C less than the norm. February temperatures showed a similar fluctuation with an average matching the norm. January has been consistently colder than the norm, and has averaged 1.8° C less than the norm. Freezing has interrupted operations for 5 to 10 days during January and February each year.

It would be easy to provide adequate frost protection for the distribution system to avert this problem, but the effects on treatment efficiency may make it more desirable to opt for short-term storage of the untreated wastewater. This influence of weather conditions on treatment efficiency will be covered in the section on treatment performance.

PERCENT RUNOFF

Combined runoff from the three plot area (0.13 ha) was measured using a V-notch weir equipped with a stage recorder. No attempt was made to obtain a total water balance including evaporative losses and the amount of deep percolation. The specific purpose of these measurements was to approximate the fraction of the applied water that would be recovered as immediate and direct runoff for discharge to surface waters. Data for 87 runoff events from December 1973 through March 1974 totaling 7,815 $m^3$ of measured runoff from 16,691 $m^3$ of applied wastewater are summarized in Table 2. These data indicate that the overall recovery as runoff was about 50 percent of the applied wastewater, while the monthly recoveries ranged from a summer low of

Table 1. WINTER TEMPERATURES

| Winter Season | Mean Temperature °C | | |
|---|---|---|---|
| | Dec. | Jan. | Feb. |
| 1971-72 | 7.3 | 4.4 | 7.9 |
| 1972-73 | 3.4 | 2.4 | 5.4 |
| 1973-74 | 6.0 | 3.8 | 9.3 |
| Three-year Average | 5.6 | 3.5 | 7.5 |
| Long-term Norms | 6.5 | 5.3 | 7.5 |

Table 2. FRACTION OF APPLIED WASTEWATER MEASURED AS DIRECT RUNOFF

| Month | Events Tabulated | Volume Applied Per Event $M^3$ | Runoff Measured Per Event $M^3$ Mean | Range | Percent Runoff |
|---|---|---|---|---|---|
| J | 10 | 18 | 14.4 | 10.1-17.2 | 80 |
| F | 9 | 18 | 10.6 | 6.8-13.7 | 59 |
| M | 9 | 18 | 8.7 | 5.5-11.5 | 48 |
| A | 6 | 18 | 6.8 | 3.2- 9.8 | 38 |
| M | 0 | -- | -- | -- | -- |
| J | 8 | 21 | 5.1 | 2.7- 8.2 | 24 |
| J | 8 | 21 | 4.8 | 3.5- 7.6 | 23 |
| A | 12 | 21 | 7.1 | 3.7-13.0 | 34 |
| S | 5 | 21 | 9.3 | 5.9-12.8 | 44 |
| O | 5 | 18 | 4.8 | 2.8- 8.1 | 26 |
| N | 11 | 18 | 12.0 | 8.4-17.0 | 66 |
| D | 4 | 18 | 13.8 | 12.5-16.0 | 76 |
| Overall Values | 87 | 19.1 | 9.0 | 2.7-17.2 | 47 |

about 25 percent to a winter high of 80 percent. The seasonal relationship between wastewater applications and measured runoff is shown in Figure 3. These results for monthly values show that the seasonal loading pattern selected for use did not maintain a consistent runoff fraction for this short period of record. Providing that other factors did not become limiting, a greater increase in the warm weather loading and extension of loadings from March through October could be utilized to obtain a more consistent fraction of runoff and to have more flexibility for seasonal resting of the treatment areas for maintenance operations. Seasonal shutdown for maintenance activities, such as vegetation removal, is an integral part of the overall operating plan.

## SYSTEM ODORS

The potential for obnoxious odors in the vicinity of wastewater management systems utilizing land application techniques is a question frequently encountered at symposia and conferences. Odors in the vicinity of the raw sewage wet well, the distribution booms, and the general plot area were assessed qualitatively throughout the 3-year period of operation. The sewage arriving at the wet well through the sewerage system was septic and, consequently, had the characteristic septic odor. Some type of odor control at this point is a key factor, if one wishes to maintain odors at a low level throughout the remainder of the system components. The arrangement provided for settling and comminution (Figure 1) for this pilot system aerated the sewage and reduced the odor to the "musty" odor typical of fresh domestic sewage. Residence time in the distribution system was not sufficient for a return to septic conditions and the concommitant return of obnoxious odors to be emitted at the boom nozzles. Transient odors were noticed occasionally near the boom nozzles when pumping was resumed following an extended shutdown period. Otherwise, the vicinity of the distribution boom was characterized by the "musty" odor of fresh sewage. This odor dissipated rapidly with distance and was usually dispersed within a distance of 15 m. Occasional detection of this odor beyond the 15 m distance was associated with brisk winds and comparatively high humidity. The general area of the overland-flow plots other than in the vicinity of the distribution booms was characterized by absence of any odors. Visitors to the site were repeatedly surprised by this lack of odors in view of the fact that raw sewage was being applied directly to the land.

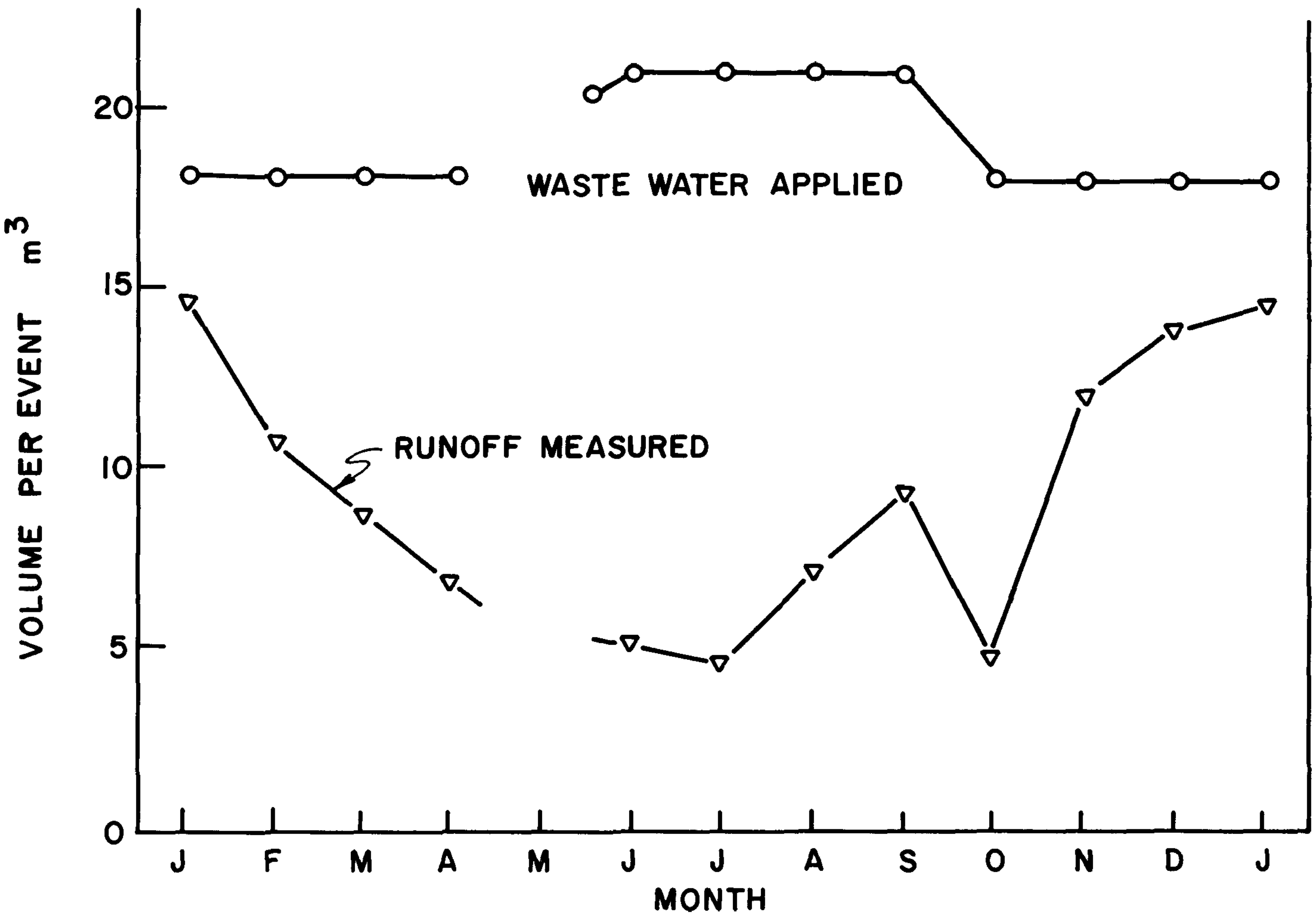


FIGURE 3 - WASTEWATER APPLIED VERSUS RUNOFF

## SECTION VII
## TREATMENT PERFORMANCE

Treatment performance for the first study period from March 1971 through September 1973 has been presented in detail and discussed by Thomas, Jackson, and Penrod[1]. Data from this initial period of operation will be utilized again to illustrate the continuing performance of the system over the 36-month operating period, but it will not be covered in detail comparable to that in the previous report. The emphasis in this report will be placed on overall performance for the entire study period from March 1971 through March 1974, and the phosphorus removal phase of the study from November 1972 through March 1974.

### WASTEWATER QUALITY

The raw wastewater data summary in Table 3 compares the results of analyses for 25 samples taken during the first 18-month study period and 14 samples taken during the second 15-month study period. The parameters listed are commonly used to express the solids content, the oxygen demand, the major nutrient content, and the bacterial population of wastewaters. Aluminum was measured in the second study period, because aluminum sulfate was being added to precipitate phosphorus. The data presented in Table 3 indicate two factors of special interest for assessment of the project results. Overall, the suspended solids, oxygen demand, major nutrient content, and bacterial population are within the range that is considered normal for domestic wastewaters. Differences in the composition of the wastewater between the two study periods were slight except for the suspended solids content. This marked increase in the total suspended solids and other differences directly associated with this definite increase was not identified as to cause, because wastewater characterization was not an objective of the study. It does appear that the change was associated with a nonorganic since the oxygen demand and total organic carbon content of the wastewater showed no comparable change. There was an apparent effect on treatment efficiency, which will be covered in a later section.

Table 3. QUALITY OF RAW COMMINUTED WASTEWATER FOR TWO STUDY PERIODS

| Parameter | Mean concentration, mg/l First 18 months | Last 15 months |
|---|---|---|
| Number of Samples | 25 | 14 |
| Total Solids | 1014 | 1110 |
| Total Volatile Solids | 300 | 310 |
| Total Suspended Solids | 160 | 240 |
| Total Volatile Suspended Solids | 123 | 180 |
| Total Dissolved Solids | 854 | 880 |
| Biochemical Oxygen Demand | 150 | 160 |
| Chemical Oxygen Demand | 314 | 334 |
| Total Organic Carbon | 89 | 94 |
| Total Nitrogen | 23.6 | 21.3 |
| Kjeldahl Nitrogen | 22.8 | 21.2 |
| Ammonia Nitrogen | 17.0 | 12.5 |
| Nitrate plus Nitrite Nitrogen | 0.8 | 0.1 |
| Total Phosphorus | 10.0 | 9.8 |
| Aluminum | -- | 0.7 |
| Total Coliform | | $7.2 \times 10^6$ |
| Fecal Coliform | | $1.0 \times 10^6$ |

Using the mean values from Table 3 and the average liquid loadings, one can calculate the mass loadings for parameters of interest. For example, the biochemical oxygen demand loadings for the first 18-month study were 125, 147, and 169 kg/ha/week, respectively, for the liquid loadings of 7.4, 8.6, and 9.8 cm/week. The biochemical oxygen demand loading was 180 kg/ha/week for all three plots in the 15-month study, because all plots were dosed at the 9.8 cm/week liquid loading, and there was a slight increase in the average biochemical oxygen demand. It is of particular interest to note that nitrogen loading ranged from 910 to 1,200 kg/ha/year in the 18-month study and was at the 1,200 kg/ha/year value on all plots for the 15-month study.

STUDY OF APPLICATION RATES - 18 MONTHS

The results of the first 18-month study have been detailed in a previous report[1], so coverage in this report will be a condensation to provide background for detailed coverage of treatment obtained over the entire 36-month period of operation, and for detailed coverage of phosphorus removal during the second 15-month study period. Findings of importance to the coverage of the overall 36-month period and the 15-month phosphorus removal period include treatment changes during system start up, seasonal variations in treatment capability, and the effects of loading rates on treatment capability.

It was observed that a several-month period was needed to age a newly prepared and seeded treatment area. The major stabilization period took three to four months, but gradual changes extended for a much greater time for some parameters. The steady state removal of suspended solids and oxygen demanding substances at about 95 percent was not achieved until a dense vegetative cover was developed some nine months after the start of operations. Conversely, phosphorus removal started out at about 40 percent removal, improved rapidly to about 75 percent removal for a few months, and then declined to a steady state seasonal range of 40 to 60 percent removal. These observations indicated a need for a conditioning period when collecting data to evaluate new operating procedures. The collection of data to evaluate the removal of phosphorus by adding aluminum sulfate was preceded by a 3-month conditioning period with all three plots on the same operating mode. Collection of data during this period showed that the plots were fully acclimated, and performed as replicates at the initiation of the phosphorus removal study. Data for the acclimation period is presented and discussed in the coverage of the treatment for the 36-month period.

Seasonal variations in treatment capability observed during the initial 18-month study period were comparatively minor except for removal of the nutrients, nitrogen and phosphorus. Nitrogen removal dropped off during this first winter period of operation. The drop-off in nitrogen removal resulted in a substantial increase in the nitrate nitrogen content of plot runoff. Law, Thomas, and Myers[4] have observed that high nitrate in overland-flow effluent occurs when system operation is resumed following system shutdown. It may be that the observed drop-off in winter nitrogen removal was largely due to the brief shutdown periods necessitated by freezing weather, rather than a loss of the capability of a regularly operating system to remove nitrogen. Seasonal variation in the removal of phosphorus was less pronounced than the variation in the removal of nitrogen. The change in the concentration of phosphorus in the runoff from summer to winter amounted to a total mass of phosphorus comparable to that removed by plant harvesting. These results indicate that the observed difference between summer and winter phosphorus removal is comparable to plant uptake and removal by harvesting.

The effects of loading rates on treatment capability were comparatively slight. Each one of the rates, 7.4, 8.6, and 9.8 cm/week showed slight advantages for removal of one or more constituents. The two higher rates showed somewhat better consistency than the lower rate, and the 9.8 cm/week rate showed a slight overall advantage. These results indicated that the optimum hydraulic load exhibits a broad peak, and that further study could be focussed on the higher loading rate of about 10/week. The hydraulic application rate of 10 cm/week was selected for use in the phosphorus precipitation phase of the overland-flow study.

OVERALL STUDY - 36 MONTHS

The overall study provides data for several comparisons on long-term trends and seasonal patterns, as well as the specific hydraulic load and phosphorus removal evaluations. The overall study period covers two summer and three winter seasons and a 15-month period when the three plots were operated essentially as replicates for all parameters except for phosphorus. Sixteen parameters were measured to evaluate treatment capability with some 40 determinations being made for each parameter during the 36-month study period. Data summaries for all parameters are included in the appendices. Data presented in the text are focussed on treatment efficiencies for suspended solids, biochemical oxygen demand, chemical oxygen demand, nitrogen, phosphorus, and coliform bacteria. The presentation of data addresses concentration data and does not imply a mass balance of constituents. Plots in Figures 4 through 7 are 3 point moving averages. This technique was used to obtain smoother curves, which better illustrate small differences. A tabular summary of plot runoff quality for both phases of the 36-month study is presented in Table 4.

Suspended Solids Removal

Treatment efficiency for suspended solids (TSS) is summarized in Figure 4. Data for all three plots exhibit a period of about 100 days during which the TSS in the plot runoff declined steadily. Following this period of acclimatization removal of TSS remained very stable at about 95 percent. The concentration of TSS was relatively low with all recorded values in the range of 4 mg/l to 41 mg/l after 100 days of operation. As was shown in Table 3, the average TSS content of the raw wastewater was 160 mg/l during the first 18 months of study and 240 mg/l during the final 15 months of study. This difference in raw wastewater concentration was reflected in plot runoff concentration. The average TSS concentration in the runoff for all plots was 8 mg/l, when that of raw wastewater was 160 mg/l, and 16 mg/l when that of the raw wastewater was 240 mg/l. Seasonal variation for TSS in the plot runoff may be influenced by this change in raw wastewater characteristics. Regardless of this possible influence, there is no difference between summer and winter treatment efficiency. The concentration of TSS was 11 mg/l for both seasons.

Comparison of TSS data for the three plots operating at the same hydraulic load indicates close agreement for data from the three plots. As shown in Table 4, the mean values were 16, 15, and 18 mg/l, and a statistical comparison shows that the observed difference is not statistically significant at the 5 percent level of probability.

Overall, the TSS data collected during this 36-month period of operation shows that overland-flow treatment produces an effluent containing less than 20 mg/l consistently with influent TSS up to 240 mg/l and hydraulic load up to 10 cm/week.

BOD Removal

Treatment efficiency for biochemical oxygen demand (BOD) was determined analytically throughout the 18-month hydraulic load study as shown by the data in Table 4.

During this study period, 40 sets of data were collected to determine the ratio of BOD to chemical oxygen demand (COD) and to total organic carbon (TOC). The mean

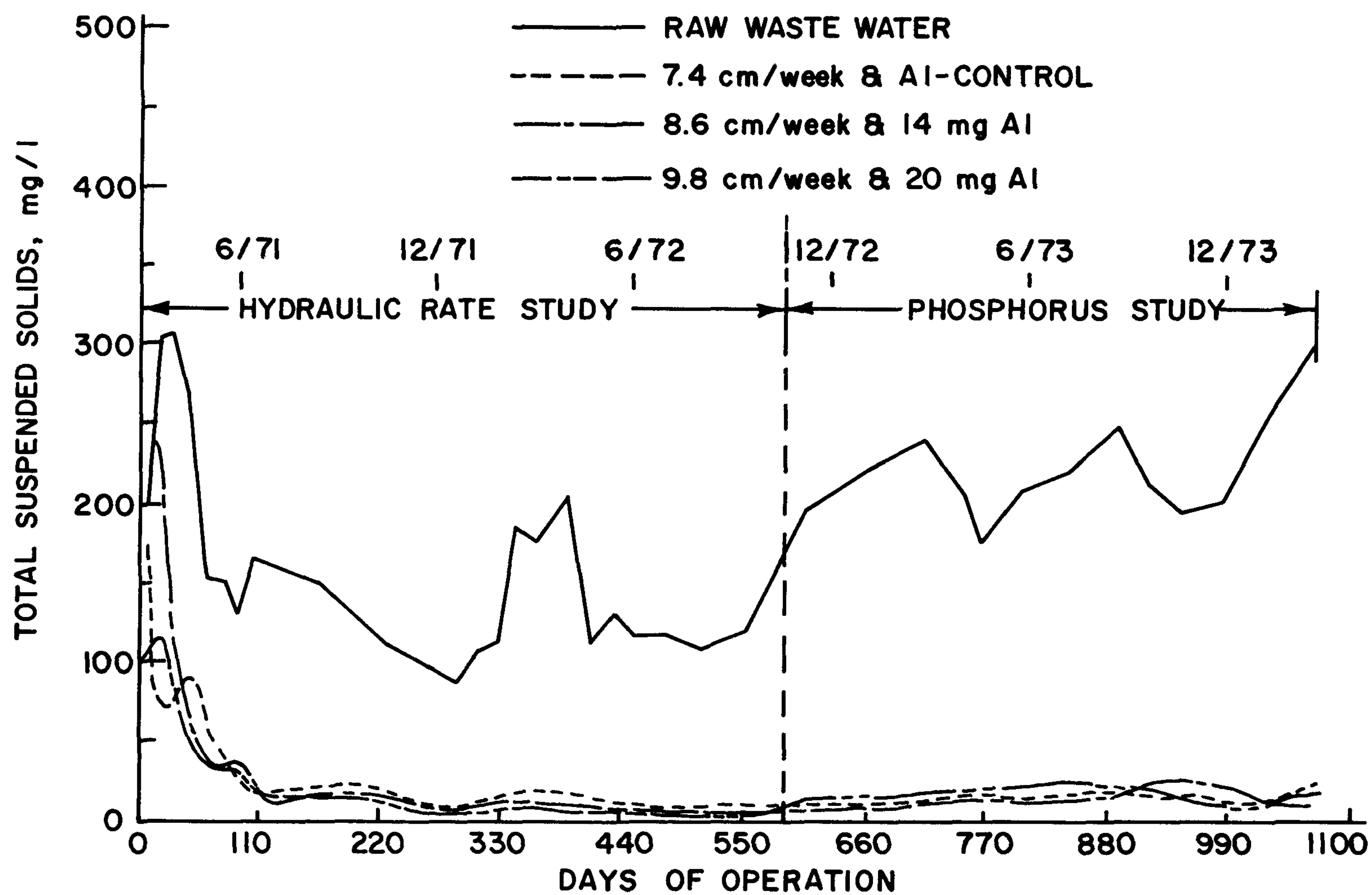


FIGURE 4 — SUSPENDED SOLIDS VERSUS DAYS OF OPERATION

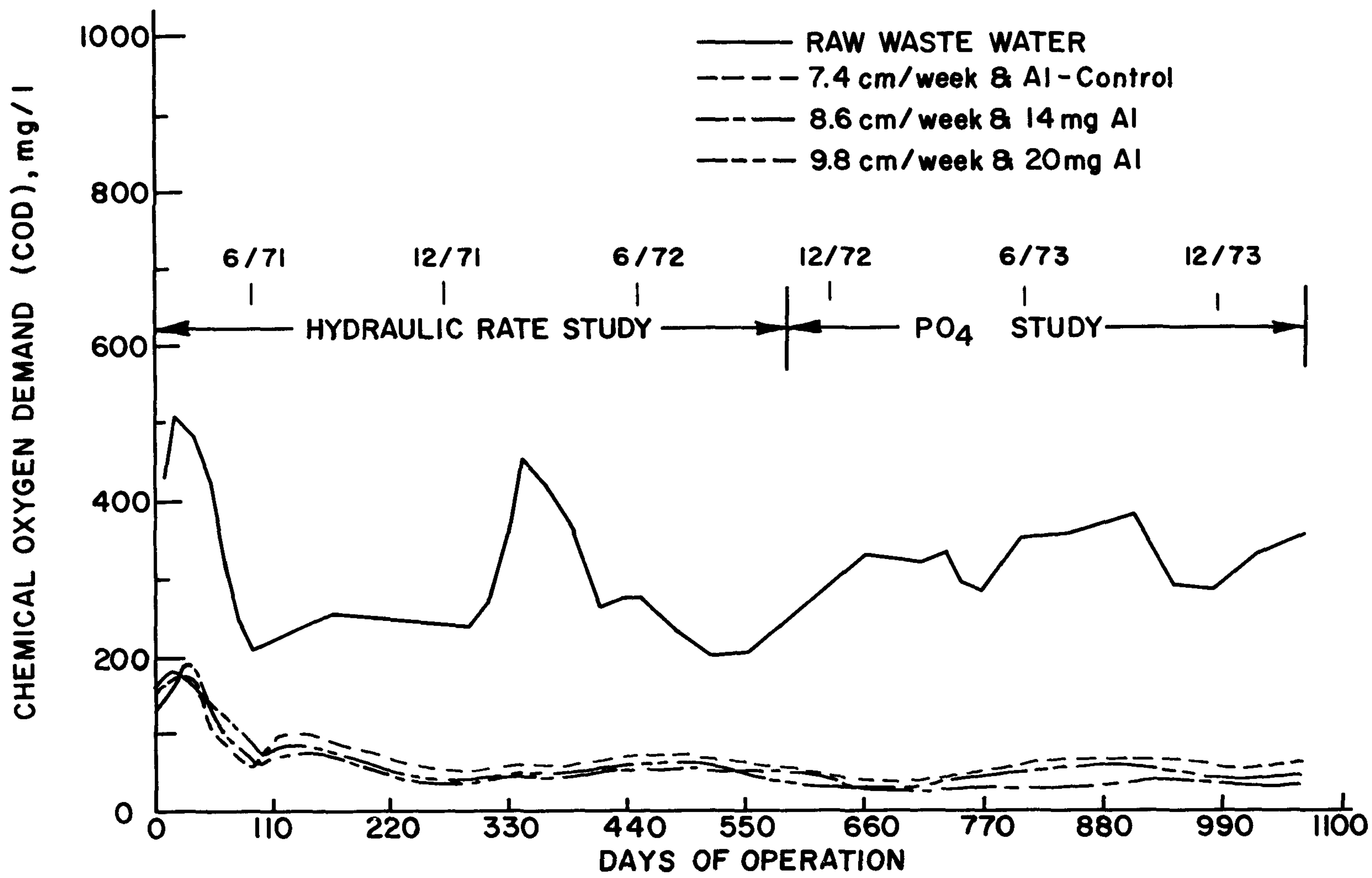


FIGURE 5 - CHEMICAL OXYGEN DEMAND VERSUS DAYS OF OPERATION

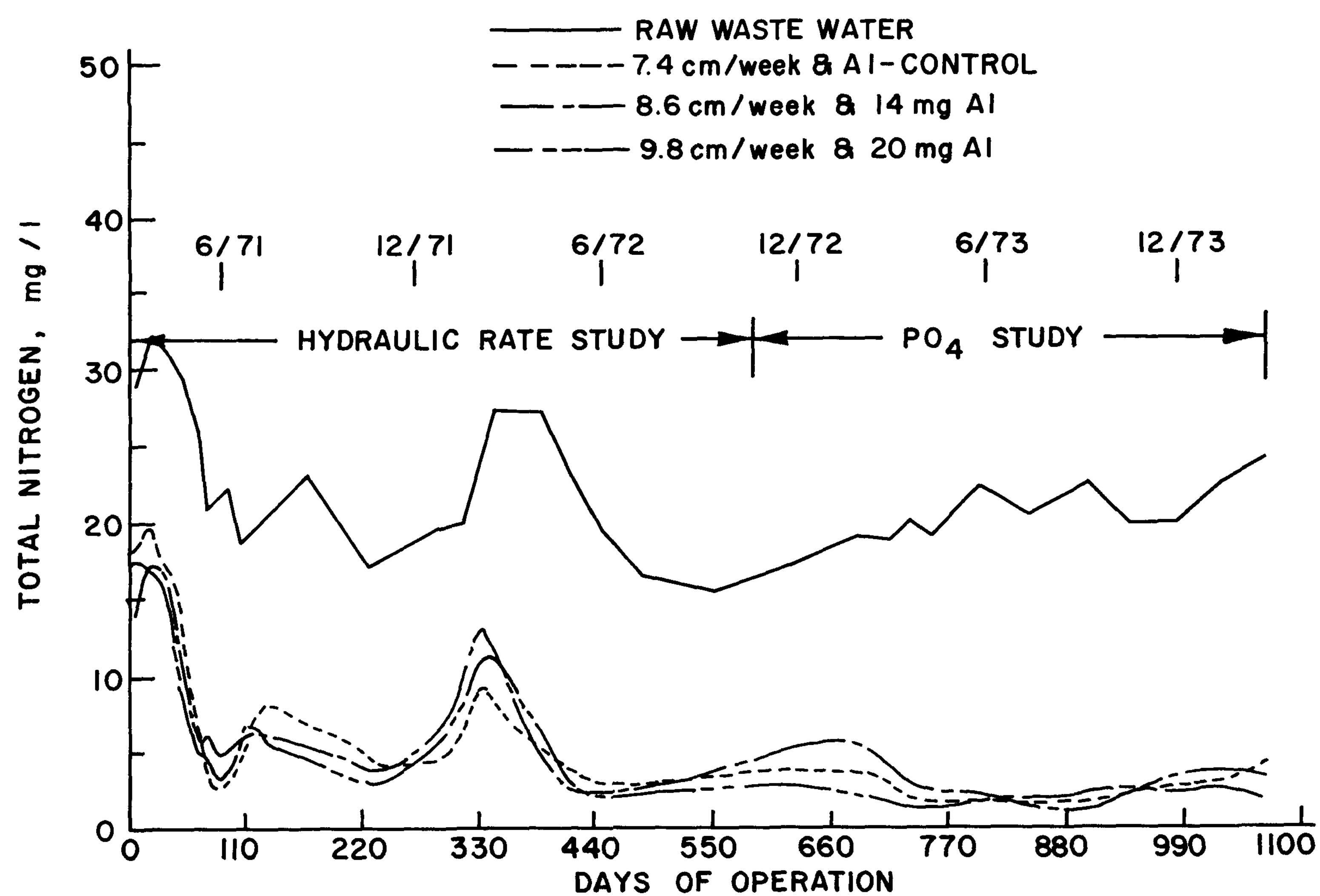


FIGURE 6 — NITROGEN VERSUS DAYS OF OPERATION

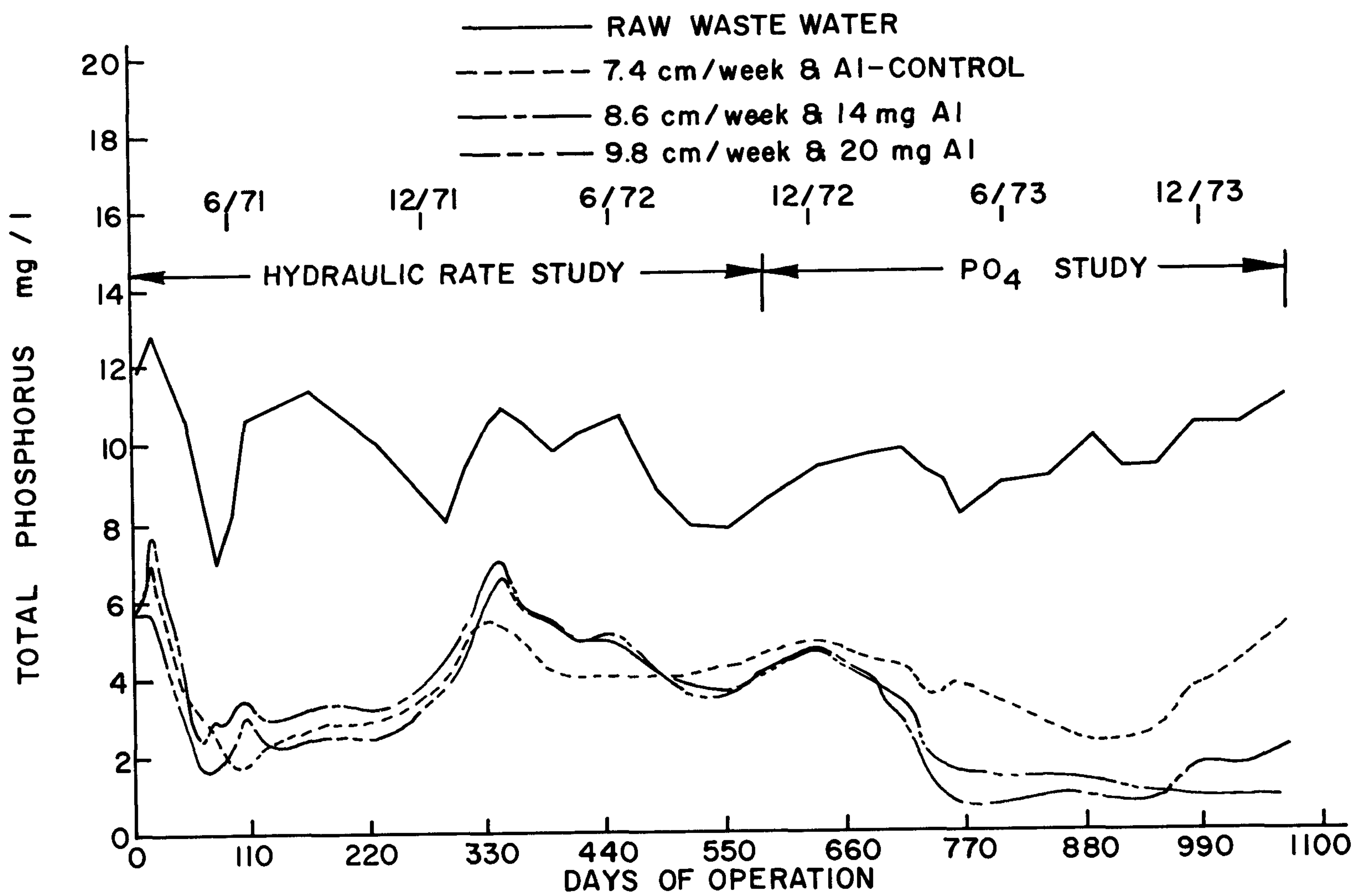


FIGURE 7 - PHOSPHORUS VERSUS DAYS OF OPERATION

Table 4. PLOT RUNOFF QUALITY

| Parameter | Hydraulic study - 18 months[1] | | | Phosphorus study - 15 months[2] | | |
|---|---|---|---|---|---|---|
| | 7.4 cm/wk | 8.6 cm/wk | 9.8 cm/wk | No $Al\ SO_4$ | 14 mg/l $Al\ SO_4$ | 20 mg/l $Al\ SO_4$ |
| | Concentration mg/l | | | | | |
| TS | 726 | 755 | 765 | 770* | 790* | 830* |
| TVS | 170 | 162 | 158 | 118 | 114 | 125 |
| TSS | 11 | 7 | 8 | 16* | 15* | 18* |
| TVSS | 6 | 4 | 5 | 7 | 6 | 8 |
| TDS | 715 | 748 | 757 | 750 | 710 | 810 |
| BOD | 12 | 10 | 8 | 10[3] | 7[3] | 9[3] |
| COD | 57 | 52 | 51 | 54† | 37* | 45*† |
| TOC | 22 | 16 | 17 | 19* | 13* | 17* |
| TN | 5.0 | 5.8 | 5.5 | 2.9* | 3.1* | 2.0* |
| KN | 2.4 | 2.9 | 2.4 | 2.4 | 2.4 | 1.6 |
| $NH_4$ N | 0.6 | 1.5 | 1.0 | 0.8* | 1.1* | 0.5* |
| $NO_3 + NO_2$ N | 2.6 | 2.9 | 3.1 | 0.5* | 0.7* | 0.4* |
| T-P | 4.4 | 4.9 | 4.8 | 37* | 1.6† | 1.5† |
| Al | -- | -- | -- | 0.15 | 0.22 | 0.34 |
| | Counts/100 ml | | | | | |
| T-Coli | -- | -- | -- | $.3x10^6$ | $0.2x10^6$ | $0.2x10^6$ |
| F-Coli | -- | -- | -- | $.09x10^6$ | $0.03x10^6$ | $0.02x10^6$ |

1/ Excludes data for 100 day acclimation period.

2/ Means identified with an asterisk differ from means identified with a dagger with the probability $\leqq$ .01.

3/ Calculated from COD and TOC data.

ratio of BOD to COD was 0.18 with a range of .16 to .21, while the mean ratio of BOD to TOC was 0.54 with a range from .47 to .62. These data showed that mean BOD could be estimated accurately from the COD and TOC data, and BOD was not measured directly during the 15-month phosphorus study.

BOD values measured during the 18-month hydraulic study and the calculated values for the 15-month phosphorus study show that overland-flow treatment produces an effluent with a BOD of less than 15 mg/l when receiving a raw wastewater containing 150 to 160 mg/l BOD at hydraulic loads up to 10 cm/week. Seasonal and long-term trends for BOD removal were comparable to those for COD and TOC, which are covered in detail in the next section.

COD And TOC Removal

Treatment efficiencies for COD and TOC were very similar and will be covered together. The COD data are illustrated in Figure 5 and are representative of TOC data and the overall treatment efficiency pattern for BOD. Data for all three plots exhibit similar changes over the duration of the study. The time period for reaching 75 percent removal of COD was quite comparable to the 100-day period observed for reaching the stable 95 percent removal of TSS; however, the removal of COD continued to improve slowly for an additional 100-day period and stabilized at about 85 percent some 200 days into the study.

The COD and TOC data in Table 4 indicate that there may be a slight but definite improvement associated with the addition of aluminum sulfate. Pooled averages for the two study periods show that COD removal was 84 percent for the 10 cm/week load without aluminum sulfate, and 88 percent for the two plots receiving aluminum sulfate. TOC removals for the same comparison were 80 and 84 percent, respectively. Treatment efficiency for COD also exhibits small but definite seasonal changes with removal being best during the winter to early spring and poorest during the summer. Comparison of mean data for the three cold seasons (December through February) versus the data for the two warm seasons shows 87 percent and 83 percent treatment efficiencies, respectively. The weighted mean COD in the plot runoff was 44 mg/l during the warm season. Overall, the data show that overland-flow treatment stabilizes rather slowly for removal of COD and TOC and may not reach a steady state until the second year of operation. The stable treatment efficiency for both parameters is in the 80 to 85 percent range. For conditions at this site and with a hydraulic load of 10 cm/week, the plot runoff COD varied seasonally from 45 to 55 mg/l, and the plot runoff TOC was in the 15 to 20 mg/l range.

Nitrogen Removal

Treatment efficiency for the plant nutrient nitrogen is illustrated in Figure 6. Data for all three plots exhibit similar patterns of behavior with pronounced periods of sharply differing treatment efficiency. The acclimatization period was about 80 days, which is somewhat less than the 100-day period to reach a stable level of 95 percent TSS removal. Nitrogen is intimately involved in microbial metabolism and plant nutrition, and the subsequent periods of sharply changing treatment efficiency can be attributed to this fact. It is reasonably well accepted that microbial denitrification is a principal mechanism influencing nitrogen removal, and it is well documented that crop uptake and harvest also are important factors. Tracing operational procedures and seasonal management in relation to these two factors provides supporting evidence to explain the observed patterns of nitrogen removal following the acclimatization period.

The sharp increase in runoff nitrogen at day 110 results from an extended shutdown to modify the distribution system. Extended shutdown of a system changes the oxygen status to inhibit the denitrification process, and substantial nitrate nitrogen will be present in the runoff. The slow decline in runoff nitrogen following day 110 suggests that full recovery of microbial denitrification may be much slower in fall and winter than initial acclimatization in summer. The sharp rise in runoff nitrogen in late winter at day 330 was associated with a severe cold snap. Temporary shutdowns, temperatures in the teens, or the combined influence of both, severely inhibited denitrification and nitrate concentrations up to 10 mg/l were measured in the plot runoff. A similar but less noticeable period occurred in the winter of 72-73, and there was virtually no such period in the mild winter of 73-74. The excellent treatment efficiency observed in the summer is the result of favorable climatic conditions for both microbial denitrification and removal by plant harvest.

Overall treatment for nitrogen removal at this site with the 10 cm/week hydraulic load was about 85 percent. There was a seasonal pattern directly related to the severity of winter conditions. Summer removal was consistent at about 90 percent, while winter removal ranged from less than 75 percent in the severest winter to about 85 percent in the mildest winter. The 3-year mean nitrogen concentration in the plot runoff was 5.8 mg/l for winter and 2.0 mg/l for summer.

Phosphorus Removal

Treatment efficiency for the nutrient phosphorus is illustrated in Figure 7. During the hydraulic rate study, data from all three plots exhibited similar patterns of behavior. A period of rapidly improving treatment efficiency during the period of acclimatization lasted about 80 days. This initial sharp improvement in treatment efficiency to a maximum value of about 80 percent was followed by a gradual loss in treatment efficiency through the summer and fall of 1971 to values of about 50 percent. The 12-month period following showed a minor seasonal pattern with somewhat better treatment efficiency in summer when plant uptake was at its highest level. Overall, the treatment efficiency for this 12-month period averaged about 55 percent ranging from a summer high of 60 percent to a winter low of 50 percent. This relatively stable phosphorus removal at about 55 percent contributed to the decision to initiate the phosphrous removal study in November 1972. All three plots were adjusted to the same hydraulic load of 10 cm/week and were operated as true replicates for about 2 months. Aluminum sulfate addition was started early in January 1973 and continued to the end of the study in March 1974. Data for the plot not receiving aluminum sulfate exhibited a more distinct seasonal pattern than it had in the previous year with late fall treatment efficiency reaching about 70 percent instead of 60 percent. Data for both plots receiving aluminum sulfate exhibited a quick response with the phosphorus concentration in the runoff dropping below 2.0 mg/l within 2 months. The phosphorus concentration in the plot runoff remained below this value for the remainder of the study. Specific data on the phosphorus removal study presented in Table 5 will be used to further detail the improved phosphorus removal achieved by addition of aluminum sulfate.

We encountered considerable difficulty with our system for adding aluminum as a concentrated aluminum sulfate solution using a metering pump. The concentration of aluminum at the distribution-boom nozzle varied greatly as shown in Table 5, and after 15 months of operation, it was determined that a precipitate was deposited in the delivery line between the point of injection and the distribution-boom nozzle. These operational problems undoubtedly affected the treatment efficiency and may

Table 5. SPECIFIC DATA FOR THE PHOSPHORUS REMOVAL STUDY COVERING JUNE 1973 THROUGH FEBRUARY 1974

| | Aluminum Added mg/l | | Plot Runoff Concentrations day 770 thru 1100 mg/l | | | |
|---|---|---|---|---|---|---|
| | | | Aluminum | | Phosphorus | |
| | Mean | Range | Mean | Range | Mean | Range |
| Control plot | 0 | -- | .15 | .07-.16 | 3.4 | 1.9-6.0 |
| Low Al plot | 14 | 2-27 | .22 | .06-.30 | 1.5 | 0.3-3.9 |
| High Al plot | 20 | <5-40 | .34 | .10-.82 | 0.9 | 0.5-1.4 |

account for observed anomalies between the low and high aluminum additions. The raw wastewater contained 0.7 mg/l of aluminum with a range of 0.13 to 1.3 mg/l, and the phosphorus in the raw wastewater was 10.4 mg/l with a range of 9.0-12.4 mg/l during the last 10 months of the phosphorus study. Referring to Figure 7, we observe that the 14 mg/l aluminum addition reduced phosphorus in the plot runoff sharply to less than 1.0 mg/l where it remained for about 6 months followed by an abrupt increase during the last 3 months of study. This sharp increase was associated with a decrease in aluminum concentration at the distribution-boom nozzle. During the period having less than 1 mg/l of phosphorus in the plot runoff, the aluminum concentration at the nozzle averaged 15 mg/l and ranged from 11 to 27 mg/l. During the last 3 months, the aluminum concentration at the nozzle averaged 9 mg/l with a range of 7 to 11 mg/l.

The 20 mg/l aluminum addition produced a sharp decrease to about 1.5 mg/l followed by a gradual but steady decrease to less than 1.0 mg/l at the end of the study. During this period of gradual but steady decrease, the aluminum concentration at the nozzle averaged 23 mg/l with a range of 17 to 40 mg/l.

The addition of aluminum to the raw sewage did cause a slight increase in the runoff concentration of aluminum. As shown in Table 5, the increase was directly proportional to the amount of aluminum added to the raw wastewater but was a small fraction of the total added.

Although the observed results are confounded by operating problems, it is clear that addition of aluminum to the raw wastewater enhances phosphorus removal. There are definite indications that a 1: 1 stoichiometric balance of aluminum to phosphorus reduces a raw wastewater concentration of 10.4 mg/l to about 1.5 mg/l, while a 2: 1 balance achieves an additional reduction in the runoff concentration to about 1.0 mg/l.

Coliform Reduction

During the 15-month phosphorus study, total coliform and fecal coliform were determined in the raw wastewater and the plot runoff. There was no difference in the degree of reduction between plots for total coliform, while the two plots receiving aluminum sulfate had somewhat lower counts for fecal coliform. Overall, the reduction was about 95 percent for total coliform. Fecal coliform reduction was about 90 percent without aluminum sulfate and 97.5 percent with aluminum sulfate. The total coliform counts in the plot runoff were about 200,000 per 100 ml, while the fecal coliform counts in the plot runoff were about 90,000 per 100 ml without aluminum sulfate addition and about 25,000 per 100 ml with aluminum sulfate addition.

## SECTION VIII
## DISCUSSION

Data collected over a 3-year period show that overland flow is capable of providing year-round treatment of raw domestic wastewater in mild climates. Removal of suspended solids, biochemical oxygen demand, nitrogen, and phosphorus exceeds removals achieved by conventional secondary processes. Overall, overland flow would be classified as an advanced waste treatment process. Removal of suspended solids and oxygen demanding substances are readily explained as a result of microbial biooxidation. There is a wealth of published information to support this explanation. Removal of nitrogen and phosphorus are not explained as readily on the basis of well-documented theory. Hoeppel, Hunt, and Delaney[6] (1974) and Thomas, Jackson, and Penrod[1] have discussed the removal of these constituents and offered hypotheses to explain their removal by overland-flow treatment. Complementary research is now in progress to test the hypothesis that denitrification is a dominant factor in nitrogen removal.

Thomas, Jackson, and Penrod[1] detailed factors influencing phosphorus removal by overland flow. They suggested that phosphorus removal could be improved by chemical precipitation without adverse effects on removal of other constitutents. The results of the 15-month phosphorus removal study demonstrate that phosphorus removal can be increased to about 90 percent by adding 1.5 to 2.0 mg of aluminum for each mg of phosphorus. This addition of aluminum does increase the aluminum content of the plot runoff by 50 to 100 percent with the actual concentration being raised from 0.15 mg/l to a high value of 0.34 mg/l. The addition of 20 mg/l of aluminum matches the National Academy of Science's[(7)] recommended maximum concentration in irrigation waters for up to 20 years' use on neutral to alkaline soils. Although it is possible to remove phosphorus by precipitation with aluminum, additional work is needed to determine management practices for avoiding aluminum toxicity in the soil. Another alternative for achieving phosphorus removal is the use of soil infiltration following overland flow. This approach has the added benefits of virtually complete removal of suspended solids, oxygen demanding substances, and fecal bacteria. This combination of overland flow followed by high-rate infiltration is now under study at the Robert S. Kerr Environmental Research Laboratory. The next research report in this series on overland flow will cover this treatment train.

Reliability is an important consideration for determining the practical implementation of a waste treatment process. Over the 36-month duration of this pilot study, the system has shown excellent reliability, and the quality of the plot runoff has varied very little once the system was stabilized. The three-point moving averages plotted in Figures 3 through 7 are indicative of this consistency, but they do mask some of the variability in the data. Relative frequency data give a clearer picture of this consistency. From day 110 to day 1080, the maximum suspended solids value recorded was less than 50 mg/l for all three plots and 90 percent of all values were less than 25 mg/l. Similar reliability was observed for other parameters including oxygen demand measurements and the nutrients nitrogen and phosphorus.

The encouraging results from this 3-year pilot study are being tested at operational-scale facilities in Oklahoma and South Carolina at flows in the 8 to 16 $m^3$ per hour (50,000 to 100,000 gpd) range. These field studies will evaluate the performance of overland flow in two modes of operation, with raw wastewater as one source, and oxidation pond effluent as the other source. Evaluation of design components will include hydraulic load, distribution devices, operational requirements, and system costs. Assessment of system performance will focus on treatment capability for traditional parameters, but it will also include studies on aerosols, odors, crop quality, soil properties, and groundwater quality.

## SECTION IX

## REFERENCES


1. Thomas, R. E., K. Jackson, and L. Penrod. Feasibility of Overland Flow for Treatment of Raw Domestic Wastewater. Robert S. Kerr Environmental Research Laboratory. EPA Series No. 660/2-74-087, July 1974. 31 p.

2. Luley, H. G. Spray Irrigation of Vegetable and Fruit Processing Wastes. J. Water Pollut. Contr. Fed. 35: 1252-1261, October 1963.

3. Bendixen, T. W., R. D. Hill, F. T. Dubyne, and G. G. Robeck. Cannery Waste Treatment by Spray Irrigation-Runoff. J. Water Pollut. Contr. Fed. 41: 385-391, March 1969.

4. Law, J. P., R. E. Thomas, and L. H. Myers. Cannery Wastewater Treatment by High-Rate Spray on Grassland. J. Water Pollut. Contr. Fed. 42: 1621-1631, September 1970.

5. Kirby, C. F. Sewage Treatment Farms--Post Graduate Course in Public Health Engineering, Session No. 12. Department of Civil Engineering, University of Melbourne, Melbourne, Australia. 1971. 14 p.

6. Hoeppel, R. E., P. G. Hunt, and T. B. Delaney, Jr. Wastewater Treatment on Soils of Low Permeability. Water Ways Experiment Station, Corps of Engineers, Vicksburg, Miss. Miscellaneous Paper Y-73-2. 1974.

7. Methods for Chemical Analysis of Water and Wastes. Environmental Protection Agency, Cincinnati, Ohio. Publication No. 16020---07/71. July 1971. 312 p.

8. Water Quality Criteria, 1972. National Academy of Sciences, National Academy of Engineering, Washington, DC. EPA Series No. R3-73-033, March 1973. pp 338-340.

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*


| 1. REPORT NO. | 2. | 3. RECIPIENT'S ACCESSION NO. |
|---|---|---|
| EPA-600/2-76-131 | | |

| 4. TITLE AND SUBTITLE | 5. REPORT DATE |
|---|---|
| OVERLAND FLOW TREATMENT OF RAW WASTEWATER WITH ENHANCED PHOSPHORUS REMOVAL | June 1976 (Issuing Date) |
| | 6. PERFORMING ORGANIZATION CODE |

| 7. AUTHOR(S) | 8. PERFORMING ORGANIZATION REPORT NO. |
|---|---|
| R. E. Thomas, B. Bledsoe, and K. Jackson | |

| 9. PERFORMING ORGANIZATION NAME AND ADDRESS | 10. PROGRAM ELEMENT NO. |
|---|---|
| Robert S. Kerr Environmental Research Laboratory<br>Office of Research and Development<br>U.S. Environmental Protection Agency<br>Ada, Oklahoma 74820 | P.E. 1BC611 AP No. L611C<br>11. CONTRACT/GRANT NO. |

| 12. SPONSORING AGENCY NAME AND ADDRESS | 13. TYPE OF REPORT AND PERIOD COVERED |
|---|---|
| Same as above | Final 3/71 through 6/73 |
| | 14. SPONSORING AGENCY CODE<br>EPA-ORD |

15. SUPPLEMENTARY NOTES



16. ABSTRACT

A pilot-scale field study was conducted to evaluate the capability of overland flow to provide complete treatment of raw comminuted wastewater on a year-round basis in a mild climatic zone. Raw comminuted wastewater was applied through a specially designed distribution system which operated at low pressure and prevented the formation of aerosols. This specially designed applicator operated at a pressure of 1.0 kg/sq cm (15 psi) and was used to apply wastewater to three experimental plots at 7.4, 8.6, and 9.8 cm/week rates of loading. Wastewater and plot runoff samples were collected periodically to compare treatment efficiencies for the three loading rates and to determine seasonal influences on treatment efficiency. Fifteen parameters including suspended solids, biochemical oxygen demand, nitrogen, and phosphorus were used to evaluate treatment efficiencies. The results of this 18-month field study showed overland flow to be an effective process for achieving advanced waste treatment of raw comminuted wastewater via a simple system with no sludge production.


17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Sewage treatment<br>Land use<br>Nitrogen cycle<br>Phosphorus cycle | Overland flow | 2C<br>14B |

| 18. DISTRIBUTION STATEMENT | 19. SECURITY CLASS *(This Report)* | 21. NO. OF PAGES |
|---|---|---|
| RELEASE TO PUBLIC | UNCLASSIFIED | 44 |
| | 20. SECURITY CLASS *(This page)* | 22. PRICE |
| | UNCLASSIFIED | |

EPA Form 2220-1 (9-73)



* U. S. GOVERNMENT PRINTING OFFICE: 1976-657-695/5440 Region No. 5-11