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Feasibility of Overland Flow for Treatment of Raw Domestic Wastewater

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FEASIBILITY OF OVERLAND FLOW FOR TREATMENT OF RAW DOMESTIC WASTEWATER

by

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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.

This report was submitted in fulfillment of Project No. 16080 WPH (Task 12, ROAP 21-ASH) as an in-house project by the Water Quality Control Branch, Robert S. Kerr Environmental Research Laboratory, under the sponsorship of the Environmental Protection Agency. Work was completed as of June 1973.

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SECTION I

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 containing less than 10 mg/l of suspended solids and biochemical oxygen demand.
- A well operated system should achieve 90 percent nitrogen removal in the summer, but nitrogen removal may drop substantially in the winter.
- Phosphorus removal should be about 50 percent with relatively minor seasonal variation.

SECTION II

RECOMMENDATIONS

- Overland flow should be tested and demonstrated at selected communities to validate the results of this pilot study.
- Initially, these communities should be located at places with climatic conditions comparable to or milder than the test site.
- Capital and operating cost data should be included in all evaluation programs for full-scale operational systems.
- Pilot-scale testing should be continued to evaluate phosphorus removal by chemical precipitation.
- Pilot-scale studies should be conducted to evaluate the effect of pretreatment on treatment efficiency and system loading.

SECTION III

INTRODUCTION

Treatment of wastewater by allowing it to trickle over gently sloping ground is most commonly referred to as "spray-runoff" or "overland flow." Overland flow is preferred by the authors and will be used in this report on the treatment of raw comminuted sewage. Overland flow has been selected frequently by the food processing industry for the treatment of seasonal wastewater discharges and, in several cases, for year-round wastewater discharges. Use of the overland-flow concept by food processors in the United States appears to originate from experiences with a spray disposal system discussed by Luley[1] in 1963. Subsequently, the concept has been further developed and purposely installed as the treatment system at a number of locations. Treatment of domestic wastewater by overland flow is also practiced at a few locations in foreign countries. The approach utilized at Werribee for treatment of wastewater from the City of Melbourne, Australia is a good example of a system which has been in service for many decades. The treatment efficiency achieved by the overland-flow approach is contingent on many factors, and the quality of the effluent produced can vary greatly. It is this aspect of the overland-flow treatment process which will be further elaborated in this report.

The variability of system design and effluent quality can be exemplified by a comparison of the system at Werribee as described by Kirby[2] in 1971 and the system at Paris, Texas as described by Law, Thomas, and Myers[3] in 1970. Kirby reports that the Werribee system consists of bays which are 365 meters long prepared as for border check irrigation and seeded with Italian rye grass. Sedimented domestic wastewater is treated continuously by introducting it into one end of the bay and allowing it to trickle slowly over the length of the bay. The bay is operated continuously throughout the winter season from May through September at an average areal loading of 1.9 cm per day. This method of operation results in some anaerobiosis at the inlet end of the bays, but downslope aerobiosis contributes to good overall treatment efficiency. Kirby[2] estimates the removal of pollutants to be 96 percent for biochemical oxygen demand, 95 percent for suspended solids, 60 percent for total nitrogen, and 35 percent for total phosphorus. These percentage removals would produce an effluent from the bays containing about 25 mg/l of biochemical oxygen demand and suspended solids. Concentration data for nitrogen and phosphorus were not reported by Kirby.[2] Law, Thomas, and Myers[3] report that the Paris, Texas system consists of graded slopes with intercepting terrace ditches at 45- to 100-meter spacings. Screened cannery wastewater is sprayed intermittently at the tops of the 2 to 6 percent slopes (just below an intercepting terrace) and the treated wastewater is collected in the next intercepting terrace downslope. This system is operated all year at an areal loading of 0.9 cm per day applied during spraying periods of 6 or 8 hours. Law, Thomas, and Myers reported that this system produced an effluent with an average biochemical oxygen demand of 9 mg/l; a suspended solids content of 16 mg/l; a total nitrogen concentration of 2.8 mg/l; and a total phosphorus concentration of 4.3 mg/l. These concentrations were obtained as a result of 98.5 percent reduction of biochemical oxygen demand, 93.5 percent reduction of suspended solids, 84 percent reduction of total nitrogen, and 40 percent reduction of total phosphorus. The treatment efficiencies achieved by these two systems cited as examples and by other overland-flow approaches reported in the literature indicate that overland flow has potential for achieving a high level of advanced waste treatment and should be developed as one method of achieving "best practicable waste treatment technology" referred to in PL 92-500.

A recent evaluation of research needs[4] indicated that there were about 5,300 small communities in the United States which did not have waste treatment facilities in 1965. In preparing this report on research needs, the Federal Council for Science and Technology concluded that these small communities, having an average population of 6,000 and representing a total population of 33 million, would find the cost of conventional waste treatment a heavy burden and research toward low-cost treatment methods was urgently needed. Overland flow is a low-cost treatment method which should have its greatest utility in these rural locations where ample land would be readily available for installation of a system.

The principal objectives of the research project reported herein were to (1) evaluate the practicality of year-round treatment of raw wastewater by overland flow in a moderate semihumid environment, (2) determine allowable loading rates for achieving a high level of advanced waste treatment, and (3) develop sufficient design data to implement a full-scale system under comparable climatic conditions.

SECTION IV

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 adverse weather conditions and the downtime due to weather influences was included as a variable for evaluation.

SITE PREPARATION AND WASTEWATER DISTRIBUTION

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 weight 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. 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 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

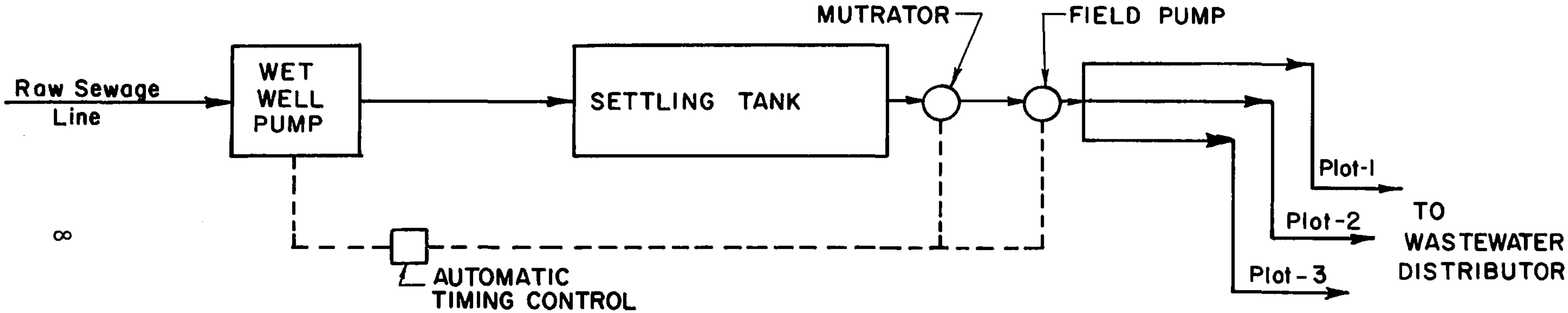

FIGURE 1. SCHEMATIC OF WASTEWATER HANDLING SYSTEM

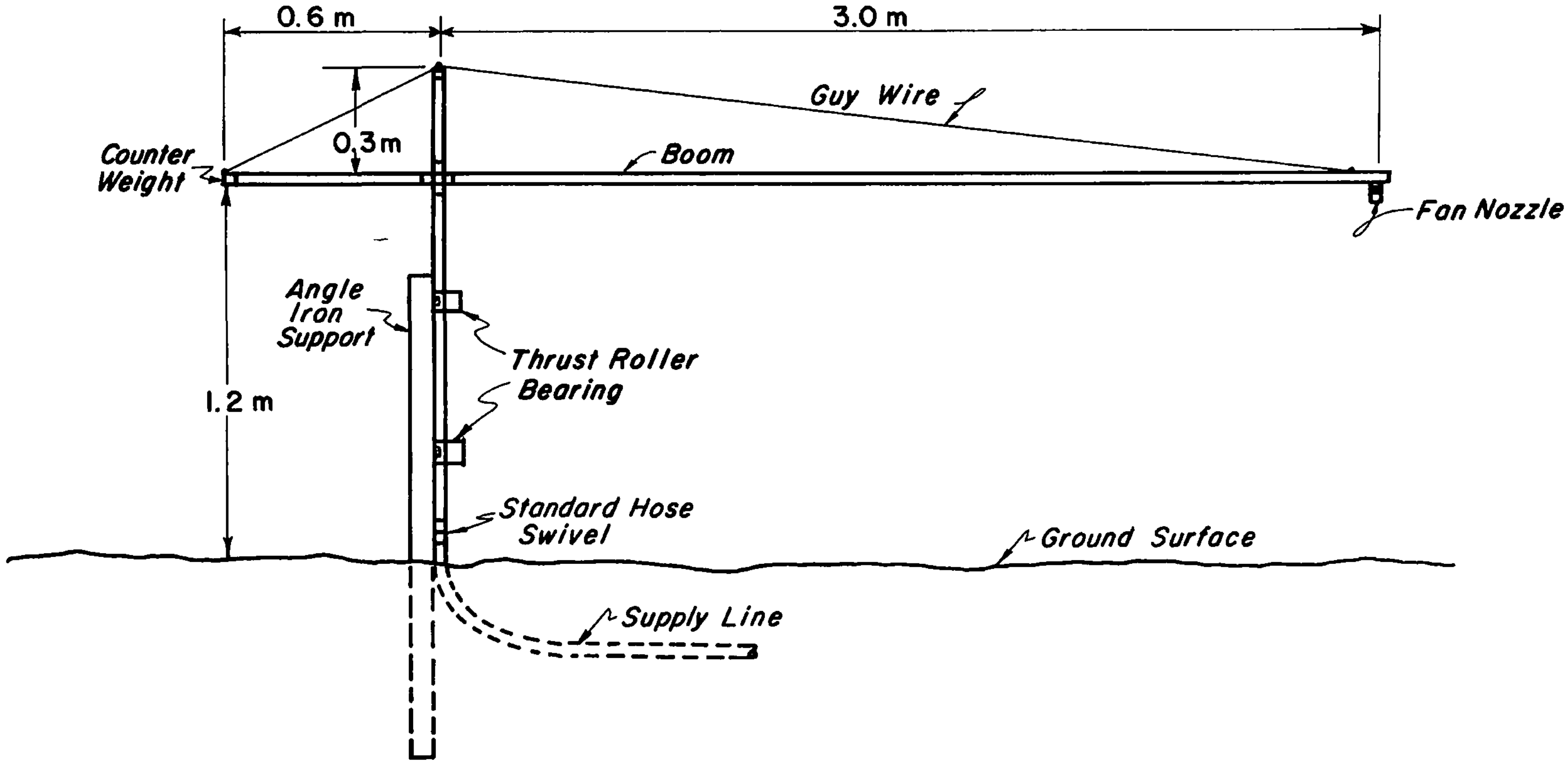

FIGURE 2. DETAIL OF WASTEWATER DISTRIBUTOR

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.

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 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[3] had shown that grab samples taken this way are comparable in chemical quality to flow proportional composite samples.

All samples were subjected to analysis for 15 chemical parameters frequently employed to characterize the solids content, oxygen demand, and nutrient content of wastewater. The analytical procedures used were selected from those published in "Methods for Chemical Analysis of Water and Wastes, 1971."[5]

SECTION V

OPERATING RESULTS

Results for operation of the wastewater distribution system will be presented in two sections because operating problems led to a major revision of the distribution system design after a shakedown and system aging period of operation lasting six 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.

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 storage requirements for a system operated in this manner. Temperatures during the winter of 1971-72 were close to the norms with the December average temperature being 0.8° C above the norm of 6.5° C, the January average temperature being 0.9° C below the norm of 5.3° C, and the February average temperature being 0.4° C above the norm of 7.5° C. Freezing interrupted operations for a total of 10 days during January and February. 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.

SECTION VI

TREATMENT PERFORMANCE

Results for the 18 months of operation covered will be presented in three sections. The first section will cover the general characteristics of the raw wastewater throughout the study period and the treatment efficiency achieved during the 6-month shakedown period of operation. This initial period of operation is a time when the system is undergoing rapid changes in treatment efficiency due to adaptation of microbial organisms, establishment of vegetation, and other environmental alterations commonly lumped under the aggregate term of "aging." Treatment efficiency achieved during this period of operation is not indicative of the efficiency expected for a well matured system. The second section will cover the period from November 1971 through April 1972 which encompasses a period of winter operation for a reasonably well matured overland-flow system. The third section will cover May through September 1972, which is representative of summer operation for a well matured overland-flow system.

WASTEWATER QUALITY AND SHAKEDOWN OPERATION

The raw wastewater data summary in Table 1 shows the results of analyses for 25 samples taken during the 18-month study period. The parameters listed are commonly used to express the solids content, the oxygen demand, and the major nutrient content of wastewaters. The data presented in Table 1 indicate that the suspended solids, oxygen demand, and major nutrient content of the wastewater used in the study are within the range that is considered to be normal for domestic wastewaters. Using the mean values from Table 1 and the average liquid

Table 1. CHEMICAL CHARACTERISTICS OF RAW WASTEWATER FOR 18-MONTH STUDY PERIOD

Parameter	Concentration, mg/l		
	Mean	Maximum	Minimum
Total Solids	1014	1660	650
Total Volatile Solids	300	525	149
Total Suspended Solids	160	420	52
Total Volatile Suspended Solids	123	306	40
Total Dissolved Solids	854	1504	525
Biochemical Oxygen Demand	150	273	84
Chemical Oxygen Demand	314	620	130
Total Organic Carbon	89	198	21
Total Nitrogen	23.6	36.8	10.7
Kjeldahl Nitrogen	22.8	36.8	8.3
Ammonia Nitrogen	17.0	29.0	6.9
Nitrate plus Nitrite Nitrogen	0.8	-	-
Total Phosphorus	10.0	15.0	4.8

loadings of 7.4, 8.6, or 9.8 cm per week, one can calculate the mass loadings for parameters of interest. For example, the biochemical oxygen demand loadings at the 9.8 cm/week rate average 147 kg/ha/week with a summer high of 169 kg/ha/week and a winter low of 125 kg/ha/week. It is of particular interest to note that continuous year-round operation results in annual nitrogen loadings ranging from a low of 910 kg/ha to a high of 1,200 kg/ha. This nitrogen loading is substantially more than can be removed by crop uptake and harvesting.

As has been stated, nozzle plugging interfered with the scheduled operation of the system during the shakedown period. The nozzle plugging problem and other start-up operational problems reduced the plot wastewater loadings to about 80 percent of the scheduled 7.4, 8.6, and 9.8 cm/week rates. This was not considered to be a problem in evaluating treatment performance because it was known that a several-month period was needed to age the system and to establish vegetative cover on the newly prepared and seeded plot area. The major stabilization period took from two to four months, as is shown by the time plots for total nitrogen and total suspended solids in the runoff from the 9.8 cm/week loading in Figure 3. As is shown, the concentration of total nitrogen in the plot runoff declined rapidly from an initial level of about 18 mg/l to values of about 5 mg/l within 60 days, while the total suspended solids declined more slowly from an initial value of about 120 mg/l to values of less than 25 mg/l after 120 days of operation.

Chemical data showing the treatment efficiency changes for other parameters during the period of system aging are presented in Table 2. All of the nitrogen forms and total phosphorus exhibited the rapid changes illustrated by the plot for total nitrogen in Figure 3. Biochemical oxygen demand exhibited a slower change more comparable to that illustrated by the graph for total suspended solids in Figure 3. Changes for chemical oxygen demand and total organic carbon were less dramatic and also extended over most of the period of aging. A comparison of the mean values of all parameters for June and July indicates that treatment efficiency was adequately stabilized for initiation of the comparison of seasonal influences on treatment efficiency for the three loading rates.

Table 2. TREATMENT EFFICIENCY IMPROVEMENT DURING SYSTEM AGING IN 1971

	Mean monthly concentration in runoff for all rates, mg/l				
Parameter	March	April	May	June	July
Total Suspended Solids	172	71	42	21	25
Biochemical Oxygen Demand	102	44	41	29	23
Chemical Oxygen Demand	158	148	104	71	95
Total Organic Carbon	56	55	36	31	42
Total Nitrogen	17.8	11.6	5.1	5.0	6.7
Kjeldahl Nitrogen	16.7	11.5	5.1	4.3	5.2
Ammonia Nitrogen	12.9	4.2	1.8	1.6	1.4
Total Phosphorus	5.9	3.9	2.4	2.4	2.3

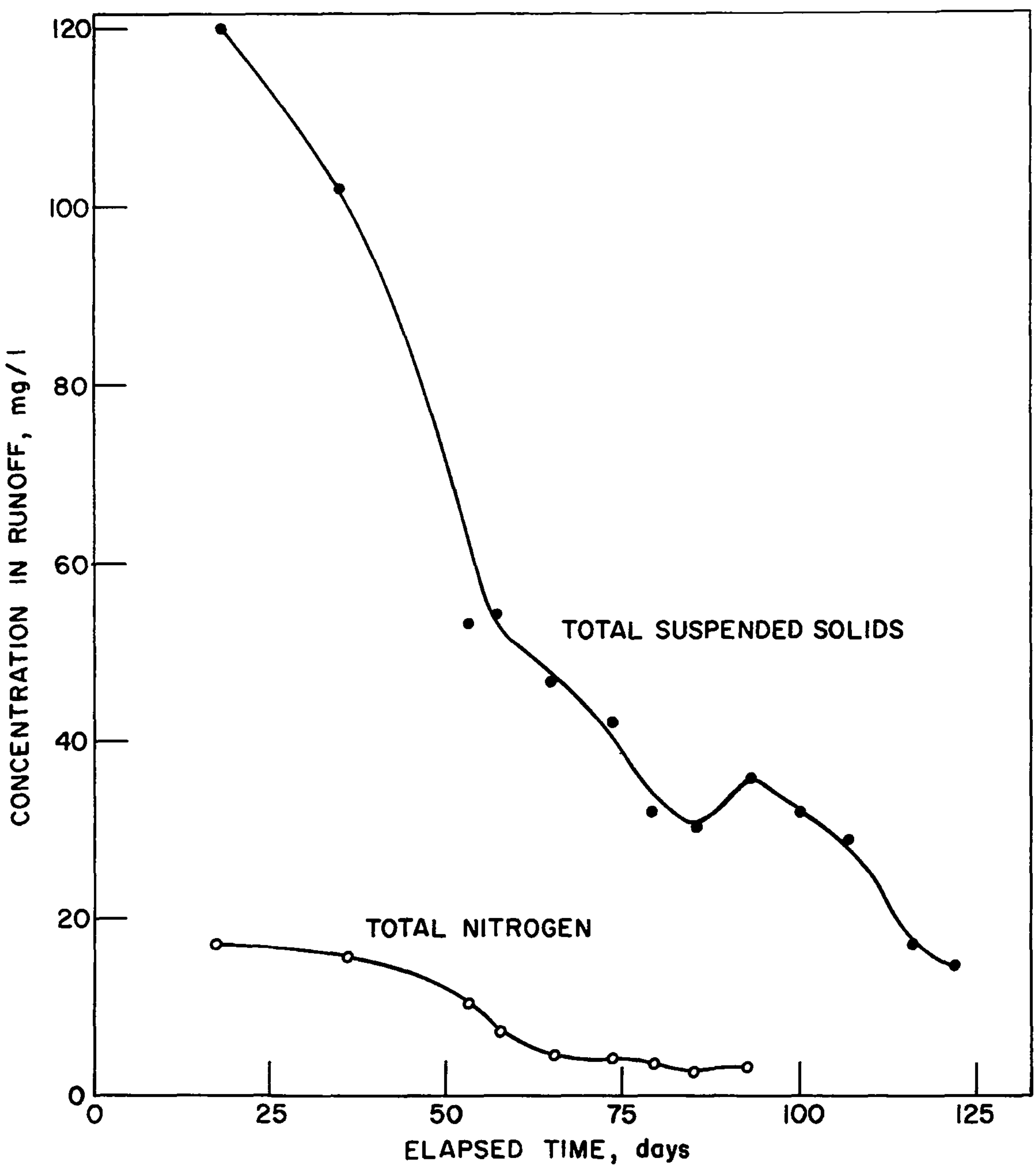

FIGURE 3. CHANGES IN TREATMENT EFFICIENCY DURING SYSTEM AGING

Since treatment efficiency was stabilizing and nozzle clogging was interfering with achievement of the desired loading, it was decided to shut the system down in August 1971 to incorporate the sedimentation and skimming tank into the distribution system. With these modifications completed, the system was placed back into operation in November 1971 at the scheduled loading rates.

WINTER TREATMENT PERFORMANCE

This data reporting period covers operations from November 1971 through April 1972 and covers the first winter season of operation for the test site. From November 1, 1971 through December 15, 1971 and from March 16, 1972 through April 30, 1972, the system was operated at the 7.4, 8.6, and 9.8 cm/week loading rates. In the interim period from December 16, 1971 through March 15, 1972, the system was operated at the 6.3, 7.3, and 8.2 cm/week winter loading rate. Therefore, the average loading for this reporting period was 6.8, 8.9, and 9.1 cm/week. Chemical quality data for the runoff from the three plots for this period of operation are summarized in Table 3. Differences in the treatment performance achieved at the three rates of loading were minor and inconclusive, as far as identifying one rate as being superior. Each of the three loading rates was identified as the best performer for three or more of the parameters listed in Table 3. Using total suspended solids and biochemical oxygen demand as key measures of treatment efficiency, the higher loadings have a slight advantage over the lowest loading. Alternatively, using the major nutrients nitrogen and phosphorus as the key parameters for consideration, the lowest loading rate shows a distinct advantage over the higher loading rates. The small and inconsistent differences exhibited during this period of operation suggest that the optimum loading of raw comminuted wastewater to an overland-flow system exhibits a rather flat peak and that all three of the evaluated loading rates fall close to the optimum.

The hypothesis that all three rates fall near a broad optimum for loading is substantiated by the fact that the quality of runoff from all three plots is indicative of a relatively high level of advanced waste treatment. Treatment efficiency for suspended solids and biochemical oxygen demand was 92 to 95 percent. As shown by the data plotted as a moving 3-point average in Figure 4 for each of the three rates of loading, the concentration of suspended solids and biochemical oxygen demand increased slightly during winter operation even though the loading rate was reduced for winter operation. Even with the slight increase, the maximum concentrations for these parameters remained well below 20 mg/l, which is considered an excellent level of secondary treatment. The other measures of solids and oxygen demand, as shown by the data in Table 3, substantiated the high treatment efficiency illustrated by the graphic presentation of data for total suspended solids and biochemical oxygen demand.

Table 3. CHEMICAL QUALITY OF PLOT RUNOFF FOR WINTER OPERATION FROM NOVEMBER 1971 THROUGH APRIL 1972

	Mean concentration, mg/l		
Parameter	7.4 cm/wk plot	8.6 cm/wk plot	9.8 cm/wk plot
Total Solids	702	722	727
Total Volatile Solids	174	174	169
Total Suspended Solids	12	8	9
Total Volatile Suspended Solids	7	5	5
Total Dissolved Solids	690	714	718
Biochemical Oxygen Demand	12	11	8
Chemical Oxygen Demand	53	48	46
Total Organic Carbon	22	14	15
Total Nitrogen	5.4	7.2	6.8
Kjeldahl Nitrogen	2.4	3.6	2.9
Ammonia Nitrogen	0.5	2.0	1.3
Nitrate Nitrogen	2.8	3.4	3.7
Total Phosphorus	4.4	5.4	5.1

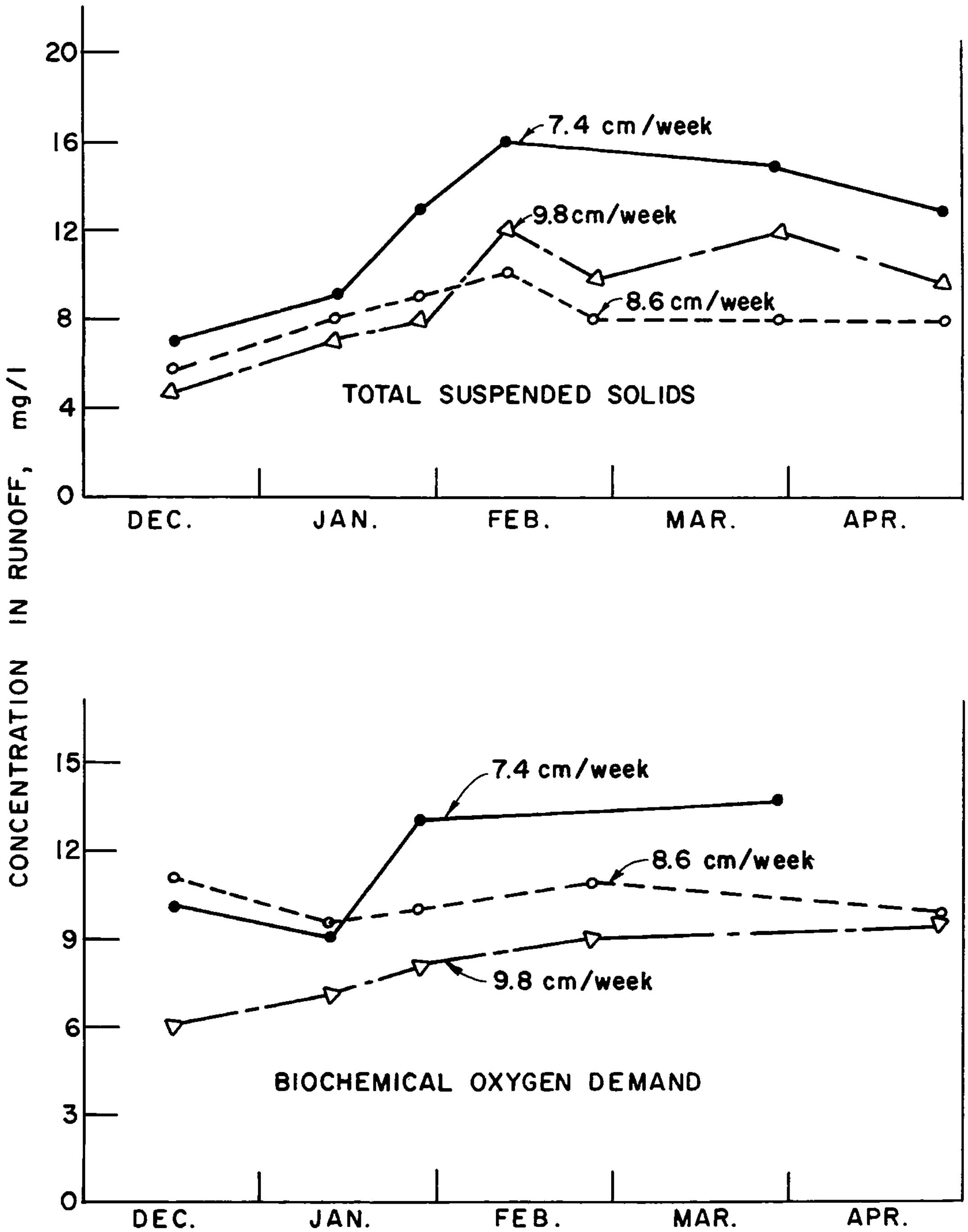

FIGURE 4. REMOVAL OF SUSPENDED SOLIDS AND BIOCHEMICAL OXYGEN DEMAND IN WINTER

Total nitrogen removal ranged from 70 percent for the 8.6 cm/week loading to 77 percent for the 7.4 cm/week loading. This level of nitrogen removal was being achieved while vegetation was dormant and at nitrogen loadings of 15 to 20 kg/ha/week (equivalent to 774 to 1,020 kg/ha/year). Crop uptake could not contribute significantly to the observed loss of more than 10 kg/ha/week of nitrogen from the wastewater on the overland flow plots. The 3-point moving average plot in Figure 5, shows a substantial nitrogen peak in the plot runoff during January and February. This increase was the result of a comparatively high nitrate concentration during this period. For three sampling dates from January 13, 1972 through February 10, 1972, the mean nitrate concentration in the plot runoff was 6.0, 7.4, and 6.4 mg/l, respectively, for the 7.4, 8.6, and 9.8 cm/week plots. These results for the winter season show that there was a definite seasonal influence on total nitrogen removal. It may be that this is a true seasonal influence or it may be largely due to the brief shutdown periods necessitated by freezing weather conditions since Law, Thomas, and Myers[3] have observed that high nitrate in the effluent occurs when system operation is resumed following system shutdown.

Total phosphorus removal during winter operation was about 50 percent with a small range between the three loading rates as shown in Table 3. The 3-point moving average graphs in Figure 5, show a seasonal variation similar to that exhibited by the concentration of total nitrogen but the magnitude of the relative midwinter peak was substantially less than for nitrogen. This change in the concentration of phosphorus in the plot runoff amounts to a relatively small mass of phosphorus. The average phosphorus load to the overland-flow system ranges from 385 kg/ha/year for the 7.4 cm/week plot to 510 kg/ha/year for the 9.8 cm/week plot. This means that the equivalent of about 200 to 250 kg/ha/year is being retained on the overland-flow area and the remaining phosphorus is being discharged in the plot runoff. Phosphorus removal by plant uptake and harvest is sufficient to have a major influence on phosphorus behavior under these conditions and it is

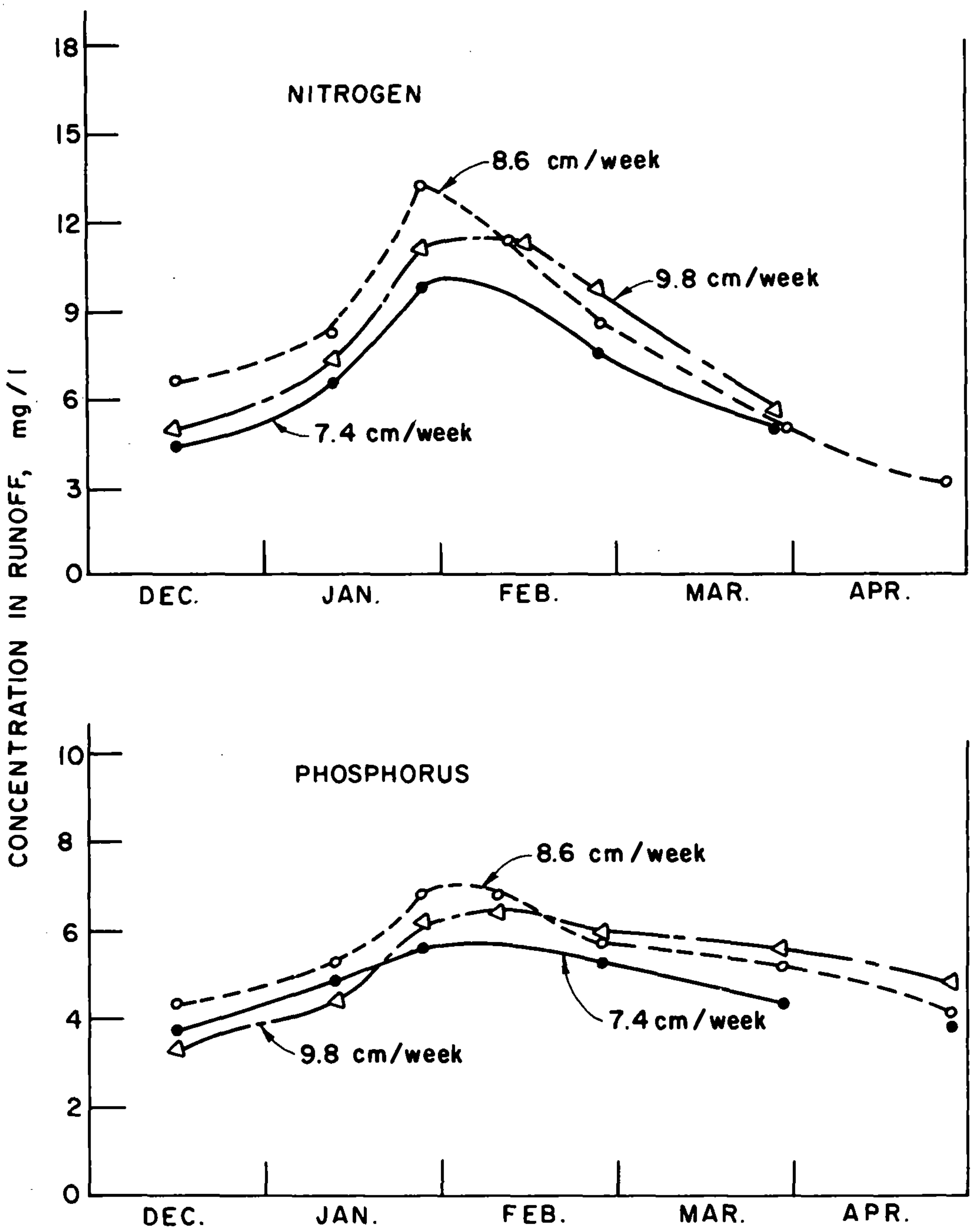

FIGURE 5. NUTRIENT REMOVAL DURING WINTER OPERATION

probable that dormancy of vegetative growth accounts for the observed changes in the concentration of phosphorus in the plot runoff.

There are many factors which could contribute to the observed behavior of nitrogen and phosphorus during the winter period of vegetative dormancy and freezing weather conditions which necessitated brief shutdown periods. Probable causes for the observed increases of total nitrogen and total phosphorus in the plot runoff during winter operation will be covered in the Discussion section.

SUMMER TREATMENT PERFORMANCE

This data reporting period covers operation from May 1972 through September 1972 and represents the second summer of system operation. The data for this period are indicative of data from a reasonably well matured system and can be expected to be representative of stabilized operating conditions. The system was operated at the average scheduled loadings of 7.4, 8.6, and 9.8 cm/week from May 1, 1972 through June 15, 1972 and at 8.5, 9.9, and 11.3 cm/week from June 15, 1972 through September 30, 1972; therefore, the average loading for this summer period of reporting was 8.2, 9.5, and 10.8 cm/week. Chemical quality data for the plot runoff for this summer period are summarized in Table 4. As was the case for winter operation, differences in the chemical quality of plot runoff between loading rates were relatively minor. Although the differences between loading rates were minor, there was a consistent trend toward a better effluent from the intermediate and highest loading rate than from the lowest rate except for the removal of total phosphorus. As was the case for winter operation, the data collected for this summer period of operation do not identify a single rate as being superior, but it does support the hypothesis that the optimum loading of raw comminuted wastewater to an overland-flow system has a relatively broad peak. For this period of operation, there is also a trend for treatment efficiency at the highest loading rate to be somewhat better than the treatment efficiency at the lowest loading rates.

Table 4. CHEMICAL QUALITY OF PLOT RUNOFF FOR SUMMER OPERATION FROM MAY 1972 THROUGH SEPTEMBER 1972

Parameter	Mean concentration, mg/l 7.4 cm/wk plot	8.6 cm/wk plot	9.8 cm/wk plot
Total Solids	814	848	817
Total Volatile Solids	142	143	140
Total Suspended Solids	8	6	8
Total Volatile Suspended Solids	5	4	4
Total Dissolved Solids	806	842	809
Biochemical Oxygen Demand	11	7	8
Chemical Oxygen Demand	73	59	58
Total Organic Carbon	23	18	19
Total Nitrogen	2.6	2.2	2.2
Kjeldahl Nitrogen	1.8	1.7	1.7
Ammonia Nitrogen	1.0	0.7	0.6
Nitrate Nitrogen	0.4	0.5	0.4
Total Phosphorus	4.0	4.3	4.3

The quality of runoff for all three loading rates continued to be indicative of the high degree of advanced waste treatment observed during winter operation, although there were substantial shifts in the percentage removal for several of the measured parameters. Removal of total suspended solids showed a slight but consistent improvement over the results for winter operation. Volatile solids and volatile suspended solids exhibited similar percent removals, while total solids and dissolved solids showed expected increases in response to greater evaporative losses during the summer season. Biochemical oxygen demand showed a slight improvement while chemical oxygen demand and total organic carbon showed small but consistent increases in comparison to winter values reported in Table 3. Percentage removal for total suspended solids and biochemical oxygen demand equalled or exceeded 95 percent and the concentration of these constituents in the plot was consistently less than 10 mg/l.

The behavior of the nutrients nitrogen and phosphorus exhibited more noticeable changes in relation to winter performance of the overland-flow system. The concentration of total nitrogen in the plot runoff which had started to decline rapidly with the onset of vegetative growth in the spring continued its decline until it reached values of less than 2.5 mg/l and remained at these levels throughout the summer, as shown by the data in Table 4. Plant uptake and harvesting can easily account for the mass of nitrogen involved in the difference between the winter removals of 70 to 77 percent and the summer removals of 89 to 93 percent. It is probable that plant uptake is a major contributor to this difference between summer and winter performance, although many other factors could contribute to the observed difference in nitrogen removal. Removal of nitrogen will be covered more extensively in the Discussion section. Removal of total phosphorus also improved somewhat with the onset of spring and rapid vegetative growth, as is illustrated by comparing the data in Table 4 to that in Table 3. Summer concentrations of phosphorus in the plot runoff ranged from 4.0 to 4.3 mg/l, in comparison to 4.4 to 5.4 mg/l for winter concentrations. The improved phosphorus removal during the summer is not sufficient to have a major influence on the overall removal of phosphorus. The differences between summer removals and winter removals are well within the influence expected from crop uptake and removal by harvesting, and removal by crop harvesting is the most logical cause for the observed difference between winter and summer performance. Phosphorus removal and probable explanations of the seasonal differences will be covered in more detail in the Discussion section.

SECTION VII

DISCUSSION

The overland-flow process has been utilized as a practical tool for treatment of organic wastewaters at a number of locations but little has been reported to identify or elaborate the mechanisms involved in the actual treatment process. The removal of suspended solids and biochemical oxygen demanding substances are readily explained as the result of biooxidation by the microbial population of the soil. There is a wealth of published information to support this explanation and there is little doubt that the explanation is valid. Explanations for the observed removals of the nutrients nitrogen and phosphorus cannot be explained so readily on the basis of existing information. Since the removal of nitrogen and phosphorus from wastewaters is becoming increasingly important for preventing the accelerated eutrophication of receiving waters, the removal of these two wastewater constituents by the overland-flow process will be discussed in detail.

As indicated in the Introduction, Kirby[2] and Law, Thomas, and Myers[3] have reported that overland flow achieves substantial removal of total nitrogen. The results of this pilot study corroborate the results of the previous research efforts. As was the case in the study by Law, Thomas, and Myers,[3] the nitrogen loading to the overland-flow system evaluated in this report greatly exceeds the nitrogen which can be accounted for by crop removal, retention in the soil, or loss in the runoff and it is apparent that nitrogen removal involves one or more additional mechanisms. The apparent loss of substantial masses of nitrogen to the atmosphere observed under these closely-controlled experimental conditions and work being conducted by Hoeppel, Hunt, and Delaney[6] support the theory that the microenvironmental conditions established in a well operated overland-flow system promote the conversion of reduced nitrogen forms to gaseous nitrogen through the mechanism of microbial nitrification-denitrification. It is our theory that nitrification takes place near the air water interface where the rate of oxygen transfer from the air into the liquid phase and oxygen diffusion through the liquid phase can meet the biochemical oxygen demand exerted by the constituents in the wastewater. Denitrification takes place deeper in the water phase where diffusion of oxygen fails to meet the biochemical oxygen demand of the wastewater constituents and the oxygen status of the liquid phase becomes favorable for denitrification. In essence, the theory stipulates that the loading of oxygen demanding constituents regulates the oxygen status to prevent anaerobic metabolism from becoming dominant, yet supports active denitrification. This theory offers a ready explanation of the substantial amount of nitrogen removal achieved by the overland-flow process which cannot be explained by crop removal or retention in the soil. The theory is also in keeping with the vast amount of published information on the environmental factors influencing the nitrification-denitrification process. Acceptance of this theory leads one to project the following general pattern for determining optimum nitrogen removal in relation to biochemical oxygen demand loading for the overland-flow process. (1) Nitrogen removal is a continuing process and should neither increase nor decrease substantially with age; (2) an underloaded system, from the standpoint of biochemical oxygen demand, will have a lower nitrogen removal capability and will produce an effluent containing high nitrate; and (3) an overloaded system, from the standpoint of biochemical oxygen demand, will also have a lower nitrogen removal capability but the effluent will contain reduced nitrogen forms rather than nitrate. This projected behavior of nitrogen can be used as a guide to balance the biochemical oxygen demand loading during preliminary tests for design purposes.

Phosphorus removal by the overland-flow process is relatively low in comparison to removal of suspended solids, biochemical oxygen demand, and nitrogen. This would be expected since the behavior of phosphorus in the plant-soil environment is substantially different from the behavior of any of these other constituents. Behavior of phosphorus in the plant-soil environment has been studied extensively and it is well established that the fraction of phosphorus involved in microbial processes and the fraction of phosphorus removed by crop uptake is relatively small in comparison to the fraction of phosphorus involved in chemical interactions within the soil matrix. The fact that it is well established and documented that most fine textured soils have the capacity to retain large quantities of phosphorus as insoluble compounds has little utility for designers of overland-flow systems. Other constraints on the design and operation of an overland-flow system dictate that close contact between the liquid phase and the soil be restricted severely. It is highly improbable that one could design and operate overland-flow systems which would achieve consistently high phosphorus removals while maintaining comparable removals of biochemical oxygen demand and total nitrogen without special consideration for phosphorus removal. For those who need to achieve a high level of both nitrogen and phosphorus removal, a probable solution is available through the chemical precipitation of phosphorus by addition of suitable cation species. The theory for this approach is readily available in the waste treatment process literature and an overland-flow system operated to achieve nitrogen removal should be amenable to phosphorus removal by chemical precipitation. Further study is in progress to explore the practicality of improving phosphorus removal by chemical precipitation.

Another alternative for achieving efficient phosphorus removal would be the utilization of soil infiltration following overland flow. This alternative provides the needed soil contact for phosphorus retention and would also provide additional polishing for removal of suspended solids, oxygen demanding substances, and fecal organisms. Studies to be initiated at the Robert S. Kerr Environmental Research Laboratory in 1974 will evaluate the overall treatment efficiency of overland flow and soil infiltration in series.

SECTION VIII

SUMMARY

Data have been reported for an 18-month operational period of an overland-flow system designed to treat raw comminuted wastewater. Fifteen chemical parameters were measured to evaluate the treatment efficiency of this wastewater treatment system. The results of this 18-month pilot study show that the overland-flow process is capable of achieving advanced waste treatment of raw comminuted wastewater when designed as a single pass treatment process with no production of sludge. Pretreatment needs are brief sedimentation for grit removal and skimming to remove floatables which may lodge in nozzle orifices after comminution.

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. The summer values for phosphorus will be slightly less than winter values, but seasonal differences in phosphorus removal will be minor.

It is noteworthy that the effluent from this pilot 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 IX

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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

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