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Land Application of Wastewater Under High Altitude Conditions

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July 1978

LAND APPLICATION OF WASTEWATER

UNDER HIGH ALTITUDE CONDITIONS

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

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ABSTRACT

The objectives of this study were to monitor and evaluate the nutrient, crop, and hydrologic parameters affecting the Thayne, Wyoming wastewater treatment system. Cheeseplant wastewater and municipal sewage were mixed, pretreated, and applied to a 15 hectare sprayfield on a year-round basis. An ice pack formed during November or December, depending on weather conditions, and lasted through the middle of April. Samples of groundwater and water from adjacent springs have shown that after three consecutive years (1975-77) of spraying wastewater on the field and with a build-up of the ice pack each winter, no significant amounts of pollutants have reached the groundwater.

Organic nitrogen was oxidized as it traveled through the ice pack and upper part of the soil mantle during the winter. Reduction of BOD_5, COD, and nitrogen forms to migrate in the ice pack was observed, clearly showing the concentration of these parameters at the surface and bottom of the ice pack.

Garrison creeping foxtail appeared to be most adapted to the sprayfield of those species tested. Reed canarygrass, smooth bromegrass, and western wheatgrass were also able to survive the harsh environment of the sprayfield. The forages studied could, at specific stages of growth, contain sufficient NO_3-N to be toxic to livestock.

This report was submitted in fulfillment of Grant No. R803571 by The University of Wyoming under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period May 1, 1975, to May 1, 1978, and work was completed as of January 1, 1978.

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Finally, the authors wish to thank Lowell Leach, Project Officer, for his encouragement and technical assistance.

SECTION 1

INTRODUCTION

The application of municipal and industrial wastewater to land for treatment has reached a high state of proficiency in warm climates. It is only natural that organizations in cold climates would like to use this technology to solve some of their wastewater problems. As is often the case, the adaptation of new technology to different environments necessitates changes in this technology and creates special problems that must be solved before the systems can perform their intended functions. It was the main objective of the University of Wyoming to monitor the land treatment system at Thayne, Wyoming, and to evaluate the nutrient, crop, and hydrologic parameters affecting the operation of the system under the severe climatic conditions found at that location.

The Town of Thayne, Wyoming, chose to use a land treatment system for their wastewater even though the growing season is short and the winter temperatures can easily reach -40°C. Engineering reports indicated a land treatment system to be cost effective and would allow the wastewater to be reclaimed without any direct discharge to surface waters and very little if any pollutants being discharged to receiving groundwater. In addition, the system would not take valuable agricultural land out of production.

The system, once in operation, did not meet the expectation of the Town of Thayne for a number of reasons. Most of the dissatisfaction with the system does not pertain to the objectives of this report and will not be addressed. This report will address itself to the results of the monitoring program and to answering the following questions: (1) will land treatment of combined municipal and industrial wastewater work under high altitude conditions where severe cold weather is normal, and (2) what problems exist in the land treatment process under these conditions and how should they be handled?

SECTION 2

CONCLUSIONS

The land treatment system used by Thayne, Wyoming, for treating its wastewater did work. This was concluded because no significant amounts of pollutants above background levels, other than total dissolved solids, were found in the groundwater below the sprayfield. The pollutants examined encompass both conservative and nonconservative materials and living matter, thus groundwater pollution from the land treatment system seems remote. Other conclusions about the wastewater treatment system are as follows:

1. High strength wastewater can be treated by land application on a year-round basis in very cold climates.

2. The ice pack that results from winter-time application works in harmony with the soil matrix to treat the wastewater.

3. Formation of an ice pack can be used as a means of liquid storage during the winter months as an alternative to the use of large holding lagoons.

4. Garrison creeping foxtail, reed canarygrass, smooth bromegrass, and western wheatgrass were able to survive the harsh environment of the sprayfield.

5. The controlled environment study indicated that the low temperatures at the field site may limit nutrient uptake although this was not as evident in the field grown forage.

6. When the combination of nutrient uptake, forage yield and quality of the livestock feed was considered, Garrison creeping foxtail appeared to be the most adapted to the sprayfield of those species tested.

7. The forage crop under the field site studied could, at specific stages of growth, contain sufficient NO_3-N to be toxic to livestock.

8. Even during the winter there were significant reductions of BOD_5 and COD in the upper 45 cm of the soil mantle although these decreases were probably attributable to filtration of the organic matter by the soil as well as an indication that some biological processes were occurring during the winter.

SECTION 3

RECOMMENDATIONS

The wastewater treatment system at Thayne operated under very severe climatic conditions. Since limited management information is available for land application systems under such conditions, many problems with management as well as system design were noted. To improve the operation and design of similar systems, the following recommendations are made:

1. Forage harvested from system should be analyzed for NO_3 as levels toxic to livestock may occur.

2. Establish the desired perennial forage species prior to or as early as possible after the initial operation of the system. This will decrease the buildup of weed species adapted to the harsh environment.

3. All laterals and mains should be buried a sufficient depth to prevent freezing. Soil should not be piled up over the pipes in lieu of a deep trench. The piled soil prevents normal farming operations and the plants that grow in these piles can cause odor and weed problems.

4. All laterals and mains should drain back to the pump wet well to prevent any water in risers and sprinkler heads after the stoppage of spraying.

5. A cleanout valve should be placed at the end of each lateral.

6. Effluent sprayed in the winter should have a temperature of 4°C or above to prevent any serious buildup of ice on the sprinkler heads.

7. No more than two-thirds of the sprayfield should be used during the winter. The remaining one-third of the sprayfield should be saved and used in the spring at the time of ablation of the ice pack. If this procedure is followed, no additional water will be added to the area under the ice pack and water logging of the soil at the time of ablation can be minimized.

8. Set times should be 30 minutes or less during the winter months. Following ablation of the ice pack, the irrigation schedule should be returned to a summer time mode. During the summer any section should not be irrigated more than once per week. More frequent irrigations will keep soil temperatures low and retard plant growth.

SECTION 4

SITE DESCRIPTION AND EXPERIMENTAL PROCEDURE

LOCATION OF STUDY

The wastewater treatment system at which this study was conducted is located at Thayne, Wyoming, and is in the center of the Star Valley (see Fig. 1). The winters in Star Valley are considered severe. According to Becker, et al., (1961), an average of 18 days (from 29 years of recorded temperature data) separates the last 0°C temperature in the spring and the first 0°C temperature in the fall at nearby Afton, and an average of 54 days separates the last -2°C frost in the spring and the first -2°C frost in the fall. Temperatures of -1°C to 1°C are considered to cause a light freeze. In the spring a light freeze may kill crops due to their young age. In the fall a light freeze will halt the growth of most plants. Temperatures of -4°C to -2°C result in so-called moderate freeze. A moderate freeze will cause moderate to heavy damage to plants which would survive a light freeze (e.g., fruit trees, lettuce, celery, etc.). Semihardy plants, such as tomatoes, will be damaged. A severe freeze will occur at temperatures of -6°C to -4°C, killing the most hardy annuals and driving perennials into dormancy. At nearby Afton, the average number of days between the last -4°C temperature in the spring and the first -4°C temperature in the fall is 110 days. This indicates an average growing season of 110 days for hardy crops such as the forage crops used and recommended for the land treatment system.

DESCRIPTION OF THE SYSTEM

The wastewater treatment system at Thayne is very simple. With a design average flow of 1325 m^3/day and a design peak flow of 4136 m^3/day, the wastewater enters a lined aerated lagoon which has a capacity of 1332 m^3 (see Fig. 2). Over 90 percent of the wastewater flow arises in the cheese factory with the remainder being domestic wastewater from the town of Thayne. At design average flow, the hydraulic detention time in the aerated lagoon will be approximately 24 hours. The influent flow is variable and has ranged from 632 to 1541 m^3/day. From the aerated lagoon the wastewater flows into a storage lagoon with a capacity of 4700 m^3. The wastewater is pumped from the bottom of the storage lagoon and sprayed on a 15 hectare sprayfield. There is no return of settled solids from the storage lagoon to the aerated lagoon, i.e., there is no cell recycle. Application of wastewater is rotated to different sections of the sprayfield each day six days a week via a high pressure solid set spray irrigation system, with each of the six sections of the sprayfield being sprayed once per week. Only small amounts of wastewater are generated on Sundays. Treated wastewater can leave the system

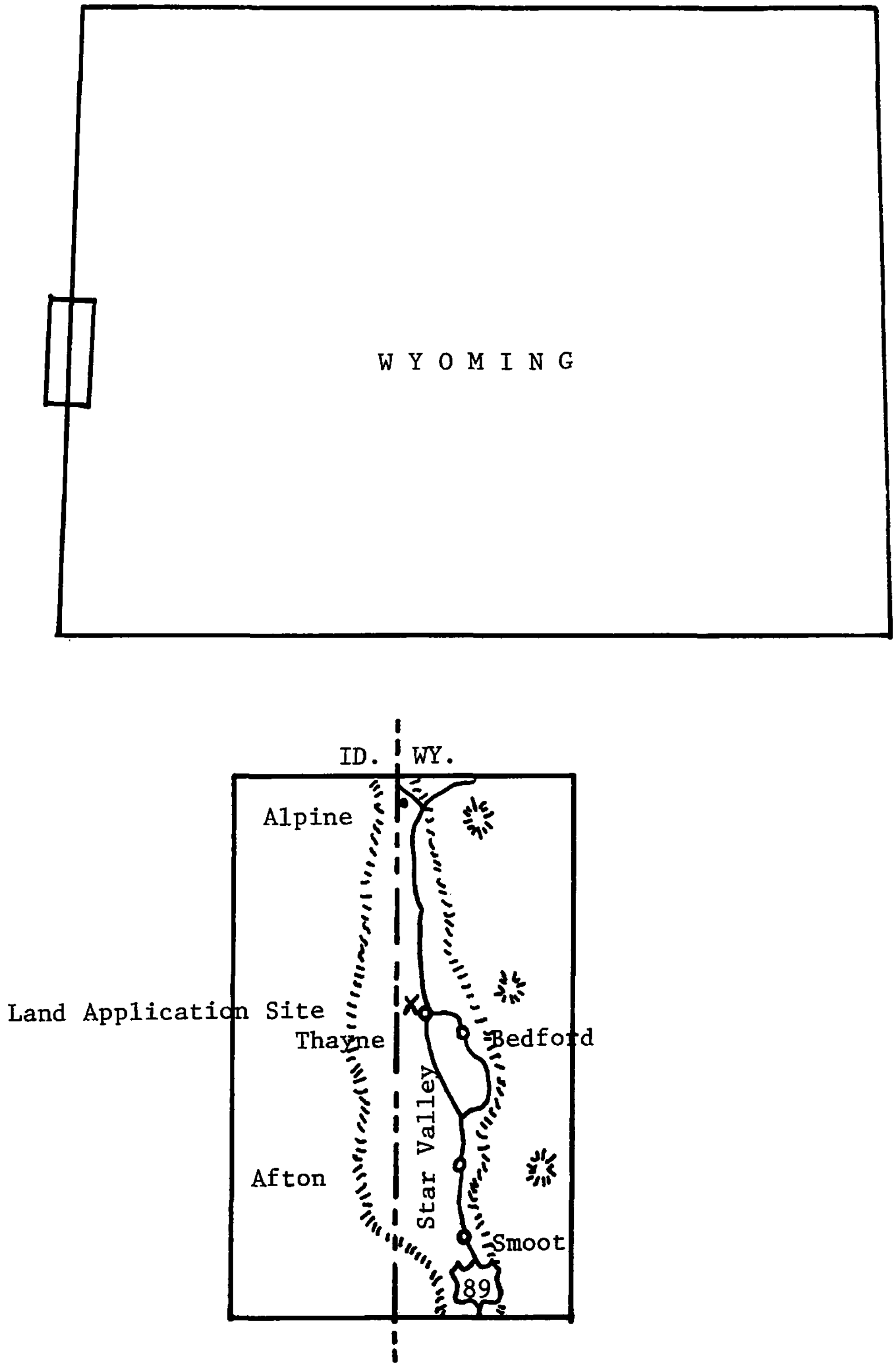

Figure 1. Site map for Thayne, Wyoming, wastewater system.

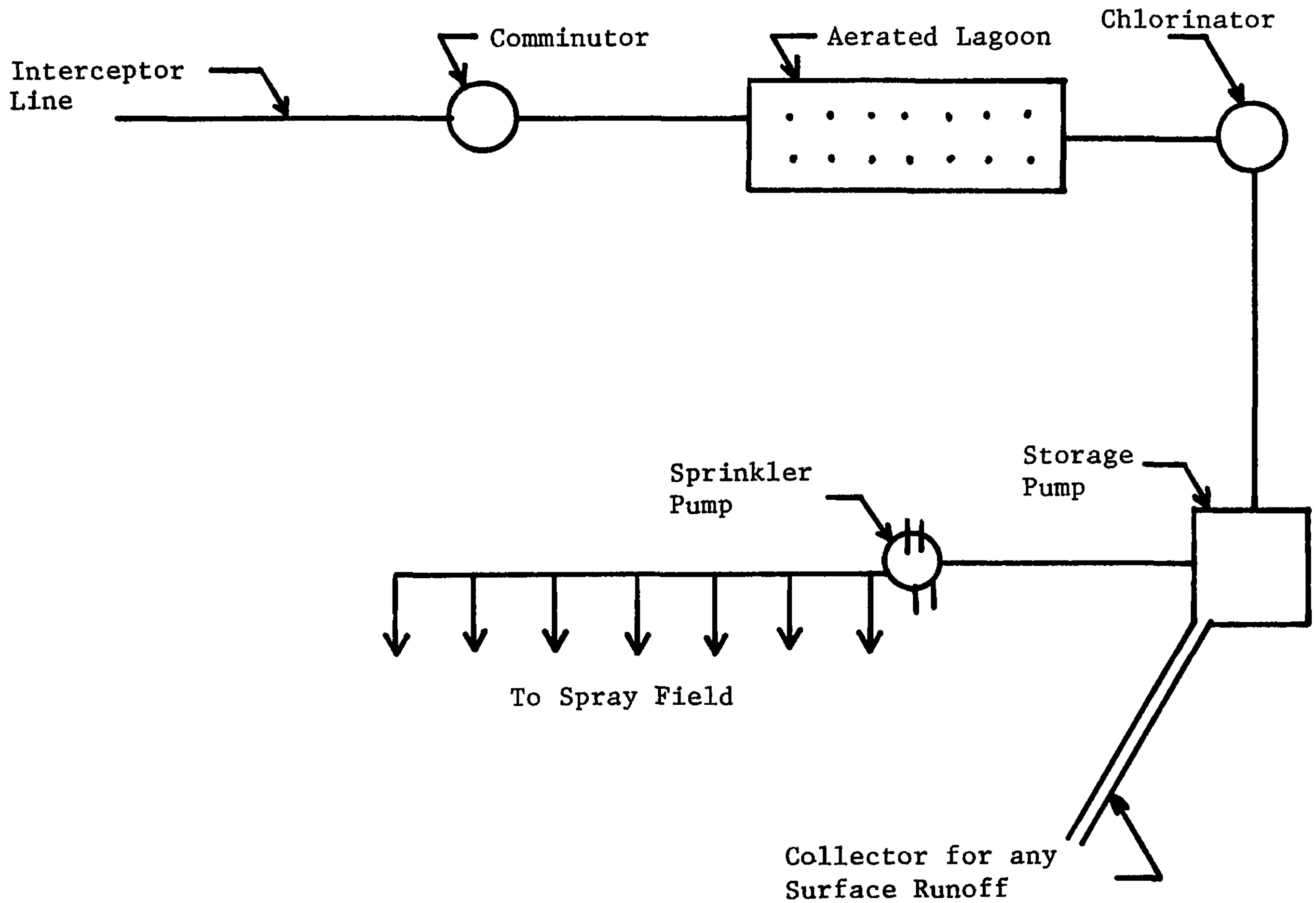

Figure 2. Schematic of Thayne, Wyoming, wastewater system.

only by deep percolation and/or evapotranspiration. All surface runoff from the sprayfield is collected in a channel on the downslope sprayfield side of a dike, and the only exit from the channel is back to the storage lagoon from where the wastewater will be resprayed on the sprayfield. The system was designed to prevent surface discharge to adjacent water courses, mainly Flat Creek. Operation of the system first began in January of 1975.

PROCEDURE FOR ENVIRONMENTAL MONITORING

The environmental monitoring consisted of (1) water sampling that attempted to ascertain the quality and changes in the wastewater from the time the water arrived at the plant until it reached the groundwater, (2) observation of climatic variables, and (3) soil sampling. Additional information was obtained on water quality during the investigation of the ice pack. This information is presented in Section 7.

Water Quality Monitoring

Shown in Figure 3 are the location of the 14 monitoring sites. They consist of the influent, water leaving the aerated lagoon, water leaving the holding lagoon, groundwater at 7 wells, water from 2 springs located below the spray field, water from an underdrain located below the lagoons, and water from Flat Creek at a site immediately below the sprayfield.

Samples were analyzed for nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), total Kjeldahl nitrogen (TKN), total organic carbon (TOC), five-day biological oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), phosphate (PO_4), pH, specific conductance, and fecal coliforms. All samples were analyzed according to "Standard Methods" (1971) after being preserved in the field and in transport according to Environmental Protection Agency recommendations for sample preservations (EPA, 1971). Spot sampling for heavy metals and certain inorganic constituents was also done. All the results are presented in Appendix I.

Climatic Monitoring

Regular monitoring of the climate began during the summer of 1975. Records were kept on air temperature, relative humidity, soil temperatures at different depths within the sprayfield, pan evaporation, wind, and precipitation. Solar radiation was collected during the latter part of the study period.

Missing data, where possible, were replaced with data from Bedford, Wyoming, which is located only 4 miles from Thayne. The results from the climatic monitoring are presented in Appendix II.

Soil Monitoring

Soil samples were from 30, 60, 90, and 120 cm depths in the sprayfield. Most of the soil samples were taken next to the agronomy plots (see Fig. 3) although some tests were taken at the north end of the field. Most of the

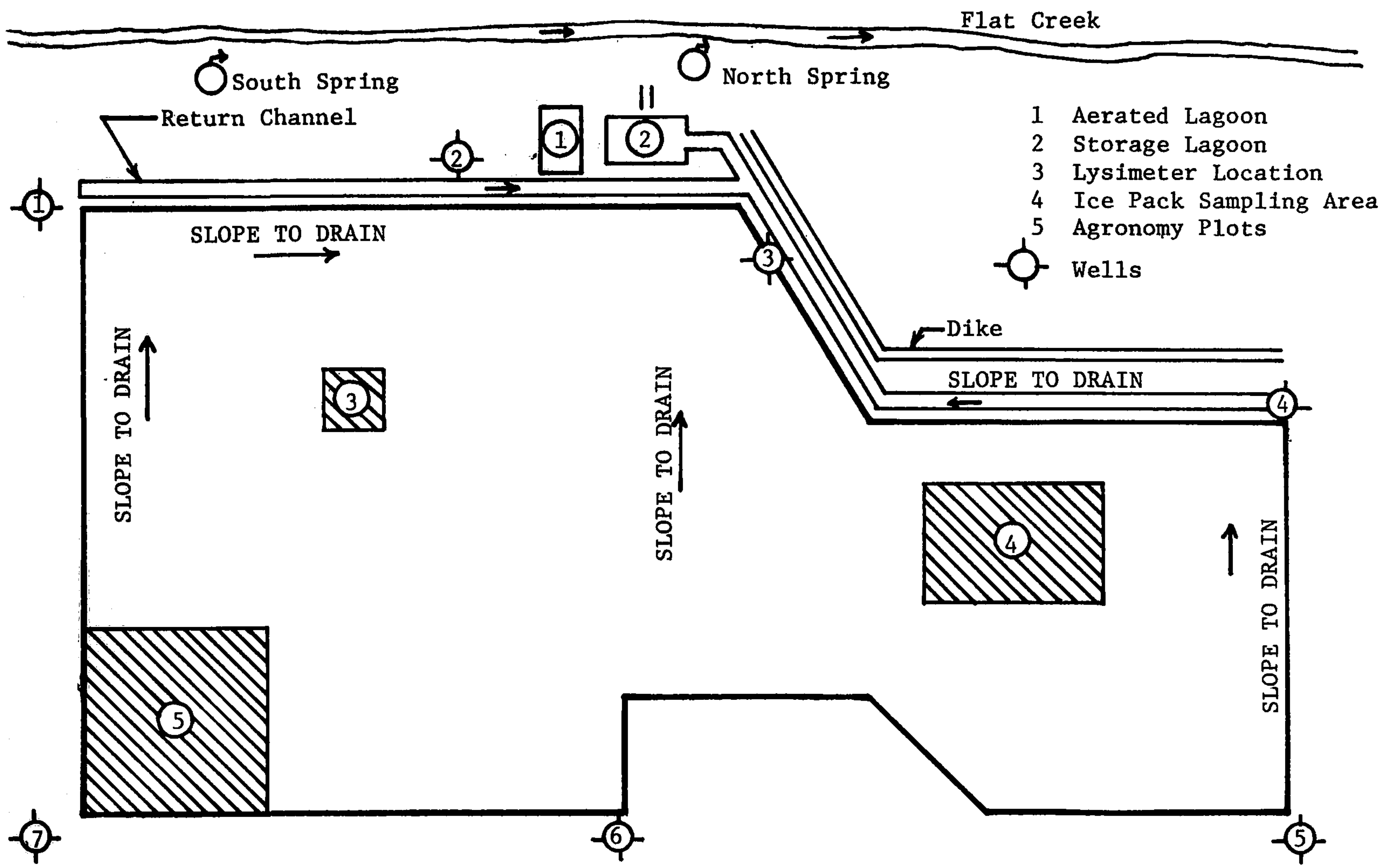

Figure 3. Location of monitoring sites.

tests taken were for the purposes of determining changes in nutrient levels. Two sets of samples taken on May 26, 1976 and August 27, 1976 were assayed for heavy metals and to determine if any change in heavy metals were occurring. Results are presented in Section 5.

FORAGE ASSESSMENT

The following forage species were irrigated with wastewater from the Thayne system: 'Rise' Reed canarygrass (Phalaris arundinacea L.), 'Manchar' smooth bromegrass (Bromus inermis Leyss.), 'Regar' meadow bromegrass (Bromus biebersteinii Roem, and Schult.), 'Kenmont' tall fescue (Festuca arundinacea Schreb.), 'Garrison' creeping foxtail (Alopecurus arundinaceus Poir.), 'Dawson' alfalfa (Medicago sativa L.), and 'Eski' sainfoin (Onobrychis viciaefolia Scop.). Two controlled environment pot experiments and field plots at Thayne, Wyoming, were used to evaluate the seven forage species for growth and quality.

Selection of Test Species

The grass and legume species used in this study were recommended for similar areas of climatic conditions and altitude in Wyoming. 'Regar' meadow bromegrass and 'Manchar' smooth bromegrass are cool season grasses that are moderate sod forming plants. They both have early spring growth and will remain green until late fall (Kail et al., 1972, Seamands and Kolp, 1975). Both are drought-hardy but 'Regar' will not tolerate poorly drained soils or high irrigation rates.

'Kenmont' tall fescue and 'Rise' reed canarygrass are both cool season grasses but are adapted to a wide variety of conditions. They are both tolerant of poorly drained soils and high irrigation rates (Kail et al., 1972, and Moyer and Seamands, 1975). They are both sod-formers, which may be beneficial in erosion control under high irrigation rates. Both have the disadvantage of having poor palatability and are not well accepted by livestock.

'Garrison' creeping foxtail is also a cool-season sod-forming grass. It produces well under irrigated conditions and can tolerate wet marshy areas (Kail et al., 1972). It has early spring growth but has poor seedling vigor, thus it is slow to establish.

The two legume species, 'Dawson' alfalfa and 'Eski' sainfoin, were chosen for their adaptability to a short season and cool climate. 'Dawson' is a wilt resistant, winter hardy variety that has done well under irrigated yield trials in Wyoming (Richardson and Roehrkasse, 1974). 'Eski' sainfoin has the distinct advantage of being resistant to the alfalfa weevil and does not cause bloat. 'Eski' has slow regrowth but has had favorable yields in Montana under irrigation (Krall et al., 1971). It has the disadvantage of poor stand persistance on some sites.

Ten additional species adapted to a short growing season were established in the sprayfield. The ten species which were planted in two replications were as follows: 'Chinook' orchardgrass (Dactylis glomerata), 'P-15594' creeping wildrye (Elymus triticoides), 'P15590' basin wildrye (Elymus cinereus), 'Critana' thickspike wheatgrass, (Agropyron dasystachyum), 'Rosanna' western wheatgrass (Agropyron smithii), 'Sodar' streambank wheatgrass (Agropyron riparium), 'Bromar' mountain bromegrass (Bromus marginatus), 'Drummond' timothy (Phleum pratense), 'Park' Kentucky bluegrass (Poa pratensis), and 'Lutana' cicer milkvetch (Astragalus cicer).

Field Study

The seven forage species were established in the sprayfield in June 1975. Plots were 1.83 by 4.57m with four replications of each species (see Fig. 4). Under normal operation of the wastewater system, the plots would receive an irrigation of wastewater once a week. The forage species were evaluated for yield and quality as well as nutrient removal and accumulation potential.

Reed canarygrass plots were established to study the effect of harvest schedules on forage yield and quality (see Fig. 4).

Ten additional species were also established adjacent to the field plots. They were sampled and analyzed for quality and chemical composition using the same methods as used for the seven primary species.

Controlled Environment Study

Soil from the sprayfield at Thayne, Wyoming, was collected, air-dried and sieved through a 1 cm screen to remove large rocks. Two kgs of the soil (Greyback gravelly loam; Typic cryoboroll) were placed in each of one-hundred-twenty-six 15.5 by 13.5 cm plastic pots and planted with one of the seven forage species. Plants were thinned to three seedlings per pot, placed in a greenhouse at a temperature of 21°C and watered with distilled water. After the plants were established and reached a uniform height, they were cut at 2.5 cm above the soil surface and the study was begun.

The seven species were placed in a growth chamber (Conviron PGW 36) with a 20/10°C day-night temperature regime, 16-hour day length, 50% relative humidity and 48.4 klux light intensity at the plant canopy. The night temperature was reduced from 20 to 10°C over a 6-hour period, held at 10°C for 2 hours, then increased to 20°C over a 4-hour period to simulate conditions at the Thayne irrigation site.

Three irrigation treatments with six replications were used as follows:

1. Effluent - the effluent was collected at the site from a sprinkler head and stored at 5°C. Effluent characteristics and nutrient levels are in Table 1. The effluent-treated pots were watered daily with 90 ml of effluents which coincided with the average 6.22 cm/week on the field disposal site.

2. Synthetic Effluent - the synthetic effluent consisted of the same concentrations of inorganic nitrogen, phosphorus, and potassium as

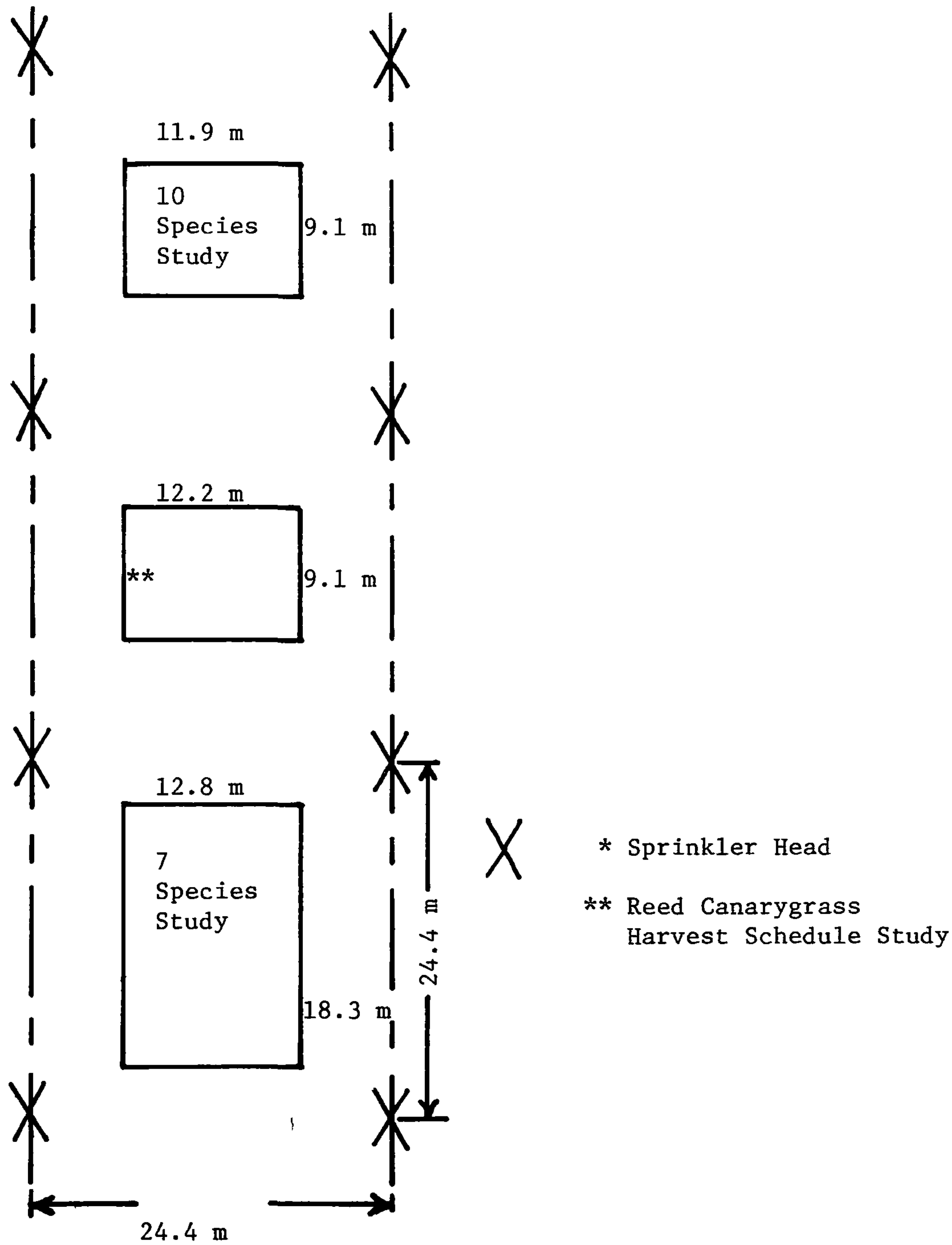

Figure 4. Field location of the three individual agronomy studies.

TABLE 1. COMPOSITION OF THREE IRRIGATION TREATMENTS USED IN CONTROLLED ENVIRONMENT POT EXPERIMENTS

	Effluent	Control	Synthetic Effluent
	mg/l		
N (inorganic)	0.1	10.1	0.1
N (Kjeldahl)	31.0		
P	0.3	6.5	0.3
K	61.0	33.3	61.0
$SO_4^{=}$	32.0		
S		45.0	
Ca	100.0		
Na	58.0		
Cl	67.0		
F	1.6		
Mg	26.0		
TDS	900		
	pH		
	5.1	6.0	5.1

the effluent (Table 1). The sources of these elements were: NH_4NO_3 for N, H_3PO_4 for P, and KOH for K. The pH was adjusted to 5.1 with HCl. Pots treated with the synthetic effluent were also watered with 90 ml per day.

3. Control - the control treatment concentrations were based on recommended fertilizer applications according to soil tests (Table 1). The control pots were given 90 ml of the control solution once weekly, and 90 ml of distilled water on the other days.

The pots' locations were randomized in the growth chamber and rerandomized each week throughout the experiment. Harvest occurred after 57 days of growth.

The experiment was continued in a greenhouse under conditions of 23/18°C day-night temperature, 16-hour day length and 60% relative humidity. Watering continued with the three treatments as before, and the plants were harvested after 34 days. To determine the effect of irrigation treatment on soil nutrient levels, soil samples from a composite of three replications were analyzed for nitrate and phosphorus by the Agricultural Consultants Laboratory, Brighton, Colorado.

The harvested plant samples were dried in a convection drying oven at 60°C for 6 days and weighed for dry forage yield before being ground to a fineness of 0.05 cm. Percentage protein was determined from 30 mg samples by the micro-Kjeldahl steam-distillation method (Association of Official Agricultural Chemists, 1955). In vitro dry matter digestibility (IVDMD) (Georing and VanSoest, 1970) was assayed using 500 mg of tissue. Rumen fluid for the IVDMD tests was obtained from a steer on a mixed grass-alfalfa diet. Phosphorus was determined by ashing a 500 mg sample at 200°C, 400°C, and 600°C for 2 hours at each temperature, extracting with .01N HCl and assaying by the Elon colorimetric method (Fiske and Subbarow, 1925).

SECTION 5

ENVIRONMENTAL MONITORING

INTRODUCTION

One of the main purposes of the environmental monitoring study was to assess the system's ability to treat Thayne's wastewater. The evaluation of the monitoring results should be tempered with the fact that the treatment system was never fully completed although the system has operated for three years. It is the opinion of the authors, however, that the system was adequate to make some judgement on the ability of this type of system to renovate wastewater.

STATUS OF SYSTEM

The system was built as described in Section 4 except for the return channel on the southwestern portion of the field. This return channel was not needed except during the summer of 1977 after part of the field was planted to barley (see Fig. 5). The planting operation destroyed the grass and the barley died. Without actively growing vegetation the field's infiltration rate decreased to the point that surface runoff occurred after approximately one-hour of irrigation (0.9 cm of water). Runoff was kept to a minimum by the operational procedures of the system's operator.

Another factor that could affect the wastewater treatment was the overloading of certain portions of the field due to pipeline failure. The most serious problem occurred during the winter of 1975-76 when the mainline serving the southern two-thirds of the field broke. The northern one-third of the field received all the wastewater from about the first of January, 1976 until the middle of May, 1976. There were numerous other small problems with the system but they would be classified as minor by comparison or did not significantly affect the operation of the system.

RESULTS OF WATER QUALITY MONITORING

Presented in Appendix I are the data collected from the 14 water monitoring sites. The strength of the influent, using COD as a measure, entering the Thayne treatment system averaged 13,200 mg/l (based on point samples). This is extremely strong when one considers that strong domestic sewage would have a value for COD around 1000 mg/l (Metcalf & Eddy, 1972). The effluent that was applied to the sprayfield averaged 9,700 mg/l (based on point samples). Thus, it appears that the pretreatment removed approximately

Figure 5. Barley strips planted in June, 1977.

25 percent of the organic load. It is of interest to note that the wastewater leaving the aerated lagoon averaged only 5,700 mg/l (based on point samples). This would suggest the holding lagoon was manufacturing COD. Surprisingly enough, data from the Wyoming Department of Environmental Quality suggests identical conclusions. The amount of algae put into the holding lagoon by the sprayfield return channel (see Fig. 6) is an unknown factor and could possibly explain the increase in COD in the holding lagoon. Records were not kept on the volume of water returning to the holding lagoon and it was judged to be a minor amount. The ponding of the water in the return channel was one of the minor problems experienced by the Thayne system.

After almost 3 years of continuous operation the overall renovation of the wastewater appears to be excellent. The groundwater beneath the field that receives the treated wastewater has not been affected. An examination of groundwater data indicated that the pollution parameters BOD_5, nitrate, ammonia, COD, phosphate, and fecal coliforms were either absent or were approximately at the same concentrations for the groundwater receiving renovated wastewater as in the groundwater unaffected by the wastewater. The downstream wells (wells 1, 2, 3, and 4) and the springs should receive the renovated water, while the upstream wells (wells 5, 6, and 7) should be free of any wastewater. It should be noted that the groundwater samples from the wells were taken from the top of the aquifer and were not homogeneous water samples from the aquifer.

Figure 6. Ponded condition in sprayfield return channel.

The treatment of the wastewater in the sprayfield does cause some deterioration of the groundwater. Although the organic and biological pollutants were removed, there was an increase in total dissolved solids (TDS). The average TDS during the monitoring period was 176 mg/l for the water in the upstream wells and 472 mg/l for the downstream wells. During May of 1977, immediately following ablation of the ice pack, the water in the upstream wells had an average TDS of 294 mg/l while water in the downstream wells had an average TDS of 871 mg/l. The effluent averaged 571 mg/l of TDS during the monitoring period.

The increase in TDS would be expected for two reasons. First, the effluent being applied to the field had a higher average TDS than did the incoming groundwater as indicated by the upstream wells. Second, anytime one passes water through a soil column some additional salts are dissolved. The soil in the sprayfield has a definite calcareous layer 45 to 60 cm below the surface. A significant increase in TDS most likely occurs for water passing through this soil.

Increases in TDS of the groundwater were kept relatively low because of the apparent high rate of groundwater movement below the field. The high rate of groundwater movement is evidenced by 1) the rate that water percolated into the lagoons during construction, 2) the rapid increase and decrease in the water table below the field, and 3) the many large springs that are located below the sprayfield and along the full course of Flat Creek that have flow rates greater than 25 liters per second (see Fig. 7).

High COD and low BOD_5 values observed in Flat Creek and the north and south spring samples during June and July of 1975 and 1976 could be attributed to the following factors: 1) toxicity to bacteria in the waters that caused low BOD_5 readings, or 2) cellulose or similar substances that are slowly biodegradable and hence produce low BOD_5. The cellulose-like substance could have been washed into the waters by the spring runoff.

The high COD values in the water from the observation wells during the same period are more difficult to explain. One possible explanation could be the presence of reduced inorganic substances such as ferrous iron sulfide, or ammonia (note presence of ammonia in wells 2 and 4). The important fact, however, is that the increase cannot be directly attributable to the sprayfield since the increased COD also occured in water not coming from the sprayfield.

RESULTS OF CLIMATIC MONITORING

To evaluate the climatic conditions at Thayne during the monitoring period with long-term climatic conditions, a comparison was made with the climatic records of Afton, Wyoming. Afton is located in the same mountain valley as Thayne (see Fig. 3) and has approximately the same climate. The elevation at the Afton weather station is 1,864 meters while the elevation of the sprayfield is approximately 1,814 meters. Since elevation is the principal cause for climatic differences within the Star Valley, the climatic conditions at Thayne and Afton should be approximately the same given only a 50 meter elevation difference.

Data from the climatic monitorings are presented in Appendix II. Comparing the temperatures and rainfall for late fall for 1975 and 1976, the 1975 fall was relatively wet and cold while the 1976 fall was relatively warm and dry. This was a major contributing factor for having the ground remain unfrozen during the winter of 1975-76 and frozen during the winter of 1976-77. It will be shown in Section 7 that it is preferable to have the ground remain unfrozen. The relatively cold winter of 1976 and the relatively warm winter of 1977 apparently affected the density of the ice pack (see Section 7).

Shown in Fig. 21 are the average monthly wind speeds. For the high pressure sprinkler system used, the wind during many hours of the month were high enough to significantly lower the uniformity of application. It should be noted that a characteristic pattern of wind occurrence in the valley is low winds during the morning hours and increasing winds in the afternoon hours. This would force curtailment of sprinkling many afternoons if there was an operational criterion for maximizing the uniformity of application.

Soil temperatures were taken inside the sprayfield and adjacent to it. At the 2.5 cm depth the soil temperature outside the sprayfield was as much as 10°C greater than inside the field. This means the time between

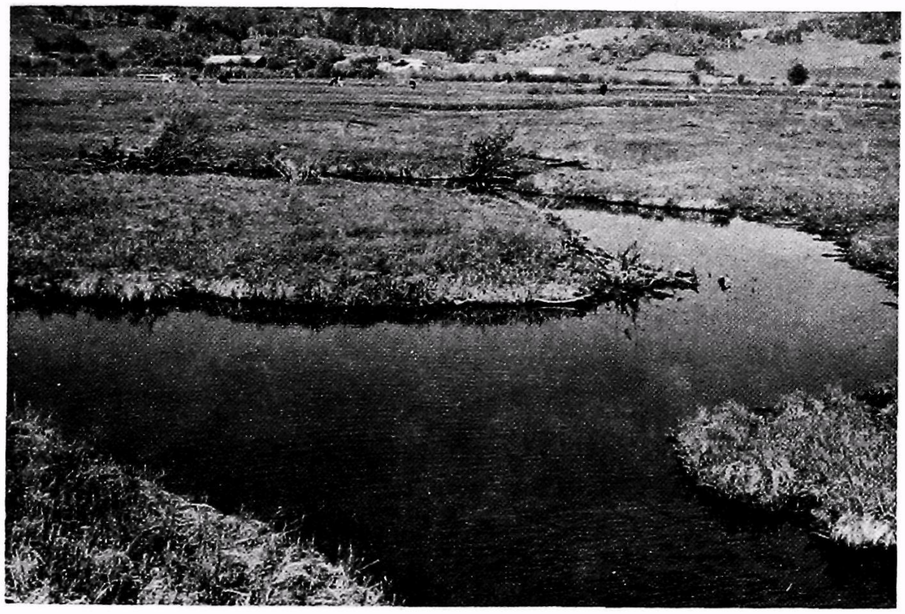

Figure 7. North spring located below sprayfield.

irrigations should be as long as possible in order to allow the soil temperature to rise and promote plant growth and microbial activity.

SOIL NITROGEN

Soil nitrogen data for 1975, 1976, and 1977 are presented in Tables 2, 3, and 4. The soil samples were taken adjacent to the agronomy plots (see Fig. 3), and a year-end sampling from within the Reed canarygrass date-of-cutting plots. Samples were taken every 30 cm down to the 120 cm depth. Adjacent to the plots, the vegetation was initially a bromegrass-alfalfa mixture but during the experiment the alfalfa was replaced by an invasion of bluegrass.

Soil nitrogen concentration generally declined in the upper 30 cm during 1977. However, an increase was noted in the July 31 sampling, returning to May levels as a result of increased effluent nitrogen content. The 60 cm and 120 cm levels exhibited no net change in reduced N during 1977, but the 90 cm level doubled in concentration. Since the other N fractions showed no such change, organic nitrogen must have leached to the 90 cm depth because of the higher rates applied and/or been converted from other N forms by plants or microorganisms. Under the Reed canarygrass, N concentrations were generally higher than adjacent to the plot area, except at the 90 cm level.

TABLE 2. SOIL NITROGEN CONCENTRATIONS FOR 1975

Sample	Date	NO_3^--N (ppm)	NH_4^+-N (ppm)	Total N (Reduced, %)
Adjacent to Plots	June 4			
30 cm depth		9	26	0.36
60 " "		3	26	0.22
90 " depth		3	20	0.18
120 " depth		<2	7.5	0.07
Adjacent to Plots	June 27			
15 cm depth		26	140	0.33
Adjacent to Plots	August 1			
15 cm depth		39	48	0.39
Adjacent to Plots	September 17			
30 cm depth		5	52	0.28
60 " "		10	44	0.16
90 " "		9	25	0.06
120 " "		5	6	0.03

TABLE 3. SOIL NITROGEN CONCENTRATIONS FOR 1976

Sample	Date	NO_3^--N (ppm)	NH_4^+-N (ppm)	Total N (Reduced, %)
Adjacent to Plots	May 26			
30 cm depth		19	44	0.31
60 " "		12	32	0.20
90 " "		7	18	0.12
120 " "		6	15	0.08
North side	May 26			
30 cm depth		24	90	0.48
60 " "		14	36	0.22
90 " "		6	31	0.12
120 " "		5	11	0.13
Adjacent to Plots	July 28			
30 cm depth		14	30	0.30
North side	July 28			
30 cm depth		54	68	0.40
Adjacent to Plots	August 27			
30 cm depth		25	104	0.38
60 " "		18	52	0.23
90 " "		10	21	0.13
120 " "		10	22	0.08
North side	August 27			
30 cm depth		22	51	0.34

TABLE 4. SOIL NITROGEN CONCENTRATIONS FOR 1977

Sample	Date	NO_3^--N (ppm)	NH_4^+-N (ppm)	Total N (Reduced, %)
Adjacent to Plots	May 12			
30 cm depth		10	129	0.43
60 " "		8	105	0.22
90 " "		3	42	0.07
120 " "		2	7	0.04
	June 8			
30 cm depth		49	175	0.36
	July 7			
30 cm depth		30	51	0.34
	July 31			
30 cm depth		134	91	0.43
	September 13			
30 cm depth		7	61	0.23
60 " "		5	25	0.21
90 " "		4	17	0.18
120 " "		2	4	0.05
Under Reed Canarygrass	September 13			
30 cm depth		5	49	0.28
60 " "		7	27	0.30
90 " "		6	21	0.12
120 " "		3	13	0.10

Over the entire study period, total N seems to have returned to levels similar to those under the previous cropping system. The higher N application rates of 1976 (northside) and 1977 were accommodated, but new equilibrium levels were probably not yet attained. The variations with depth between the springs of 1975 and 1977 were probably mostly a function of different crop species as seen earlier between sites in the fall of 1977.

Ammonium concentrations in the soil also generally declined during 1977. There was considerable variation in the top 30 cm because of fluctuations in effluent concentrations of ammonia and total N. The decline in concentration also occurred deeper in the soil, and changes were moderated with depth; that is, relative reductions were greater in the 60 cm level than in the 90 cm level, which were greater than in the 120 cm level. Since the 90 cm level did not increase in ammonium, leaching alone must not have been responsible for the organic N buildup at that depth. The soil under Reed canarygrass was lower in ammonium in the top 30 cm, similar in the second 30 cm, and progressively higher in the 90 and 120 levels than the plot samples. Ammonium thus appeared to be moved to greater soil depths under the Reed canarygrass sod than in the rather open soil of the area adjacent to the plots.

For the study period ammonium concentrations fluctuated considerably in the top 30 cm. The variations were due to interaction between seasonal effects and application schedule. In the top 30 cm, an expected seasonal pattern might be low initial amounts, increases as ammonification of organic N proceeded, then reduction as plants and microorganisms used and "tied up" ammonium. Concentrations at the end of 1976 and beginning the 1977 growing season increased because of heavier effluent applications to that area beginning in August of 1976. The variation in effluent concentrations of N in the summmer of 1977 influenced ammonium concentrations more than total N. The deeper soil layers were less affected by ammonium concentration than the top 30 cm; however, data show that ammonia concentrations fluctuated considerably.

Nitrate concentrations varied considerably more in the summer of 1977 than at any previous time. The late summer sampling (top 30 cm) produced the only reading in excess of 60 ppm, and it was over twice the previous high. Nitrification of the high N effluent had apparently occurred by that time. However, the nitrate must have been quickly taken up by plants, denitrified, or leached by the end of the growing season because concentrations in the top 120 cm of soil by then had returned to their previous low levels. Reed canarygrass sod affected concentrations of the soil slightly, reducing levels in the top 30 cm and increasing levels in the 60 and 90 cm depths.

During the study period, nitrate concentration peaked in late summer, except when effluent application was deferred until then. Amounts in the soil were usually within safe limits until nitrogen rich effluent was applied in the summer of 1977. Even then, apparent leaching was minimal, but potentially toxic levels of nitrate were accumulated in the forage.

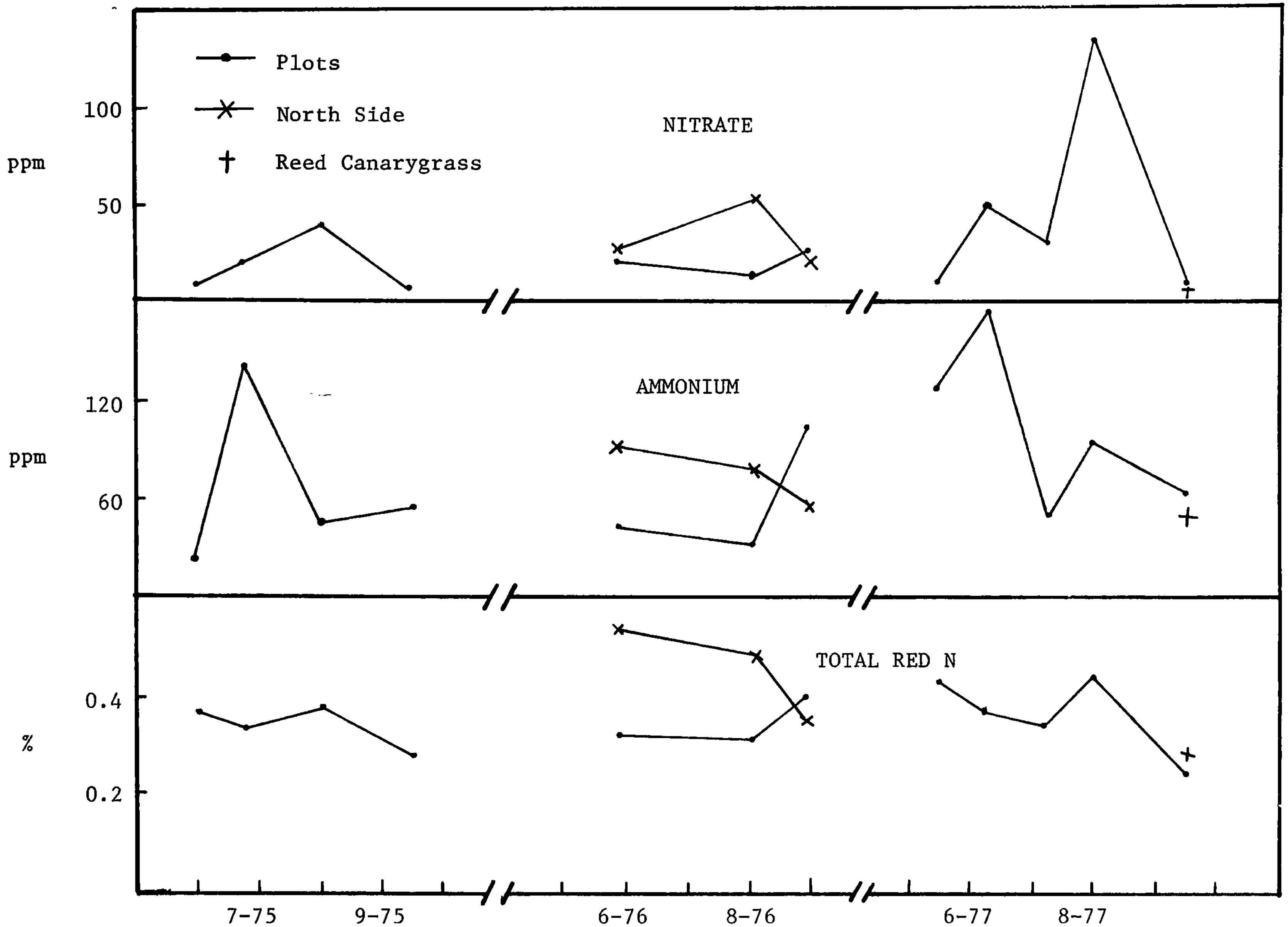

Figure 8. Average soil nitrogen levels for the 30 cm depth.

SOIL PHOSPHORUS

Soil phosphorus data for 1975, 1976, and 1977 are presented in Tables 5, 6, 7, and 8. Soil samples for these determinations were taken every 30 cm to the 120 cm depth adjacent to the agronomy plots at the beginning and ending of each growing season.

The soil phosphorus concentrations of organic, inorganic, and total phosphorus generally decrease with depth in the soil (Table 5). With essentially no effluent applications to the agronomy plot area during the period covered by the first three sample dates, the organic phosphorus concentrations at all soil depths continually decreased while the total phosphorus concentration did not change. The inorganic phosphorus concentration in the first 30 cm did increase in the May 26, 1976, sample over the two preceding samplings.

Effluent applications on the agronomy plot area started in June of 1976. The August 27, 1976, sampling produced the highest phosphorus concentrations at all depths and all forms except for organic phosphorus at the 60-90, and 90-120 cm depths. The spring sampling for 1977 showed an almost equal decline in amount of organic and inorganic phosphorus while the 1977 fall sampling showed a recovery of organic phosphorus in the 0-30 and 30-60 cm depths, while the inorganic phosphorus concentration declined at the 0-30 cm depth.

The conversion of phosphorus concentration data to quantities present at the various soil depths was influenced by the amount of soil present with the rocks and coarse gravels at the different depths. It was found that 50% of surface 30 cm of depth was soil, and the soil present was 40, 30, and 20% for the succeeding 30 cm increments of depth. This meant that the 3000 cubic meter volume for a 30 cm layer over a hectare was really occupied by 1500, 1200, 900, and 600 cubic meters of soil at the respective depths. The soils in this area of Wyoming are not inherently phosphorus deficient. Using the phosphorus shown in Table 5, the quantities of soil present at each depth were used to calculate the amounts of each kind of phosphorus present in kilograms per hectare. The results are shown in Table 6. The decrease in amounts of all phosphorus forms with increasing depth is very distinct. A decline of organic phosphorus at all depths for the first three sample periods was followed by a big increase in the August 27, 1976, sampling followed by another overwinter decline, then another increase in the September 13, 1977, sampling. The changes in amounts are larger in the 0-60 cm layers than in the 60-120 cm layers for all forms of phosphorus. The inorganic phosphorus in the last sample has returned to the level of the first sample for the 60-120 cm depths but the 0-60 cm depth is enriched by 35 percent. The organic phosphorus has increased in the top 0-60 cm by 18 percent and decreased in the 60-120 cm depth by 64 percent.

TABLE 5. SOIL PHOSPHORUS CONCENTRATIONS IN PPM BY FORM, DEPTH, AND SAMPLING DATE AT THE AGRONOMY PLOT AREA OF THE DISPOSAL SITE

Depth cms	6-4-75	9-17-75	5-26-76	8-27-76	5-12-77	9-13-77
			Organic phosphorus			
0-30	390	262	99	637	114	500
30-60	405	225	83	652	311	432
60-90	338	120	57	243	76	91
90-120	180	90	46	121	23	114
Total	1313	697	285	1653	524	1137
			Inorganic phosphorus			
0-30	1485	1688	2138	2320	2275	2116
30-60	1395	1350	1434	2230	1752	1729
60-90	1462	1080	1422	1956	1592	1502
90-120	1170	1260	1319	1774	1797	1024
Total	5512	5378	6313	8280	7416	6371
			Total phosphorus			
0-30	1875	1950	2237	2957	2389	2616
30-60	1800	1575	1517	2882	2063	2161
60-90	1800	1200	1479	2199	1668	1593
90-120	1350	1350	1365	1895	1820	1138
Total	6825	6075	6598	9933	7940	7508

TABLE 6. WEIGHT OF SOIL PHOSPHORUS IN KILOGRAMS PER HECTARE BY FORM, DEPTH, AND SAMPLING DATE AT THE AGRONOMY PLOT AREA OF THE DISPOSAL SITE

Depth	Sampling date					
cms	6-4-75	9-17-75	5-26-76	8-27-76	5-12-77	9-13-77
			Organic phosphorus			
0-30	585.0	393.0	148.5	955.5	171.0	750.0
30-60	486.0	270.0	99.6	782.4	373.2	518.4
60-90	304.2	108.0	51.3	218.7	68.4	81.9
90-120	108.0	54.0	27.6	72.6	13.8	68.4
Total	1483.2	825.0	327.0	2029.2	626.4	1418.7
			Inorganic phosphorus			
0-30	2227.5	2532.0	3207.0	3480.0	3412.5	3174.0
30-60	1674.0	1620.0	1720.8	2676.0	2102.4	2074.8
60-90	1315.8	972.0	1279.8	1760.4	1432.8	1351.8
90-120	702.0	756.0	791.4	1064.4	1078.2	614.4
Total	5919.3	5880.0	6999.0	8980.8	8025.9	7215.0
			Total phosphorus			
0-30	2812.5	2925.0	3355.5	4435.5	3583.5	3924.0
30-60	2160.0	1890.0	1820.4	3458.4	2475.6	2593.2
60-90	1620.0	1080.0	1331.1	1979.1	1501.2	1433.7
90-120	810.0	810.0	819.0	1137.0	1092.0	682.8
Total	7402.5	6705.0	7326.0	11010.0	8652.3	8633.7

TABLE 7. PERCENTAGES OF TOTAL PHOSPHORUS BY FORM, DEPTH, AND SAMPLING DATE ON THE AGRONOMY PLOT AREA OF THE DISPOSAL SITE

Depth	Sampling date					
cms	6-4-75	9-17-75	5-26-76	8-27-76	5-12-77	9-13-77
	Organic phosphorus					
0-30	7.9	5.9	2.0	8.7	2.0	8.7
30-60	6.6	4.0	1.4	7.1	4.3	6.0
60-90	4.1	1.6	0.7	2.0	0.8	0.9
90-120	1.5	0.8	0.4	0.7	0.2	0.8
Total	20.0	12.3	4.5	18.4	7.2	16.4
	Inorganic phosphorus					
0-30	30.1	37.8	43.8	31.6	39.4	36.8
30-60	22.6	24.2	23.5	24.3	24.3	24.0
60-90	17.8	14.5	17.5	16.0	16.6	15.7
90-120	9.5	11.3	10.8	9.7	12.5	7.1
Total	80.0	87.7	95.5	81.6	92.8	83.6
	Total phosphorus					
0-30	38.0	43.6	45.8	40.3	41.3	45.4
30-60	29.2	28.2	24.8	31.4	28.6	30.0
60-90	21.9	16.1	18.2	18.0	17.4	16.6
90-120	10.9	12.1	11.2	10.3	12.6	7.9
Total	100.0	100.0	100.0	100.0	99.9	99.9

TABLE 8. PERCENTAGES OF PHOSPHORUS BY DEPTH WITHIN FORM AT EACH SAMPLING DATE ON THE AGRONOMY PLOT AREA OF THE DISPOSAL SITE

Depth	Sampling date					
cms	6-4-75	9-17-75	5-26-76	8-27-76	5-12-77	9-13-77
			Organic phosphorus			
0-30	39.4	47.6	45.4	47.1	27.3	52.9
30-60	32.8	32.7	30.5	38.6	59.6	36.5
60-90	20.5	13.1	15.7	10.8	10.9	5.8
90-120	7.3	6.5	8.4	3.6	2.2	4.8
Total	100.0	99.9	100.0	100.0	100.0	100.0
			Inorganic phosphorus			
0-30	37.6	43.1	45.8	38.7	42.5	44.0
30-60	28.3	27.6	24.6	29.8	26.2	28.8
60-90	22.2	16.5	18.3	19.6	17.9	18.7
90-120	11.9	12.9	11.3	11.9	13.4	8.5
Total	100.0	100.1	100.0	100.0	100.0	100.0

The sum of the total phosphorus quantities in the profile for a given sample date was used as the base for a percentage determination for each form of phosphorus at each depth. These percentages are recorded in Table 7. These values confirm the organic phosphorus declines indicated in the previous table for the September 17, 1975 and the May 26, 1976 samplings. Also the recovery, loss, and recovery of the organic phosphorus concentrations of the 0-30 and 30-60 cm depths in the last three samplings are easily seen. These two horizons have now returned to the relative organic phosphorus proportions found at the start of the experiment. The proportions of inorganic phosphorus in the soil by depth were 36.6 ± 6.9% for 0-30 cm, 23.8 ± 0.9% for 30-60 cm, 16.4 ± 1.7% for 60-90 cm, and 10.2 ± 2.7% for 90-120 cm. The same kind of a distribution for total phosphorus was 42.4 ± 3.9% for 0-30 cm, 28.7 ± 3.3% for 30-60 cm, 18.0 ± 2.9% for 60-90 cm, and 10.8 ± 2.3% for 90-120 cm.

One further comparison was made to better visualize the proportional distribution of organic or inorganic phosphorus throughout the profile (Table 8). The sum of the organic phosphorus concentrations for the profile of a given sampling date was divided into the organic phosphorus concentration for each depth to give the percentage of the total profile organic phosphorus that can be found in each respective soil depth. The top two horizons seemed to alternately be the highest in proportion of the organic phosphorus present. The third and fourth depths were more consistent, but tended to decrease from the proportion present at the beginning of the study. The inorganic phosphorus was more consistently decreasing in proportion present as the depth increased with 42.0 ± 4.1% for 0-30 cm, 27.6 ± 2.6% for 30-60 cm, 18.9 ± 2.8% for 60-90 cm, and 11.7 ± 2.5% for 90-120 cm.

Both the organic and inorganic phosphorus concentrations could be significantly increased on a short term basis by effluent applications. The applied organic phosphorus seldom penetrated more than 60 cm into the soil and was rapidly mineralized so that little or no buildup occurred under normal cropping practice. The inorganic phosphorus levels held to a consistent distribution that decreased with depth in the profile.

Other soil characteristics were monitored during the study period, and the more pertinent data are listed in Table 9. Soil pH was reduced slightly in the upper foot, because of minor leaching losses of Ca, mg, and other basic cations.

Total salts and sodium (Na) each increased during the study period. In the top 30 cm both were increased more than two-fold, but were still below thresholds which affect crop growth. Total salts below 4.0 mmhos/cm have no effect on sensitive plants, and soil with a sodium adsorption ratio (SAR = Na/CEC) below 0.15 is not considered alkali. The 30-60 cm soil layer increased in salt and Na content, but the increase was less than in the top 30 cm. Greater depths showed no change in Na, but the 60-90 cm depth had an accumulation of other salts.

Available P and K exhibited increases down to the 90 cm depth. Changes in available P were similar to those for total P discussed earlier. The

TABLE 9. SOIL DATA FOR THE STUDY PERIOD (1975-1977) ON THE AGRONOMY PLOT AREA OF THE DISPOSAL SITE

Date	Sample Depth cm	pH	CEC meq/100g	Salt mmhos/cm	Na meq/100g	Organic Matter %	P	K	Ca	Mg	Zn	Fe
							ppm					
6/8/75	30	8.3	24	0.5	0.3	7.2	17	150	3100	440	5.0	26
5/26/76	30	8.2	22	0.6	0.3	7.2	16	140	3000	390	3.0	21
	60	8.5	16	0.6	0.4	3.7	9	70	2300	240	1.1	13
	90	8.6	13	0.4	0.4	2.0	4	48	1900	160	0.5	6
	120	8.8	12	0.6	0.3	1.4	5	33	1800	120	0.5	4
8/17/76	30	8.2	19	0.7	0.6	7.0	34	180	2400	370	3.1	17
	60	8.4	17	0.6	0.5	5.5	16	94	2300	280	1.8	13
	90	8.7	13	0.6	0.4	1.7	7	55	1900	150	0.8	6
	120	8.8	12	0.4	0.3	0.8	4	32	1800	110	0.5	4
5/12/77	30	8.1	23	1.2	0.7	5.7	65	350	3000	280	4.0	29
	60	8.2	22	0.9	0.5	5.0	17	230	2900	220	2.3	22
	90	8.5	13	1.2	0.2	2.9	13	58	2100	120	0.9	11
	120	8.8	10	0.7	0.1	0.9	13	24	1700	66	0.6	4
9/13/77	30	8.0	23	1.3	0.8	5.4	89	330	2900	370	4.1	32
	60	8.2	21	0.9	0.7	4.1	32	230	2700	210	3.0	36
	90	8.4	16	1.1	0.4	2.4	21	110	2100	110	1.5	25
	120	8.8	9	0.7	0.1	0.8	5	37	1500	56	1.0	10

wastewater was abundant in K, and increases in absolute amount were substanial in the top 60 cm. The highest amount, 350 ppm would be considered "very high" by most standards; e.g. Oregon uses 560 kg/ha of available K as the value separating "high" and "very high", and 350 ppm converts to about 780 kg/ha in the plow layer. High soil K should have little adverse effect on soil characteristics or plant growth, and is mainly reflected in K concentration of forage.

Zinc (Zn) was the only "heavy" metal contained in the wastewater in significant amounts. The upper 30 cm of soil showed some tendency to accumulate available Zn, but deeper soil layers increased relatively more. Available iron (Fe) increased at similar or greater relative rates than Zn.

SECTION 6

AGRONOMIC STUDY

INTRODUCTION

Land application of sewage effluent through crop irrigation is rapidly becoming a popular method of cleaning up undesirable wastewater since crop species can benefit from the available nutrients. Difficulty still exists, however, in selecting crop species suited to a wastewater irrigation system. The adaptability of a species depends to a great extent on climatic factors as well as the operation of the system, the nature of the waste, and the intended use of the harvested crop.

The purposes of this study were: (1) to use field plots to determine the viability of the species under the harsh environmental conditions, and (2) to use controlled environmental experiments to study the effects of the cheeseplant effluent on forage growth and quality.

FIELD STUDY

Quality factors of the seventeen forage species harvested in 1976 are listed in Table 10. The species were harvested before flowering with the onset of frost. No yield data were collected as the spray system was not operational the first part of the growing season. These quality factors appear to be in the range for acceptable livestock feed (Morrison, 1958). The protein percentages of the grass species were slightly higher than those grown in the controlled environment study. This could be due to the fact that the field plants were harvested before flowering. The _in vitro_ dry matter digestibility (IVDMD) results were lower than was observed in the growth chamber and greenhouse; however, some of the same trends were observed. Sainfoin had a low IVDMD in both the field study and the controlled environment studies. The sainfoin IVDMD data may be invalid as the steer from which the rumen fluid was collected was on an alfalfa rather than a sainfoin diet. Tall fescue and orchardgrass had the highest IVDMD of the grass species in both experiments. The ash content of the legumes was lower than the grass species. The legumes alfalfa and cicer milkvetch were superior in protein content.

Table 11 shows plant tissue concentrations of NO_3, P, K, Ca, Mg, Na, SO_4, Fe, Mn, Zn, Cu, and B. The P percentages were higher than normal in the grass species, unlike the controlled environment study, which could be explained by the early growth stage at which the field plots were harvested. The NO_3-N levels were well below the livestock toxicity level of .34 to .45

TABLE 10. QUALITY FACTORS OF 17 FORAGE SPECIES FROM FIELD PLOTS. HARVESTED AUGUST 27, 1976

	Percent				
	Protein	Fat	Fiber	Ash	IVDMD
Reed canarygrass	16.1	4.1	22.1	12.1	68.72
Smooth bromegrass	12.3	3.6	31.2	15.8	65.19
Meadow bromegrass	14.9	4.1	27.0	10.2	68.58
Tall fescue	15.2	3.7	23.4	12.0	71.44
Creeping foxtail	16.3	5.1	20.5	12.5	68.65
Alfalfa	20.4	4.7	14.2	9.4	68.00
Sainfoin	15.7	2.8	20.8	8.2	64.35
Creeping wildrye	15.0	4.3	23.0	11.5	61.78
Idaho fescue	15.7	4.4	23.0	14.9	63.87
Steambank wheatgrass	13.0	3.2	28.1	13.7	62.43
Cicer milkvetch	19.6	4.3	16.3	11.3	70.15
Basin wildrye	13.4	2.8	27.6	10.3	62.18
Western wheatgrass	12.8	2.9	30.0	12.0	64.66
Thickspike wheatgrass	12.9	3.4	32.0	11.1	59.78
Orchardgrass	13.6	4.3	27.2	13.1	71.52
Mountain bromegrass	12.8	2.9	30.1	10.0	70.23
Timothy	11.2	3.6	34.0	8.7	61.99

TABLE 11. CHEMICAL COMPOSITION OF 17 FORAGE SPECIES FROM FIELD PLOTS HARVESTED AUGUST 27, 1976

	Percent							ppm				
	NO_3-N	P	K	Ca	Mg	Na	SO_4	Fe	Mn	Zn	Cu	B
Reed canarygrass	.039	.38	2.8	.56	.26	.08	.09	150	40	18	2	3
Smooth bromegrass	.034	.34	2.0	1.0	.50	.10	.10	1500	120	121	4	5
Meadow bromegrass	.038	.32	2.6	.52	.22	.06	.06	450	64	20	4	3
Tall fescue	.046	.37	2.7	.55	.24	.15	.07	140	60	15	2	5
Creeping foxtail	.042	.37	2.6	.70	.28	.17	.11	440	96	29	4	2
Alfalfa	.045	.25	2.0	1.7	.37	.23	.12	210	33	23	6	10
Sainfoin	.030	.29	1.8	1.8	.31	.16	.13	170	56	23	5	13
Creeping wildrye	.052	.34	2.7	.65	.25	.15	.10	500	59	24	4	2
Idaho fescue	.038	.32	1.6	.71	.33	.09	.07	1200	61	19	4	3
Streambank wheatgrass	.029	.26	1.2	.83	.26	.08	.08	1300	65	16	2	4
Cicer milkvetch	.054	.38	3.5	1.2	.32	.19	.06	520	51	27	6	15
Basin wildrye	.041	.30	2.2	.54	.24	.13	.05	540	42	22	2	4
Western wheatgrass	.029	.22	1.4	.57	.18	.11	.04	450	40	13	1	5
Thickspike wheatgrass	.027	.23	1.1	.56	.22	.11	.05	700	33	13	2	4
Orchardgrass	.047	.42	2.8	.53	.29	.10	.11	300	61	17	3	4
Mountain bromegrass	.043	.33	2.6	.65	.23	.09	.07	320	52	23	6	3
Timothy	.033	.24	2.1	.44	.19	.07	.06	240	46	26	3	4

percent. Smooth bromegrass had a considerably higher concentration of Fe and Mn than any of the other species. Alfalfa and sainfoin had higher percentages of B, Ca, and S than the grass species. Overall, these concentrations do not appear to be either toxic or deficient.

Since the plots were only consistently watered for approximately two months before harvest, it would be difficult to observe any toxicities or deficiencies which might occur in the forage plants or the soil. Several years of effluent irrigation on the plots would be necessary to indicate if the chemical composition of the plants was going to change significantly.

Plant survival under the ice pack during the 1976-77 winter was very poor. Garrison creeping foxtail, reed canarygrass, smooth bromegrass, and western wheatgrass were the only species which maintained an adequate stand in 1977. The forage yield and quality of these four species are shown in Table 12. The two highest yielding species were Garrison creeping foxtail and reed canarygrass. These two species were similar in quality with the exception of mineral content and IVDMD in which Garrison creeping foxtail was higher in quality. In terms of feed for livestock the 13% higher IVDMD for creeping foxtail would make this species far superior for use as a perennial forage on a high altitude disposal site. The second cutting of creeping foxtail was not harvested because of poor water distribution; however, where it did receive water, its regrowth was considerably greater than that of reed canarygrass.

Western wheatgrass, although it was low in yield, had a superior N-free extract (NFE). It was also more digestible than reed canarygrass and contained more favorable NO_3-N and crude fiber than the other species. The mineral content of western wheatgrass was less than the other species.

Smooth bromegrass had the highest level of digestibility of the four species; however, it also had a less favorable NO_3-N content. The NO_3-N contents of Garrison creeping foxtail, reed canarygrass, and smooth bromegrass were near the toxic level for livestock.

A harvest date study on reed canarygrass was conducted to define a schedule which would result in forage palatable to livestock. Sufficient growth to allow adequate nutrient uptake was also a consideration. The reed canarygrass was in the preflower stage at the time of the first harvest on July 7, 1977. The plots harvested on July 7 were again harvested September 13. The regrowth which occurred during the 78 days following the first harvest was small as indicated by the forage yield (Table 13). The yield of the single harvest on September 13 was significantly greater than the total yield of the two cut system. However, the forage IVDMD mineral content, and P content from the one harvest at the end of the growing season were significantly lower than that of the two cut system. In most cases the forage quality of the second cutting was superior to the two first cutting treatments. The NO_3-N content of the July 7 harvest was within the toxic range for livestock.

Spring barley was not adapted to the sprayfield environment. Very poor seed germination and slow plant development was observed.

TABLE 12. FORAGE QUALITY AND YIELD OF FOUR FORAGE SPECIES WHICH SURVIVED THE FIELD CONDITIONS. HARVESTED JULY 30, 1977

Species	Protein	Fat	Crude Fiber	IVDMD	Ash	NFE	Ca	P	NO_3-N	Forage Yield
	%									Kg DW/ha
Garrison Creeping Foxtail	16.6 a*	3.8 a	31.7 a	45 b	11.6 a	36.3 b	.42 a	.32 a	.29 a	8415**
Reed canarygrass	16.4 a	3.2 a	33.4 a	32 c	9.6 b	37.4 b	.41 a	.32 a	.29 a	8585
Smooth bromegrass	20.8 a	3.5 a	30.4 ab	52 a	9.6 b	35.6 b	.66 a	.28 a	.32 a	4115
Western wheatgrass	18.2 a	3.6 a	28.4 b	44 b	8.9 c	41.0 a	.46 a	.25 a	.14 b	3775

* Means within a column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

** Forage yield was not statistically analyzed due to an uneven sprinkler pattern in the plot area. Quality samples were taken from adequately watered portions of the plots.

TABLE 13. FORAGE QUALITY AND YIELD OF REED CANARYGRASS FROM A ONE-AND TWO-CUT HARVEST SCHEDULE AT THE DISPOSAL SITE

Harvest Date	Protein	Fat	Crude Fiber	IVDMD	Ash	NFE	Ca	P	NO_3-N	Yield
	%									Kg DW/ha
7/7/77 (1st cut)	19.9 b*	3.22 b	30.5 a	48 a	11.05 b	35.2 ab	.36 b	.51 a	.38 a	4950
9/13/77 (2nd cut of 77)	28.9 a	4.85 a	19.5 b	51 a	13.08 a	33.6 b	.68 a	.55 a	.17 b	1112 6062 b
9/13/77	17.4 b	3.35 b	30.3 a	40 b	9.38 c	39.6 a	.36 b	.36 b	.20 b	8932 a

* Means within a column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Tests.

CONTROLLED ENVIRONMENT STUDY

The highest dry matter production (mg/day) in the grass species was obtained with the control treatment at both temperatures, although differences were not significant for smooth bromegrass and meadow bromegrass (Table 14). The control solution, which was based on the fertilizer requirement of the soil for forage production, contained significantly more N and P than did the effluent or synthetic treatments (Table 1). The superior growth by the control treatment suggested that N and P levels in the effluent were not sufficient for grass forage production. However, the growth rate of the legume species was not affected by irrigation treatment (Greene, 1976).

Treatment effects on protein percentage were more evident in the grass species than in the two legumes (Table 14). The effluent treated grass species contained considerably less protein than the control at the 20/10° C temperature, indicating a deficiency of available nitrogen in the effluent treatment. To maintain adequate growth and nutrient uptake of grass species at the Thayne disposal system, it may be necessary to add nitrogen. However, the 1977 field data indicated that N was not limiting. Irrigation treatments did not affect the protein percentage of the two legumes. The fact that the forage yield and protein content of the two legume species were not reduced by the effluent treatment indicates that legumes are better adapted to an effluent disposal site than grass species if nitrogen is limiting. This suggests that symbiotic dinitrogen fixation was sufficient and not affected by the effluent.

Soil concentrations of nitrate generally decreased by the end of the study from an initial value of 12 ppm (Fig. 9). This indicated that the effluent was adding insufficient amounts of nitrate to the soil. However, five of the seven species had a greater nitrate content in the soil when irrigated with effluent than in either the control or the synthetic irrigated pots. This suggests that these five species could not as efficiently utilize the nitrogen contained in the effluent (including organic N) as that in the control.

The P concentration of the plant tissue generally was not affected by irrigation treatment. However, in tall fescue at the low temperature, and reed canarygrass and meadow bromegrass at the high temperature, the effluent treatment had a higher P content than the control (Table 14). Soil analysis at the end of the experiment indicated that available soil phosphorus accumulated during the study, since the soil initially contained 17 ppm available phosphorus (Fig. 10).

The percent IVDMD for all species was similar for the effluent and control treatments (Table 14). The synthetic treatment produced a significantly lower IVDMD in creeping foxtail than the other two treatments at the cooler temperature. Meadow bromegrass had a higher IVDMD at the high air temperature when it was watered with the synthetic as compared to the control.

Dry matter production was generally greater at the higher air temperature (Table 14). However, the growth rate of tall fescue was significantly

TABLE 14. EFFECT OF THREE IRRIGATION TREATMENTS AND TEMPERATURE ON THE GROWTH, *IN VITRO* DRY MATTER DIGESTIBILITY (IVDMD), PROTEIN AND PHOSPHORUS OF SEVEN FORAGE SPECIES

Irrigation Treatment	mg dry wt/day		% Protein		% Phosphorus		% IVDMD	
	20/10C	23/18C	20/10C	23/18C	20/10C	23/18C	20/10C	23/18C
				Reed canarygrass				
Control	51.1a†	57.6a	7.9a	9.4a	.09a	.12c	71.9a	73.0a
Effluent	37.2b	39.7b	6.9b	10.6a*	.09a	.23a	72.9a	69.8a
Synthetic	34.6b	31.2c	6.7b	9.9a*	.07a	.18b*	74.3a	70.4a
				Smooth bromegrass				
Control	34.9a	55.6a*	8.8a	9.7a	.06a	.26a*	74.9a	69.1a*
Effluent	23.7a	30.0a	7.1b	11.1a*	.09a	.28a*	71.9a	67.9a*
Synthetic	30.0a	31.2b	6.8b	9.9a*	.07a	.21a*	71.3a	70.3a
				Meadow bromegrass				
Control	36.5a	56.8a*	9.2a	12.1a	.10a	.23b	76.1a	71.1b
Effluent	35.4a	37.4ab	6.8ab	12.2a*	.11a	.34a*	73.9a	72.1ab
Synthetic	25.5a	15.6b	7.5b	10.5b	.10a	.12c	73.3a	76.6a
				Tall fescue				
Control	51.2a	56.8a	6.6a	10.3a*	.07b	.27a*	78.1a	73.2a
Effluent	31.1b	37.4b	5.3b	10.2a*	.15a	.29a	77.0ab	72.5a
Synthetic	24.7b	15.6b	4.5b	10.7a*	.09b	.23a*	73.7b	76.5a
				Creeping foxtail				
Control	30.5a	49.7a*	7.8a	9.9a*	.10a	.19a	71.3a	70.8a
Effluent	21.6b	29.7b	7.1ab	10.2a*	.05b	.28a*	71.1a	71.6a
Synthetic	12.0b	19.4b	6.3b	9.0a*	.09a	.20a*	64.8b	70.1a
				Alfalfa				
Control	45.1a	105.6a*	15.4a	19.6a*	.03a	.21a*	79.0a	75.3a
Effluent	51.1a	111.8a*	16.8a	20.3a*	.03a	.16a	78.4a	76.6a
Synthetic	41.6a	92.9a*	17.1a	20.7a	.04a	.21a	79.9a	76.4a
				Sainfoin				
Control	53.7a	120.0a*	13.4a	19.3a*	.10a	.22a*		
Effluent	64.6a	117.9a*	13.2a	18.4a	.11a	.21a		
Synthetic	53.2a	105.6a*	13.2a	18.7a*	.09a	.22a		

† Species means within a column and followed by same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.
* Differs significantly from 20/10C value according to the t-test at the .05 level

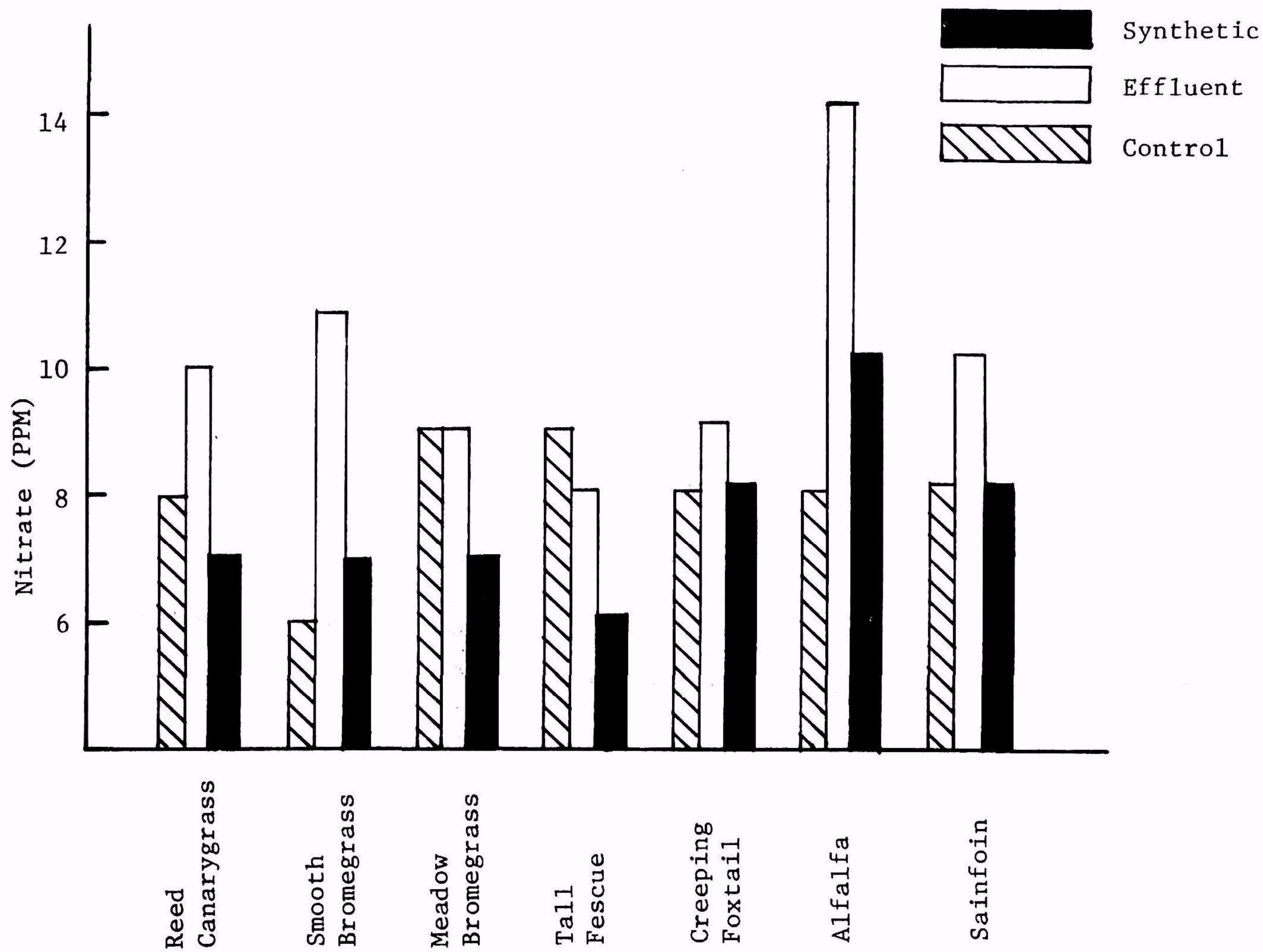

Figure 9. Soil nitrate concentrations for seven forage species irrigated with three treatments under controlled environments at the conclusion of the study. Initial concentration was 12 ppm NO_3-N.

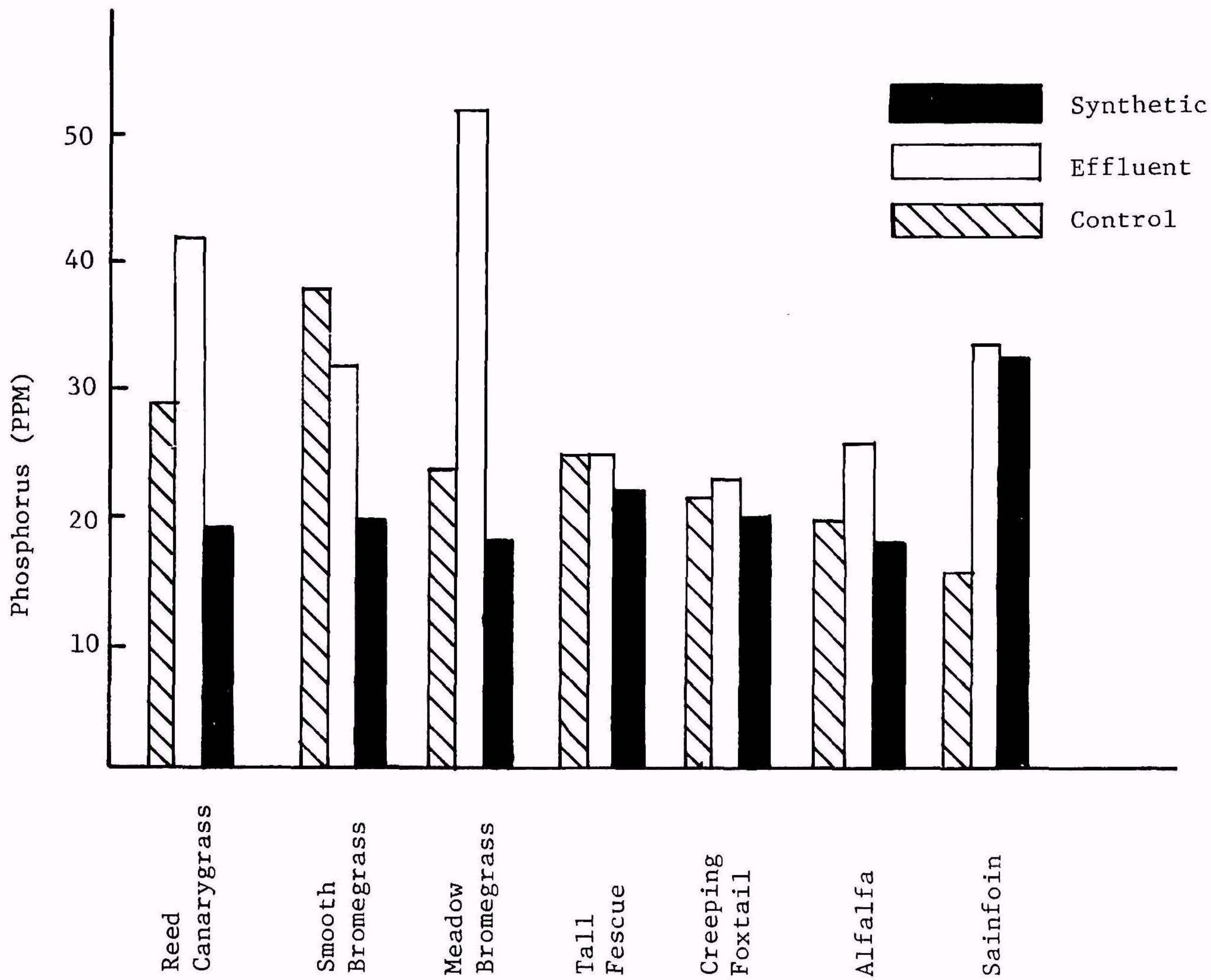

Figure 10. Soil phosphorus concentrations for seven forage species irrigated with three treatments under controlled environments at the conclusion of the study. Initial concentration was 17 ppm.

higher at the cooler than the warmer temperature when it was watered with the synthetic treatment. The growth of reed canarygrass was not significantly affected by temperature, although it was the highest yielding of the grass species at both temperatures. This response is in agreement with other studies which have shown reed canarygrass adapted to land disposal systems (Sopper, 1973). The percentage increase in yield of alfalfa and sainfoin with the higher temperature was much greater than for the grasses.

The protein content of forage when watered with effluent was significantly higher for the 23/18C air temperature for all species. Consequently the reduced protein level at the 20/10C temperature significantly lowered the feed value of the forage for livestock. The problem of low protein content with the use of effluent under high altitude conditions would be lessened if a legume were grown rather than a grass, but more of the grasses tested survived the field environment.

The forage produced under the low temperature regime generally had less than one half the phosphorus content of forage in the high temperature regime. In general, the forage from all species tested and grown under the low temperature would have to be supplemented with phosphorus when fed to most classes of livestock.

Smooth bromegrass was the only species in which IVDMD was significantly affected by temperature. The IVDMD of smooth bromegrass was reduced by the high temperature when watered with both the effluent and the control treatment.

In summary the response of the grass species to the effluent and synthetic irrigation treatments generally included reduced growth and protein. The percent P and IVDMD were not usually affected by the effluent. Legumes treated with effluent produced growth rates, protein content, P content and IVDMD which were comparable to the other treatments. Apparently there were no constituents of the effluent which significantly reduced growth, since it was not observed that plants watered with the synthetic effluent containing only N, P and K yielded more than those watered with the effluent. It appears that temperature may be the limiting factor in the high altitude effluent disposal system at Thayne, Wyoming. At the low air temperature, limited growth may limit the uptake of nutrients necessary for acceptable crop quality and, in some cases, yield.

SUMMARY

Two controlled environment experiments and the field plots were used to evaluate seven forage species for growth, quality and adaptability to cheese-plant wastewater under high altitude conditions. Ten additional species were also evaluated in the field.

The controlled environment experiments indicated that there could be a deficiency of nutrients in the effluent to adequately produce good quality forage. The control treatment tended to have better growth and quality characteristics than plants treated with effluent or a synthetic effluent,

although it was not as apparent at the warmer temperature. When the plants were subjected to a warmer environment, deficiencies of N and P were not as evident indicating that temperature may be a limiting factor for adequate availability and uptake of nutrients. The legumes showed more potential for taking up P than the grass species. Soil data showed that N was being depleted from the soil while P was accumulated.

The forage harvested from the field plots in 1976 did not show any adverse effects of wastewater on quality factors or chemical composition of the species studied. Although nitrogen existed in low concentrations in the effluent, no deficiencies existed in the plant species indicating that there was adequate nitrogen in the soil.

Four of the seventeen forage species survived the sprayfield ice pack which resulted from the 1976-77 winter. The 1977 yields of Garrison creeping foxtail and reed canarygrass were sufficient to consider them adapted to the sprayfield environment. The forage quality of Garrison creeping foxtail was superior to that of reed canarygrass. Both species produced forage sufficiently high in NO_3-N to be potentially toxic to livestock.

The regrowth of reed canarygrass which followed the first harvest was very poor although the cutting regime resulted in higher quality forage. The total season yield of a two-cut system was significantly lower than that of a single harvest at the end of the growing season.

SECTION 7

TREATMENT OF WASTEWATER IN A SPRAYFIELD ICE PACK

INTRODUCTION

While disposal of wastewater effluent on land is generally practiced during the growing season, in some situations it may be desirable to apply the effluent during the winter as well as the warmer growing season. Such a case existed at Thayne, Wyoming. Due to the continuous high volume of liquid waste from the cheese plant (approximately 1325 m^3/day), the small tax base of Thayne, and the scarcity of land available for a larger land treatment system, it was considered to be economically prohibitive to build a system utilizing wintertime storage lagoons. For this reason, effluent is applied to the sprayfield throughout the entire year, regardless of the weather conditions. This results in the formation of an ice pack on the sprayfield during the winter months. It is the effectiveness of the ice pack to renovate the wastewater that will be evaluated in this section.

SAMPLING

As the ice pack is formed, it generally allows the ground surface to remain unfrozen with percolation of the melting ice pack into the soil throughout the winter (Bunk, 1976 and DeVries, 1972). The ice pack acts as an insulator trapping soil heat beneath the pack. However, the soil does not remain unfrozen underneath the ice pack consistently. The 1976-77 winter was dry (1.3 cm of natural precipitation for November and December) with relatively warm days (see Fig. 19 & 20). The lack of natural precipitation in the form of snow on the sprayfield and the warm temperatures influenced the rate of build up of ice. As a result, spray applied on relatively warm days melted any ice or snow which may have accumulated on the field. The end result was a lack of ice cover on the sprayfield in November and the first part of December, which allowed the uninsulated soil to freeze. As a consequence, the soil did freeze down to the 50 cm level by the end of December. From discussions with residents, the soil will freeze on the average of once in ten years under normal snow conditions. Data on soil temperatures are not available for a precise estimation.

Samples were taken from the ice pack in February, March, and April of 1976 and January through April in 1977. The ice pack was sampled in the following manner: between three sprinkler laterals, samples were taken at 25 percent spacings between laterals and at 25 percent spacings between pairs of sprinkler heads (see Fig. 11). Eight sampling points perpendicular to the three laterals were used for each sampling date with the transect

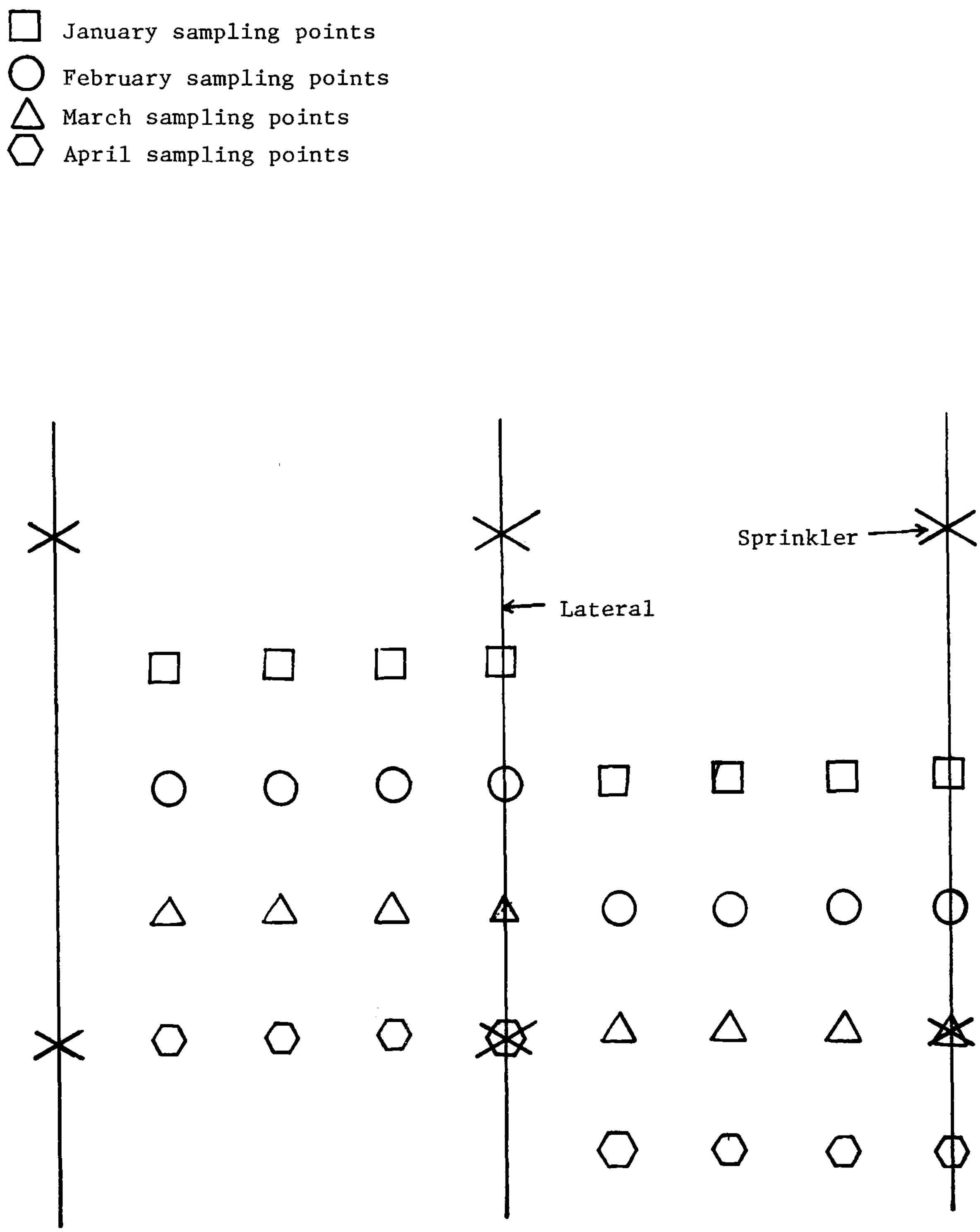

Figure 11. Location of ice pack sampling points.

moved parallel to the lateral each month. At each sampling point, four holes were bored to the soil surface with the core of ice between the four holes removed. From this core of ice, composite samples were made for each 25 percent of depth (see Fig. 12). For example, for a 120 cm hole, composite samples were made of each 30 cm section. This method of sampling tended to provide ice of similar ages at each sampling depth for all holes regardless of the relative thickness of the ice pack.

Bucket lysimeters were also placed in the sprayfield in clusters (see Fig. 13). Ice pack melt water percolated down into the lysimeters and was trapped in the buckets which were designed to collect percolate from several soil depths.

ANALYSES OF SAMPLES

All water samples were analyzed for 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), nitrite (NO_2), nitrate (NO_3), ammonia nitrogen (NH_3), total Kjeldahl nitrogen (TKN), and fecal coliforms. These samples were analyzed according to "Standard Methods" (1971) after being preserved in the field and transported according to Environmental Protection Agency recommendations for sample preservation (EPA, 1971), with the exception where samples were collected for coliform analyses. Coliform analyses of liquid samples withdrawn from lysimeters were begun immediately in the field while ice pack samples were transported in a frozen state to Laramie for analysis. Ice pack samples of similar depth spacings were composited for each sampling date. The water quality data from the ice pack are presented in Tables 15 and 16.

DISCUSSION OF RESULTS

The physical process of ice metamorphism results in a change in the nature of the ice pack with time as more and more wastewater is applied and the ice becomes thicker. The process of metamorphism begins with the freezing of the sprayed effluent, due to simultaneous heat and mass transfer with the atmosphere, as it contacts the air during spraying. When the effluent freezes, the liquid forms crystals of almost pure water while the dissolved and suspended matter in the effluent is distributed in cells between the crystals forming pockets of concentrated impurities in the ice pack (EPA, 1971_b). The pockets will have a lower freezing point due to the salts present in them. When air temperatures are low, the ice crystals are formed rapidly and tend to be very small. This causes the ice pack to exhibit a low permeability which impedes the downward percolation of the unfrozen pollutants in the ice pack.

The application of wastewater is continuous on a periodic basis during cold periods with continual transmission of pore water to the soil beneath the ice pack. After the liquid is deposited and frozen, there is a tendency in thermal metamorphism for each crystal to reduce its surface area. A fundamental consideration of thermodynamics is that a system at a fixed level of entropy will seek the lowest level of internal energy. An ice pack

Figure 12. Sampling of ice pack.

is no exception. If the crystals grow, the resulting surface area per unit mass is decreased so the internal energy of the system is reduced. In addition, surface curvature increases as energy is reduced resulting in a rounding of the ice crystals with time. This reduction of surface area per unit mass causes an increase in the permeability of the ice pack since ice crystals become coarser and pore spaces partly occupied by pollutants become larger. The process of ice crystal growth is sometimes called destructive or equi-temperature metamorphism (Bader, 1954; Ellmore, 1968; Gerdel, 1954; Summerfield and LaChapelle, 1970; USACE, 1956).

Investigations of the temperature profile of an ice pack have shown the ice pack to possess a thermally active layer with diurnal variation existing from the surface to an inversion layer. From the inversion layer to the soil-ice interface, a negative and almost constant linear temperature gradient exists with temperatures at the inversion layer of about -8°C to temperatures of 0° to 2°C at the soil-ice interface. This temperature

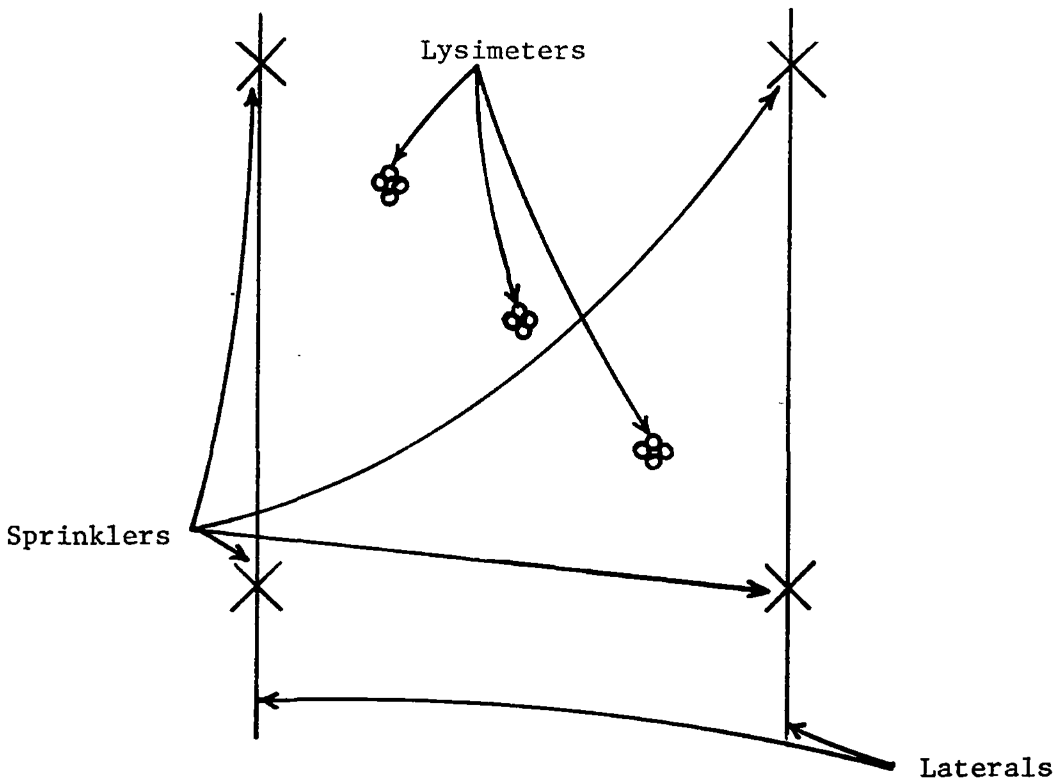

Figure 13a. Location of lysimeters between laterals.

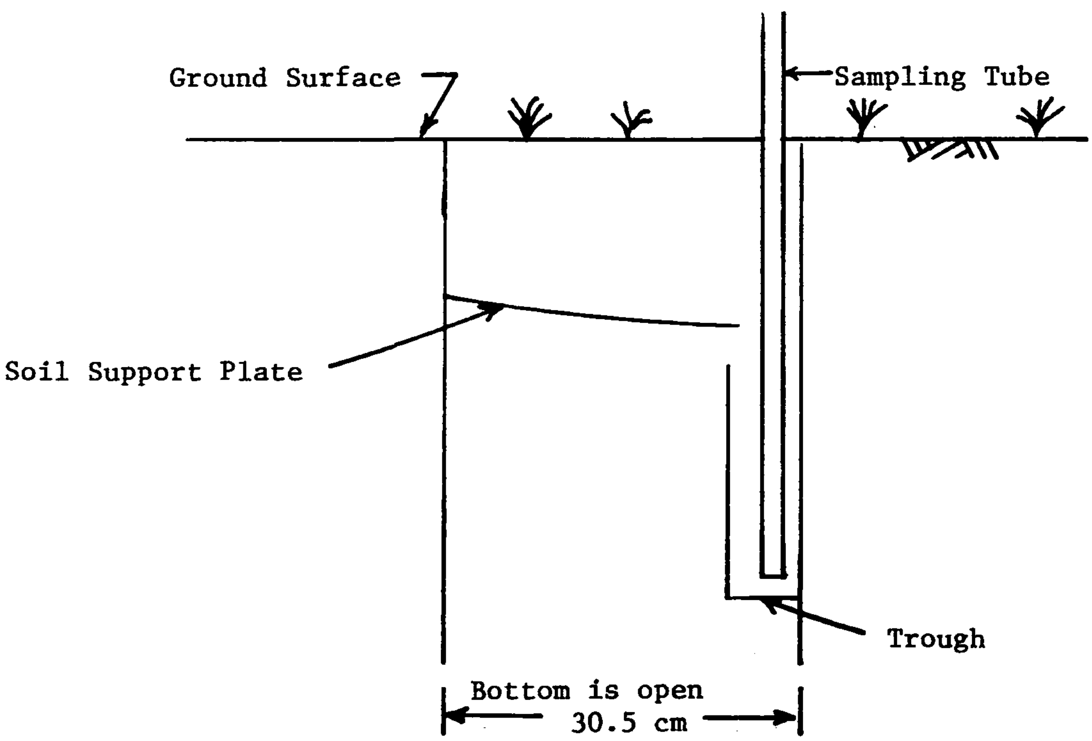

Figure 13b. Detail of typical 15 centimeter lysimeter.

TABLE 15. WATER QUALITY DATA FOR ICE PACK AT THAYNE, WYOMING -- 1976

	BOD_5 mg/1	COD mg/1	TKN mg/1	NH_3 mg/1	NO_2 mg/1	NO_3 mg/1	Total Phosphate mg/1	Fecal Coliform #/100ml	Specific Conductance μ mhos/cm
Top 25 percent									
February	244	965	3.2	0.1	0	1.2	--	0	143
March	173	5,105	8.2	0.1	0	0.5	--	63	175
April	429	8,685	32	23	0	0.2	--	0	--
2nd 25 percent									
February	139	1,110	3.5	0.0	0	0.9	--	0	--
March	129	845	7.5	0.3	0	0.2	--	825	75
April	104	835	6.6	4.8	0	0.2	--	88	--
3rd 25 percent									
February	113	1,045	3.5	0.0	0	0.6	--	0	81
March	125	835	6.6	0.2	0	0.4	--	1,038	85
April	94	980	5.5	3.9	0	0.2	--	1,338	--
Bottom 25 percent									
February	144	2,000	5.4	0.0	0	1.3	--	350	128
March	119	1,600	16.6	0.3	0	0.4	--	2,713	50
April	228	6,700	33	30.0	0	0.4	--	4,575	--
Influent									
January	617	--	14	0.9	0	0.6	--	--	670
February	330	18,000	8.4	0.0	0	0.6	--	18,200	375
March	324	19,000	28	4.9	0	1.2	--	30,000	925
April	330	13,000	7.2	0.0	0	0.4	--	1,000	1,100

TABLE 16. WATER QUALITY DATA FOR ICE PACK AT THAYNE, WYOMING -- 1977

	BOD_5 mg/l	COD mg/l	TKN mg/l	NH_3 mg/l	NO_2 mg/l	NO_3 mg/l	Total Phosphate mg/l	Fecal Coliform #/100ml	Specific Conductance μ mhos/cm
Top 25 percent									
January	65	760	30	1.9	<0.1	0.3	2.5	0	--
February	234	1,000	33	6.5	<0.1	0.6	0.6	18	600
March	640	94	13	1.1	<0.1		0.1	0	524
April	4,600	--	48	--	--	--	--	40	--
2nd 25 percent									
January	23	1,200	35	1.4	<0.1	0.4	--	--	--
February	196	260	23	0.0	<0.1	0.3	2.3	220	360
March	524	210	15	1.0	<0.1	0.2	1.8	0	--
April	1,200	--	--	--	--			40	--
3rd 25 percent									
January	65	1,200	19	6.0	<0.1	0.5	2.4	0	--
February	156	260	18	0.0	<0.1	0.1	--	160	200
March	430	210	13	1.1	<0.1	0.7	1.3	0	520
April	3,300	61	16	6.1	<0.1	0.0	0.48	1	--
Bottom 25 percent									
January	62	1,400	43	6.0	<0.1	0.3	--	0	--
February	210	490	30	0.0	<0.1	0.1	2.4	93	310
March	520	370	15	0.7	<0.1	0.1	1.7	0	260
April	1,000	--	--	--	--	--	--	--	--
Effluent									
January	610	280	87	4.2	<0.1	0.3	--	3,000	--
February	1,252	2,200	42	0.0	<0.1	2.3	2.1	12,800	--
March	640	2,600	8.5	0.9	<0.1	4.4	1.5	100,000	1,300
April	565	43	5.1	0.0	<0.1	7.1	--	0	

gradient is approximately what would be expected at Thayne where the soil generally does not freeze during the winter. The soil does not normally freeze under a deep ice pack of 0.9m or more (Bergen, 1968).

It has been suggested that during the coldest parts of the winter, the ice on the surface of the ice pack has a higher concentration of pollutants than the ice lower in the pack (Stinson, 1974). The ice below the surface of the ice pack appears to be insulated from the atmosphere by the surface ice. Since the ice below the surface is insulated, ice crystals are able to grow and the pollutants excluded from the nearby pure ice crystals in a brine-like solution, are able to drain from the pack. This results in the ice just below the surface being the purest. Ice at the surface has just received new pollutants and has not had the opportunity to drain. Ice nearest the bottom of the ice pack will demonstrate an increasing concentration of pollutants accumulating at the soil ice interface, a phenomenon probably due to the ice pack having a greater fluid conductivity than the soil just below it, or, possibly, capillary action (Bergen, 1968; Colbeck, 1974; Devries, 1972; EPA, 1971; Hanes et al., 1965; USACE, 1956).

The average density of the ice pack gradually increases throughout the ice accumulation season. This happens via a melt-freeze type of metamorphism in which the ice crystals become rounded and melt water is trapped between the grains, increasing the density of the crystals upon refreezing (Leak, 1966 and Wakahama, 1960). The density of the melted water containing contaminants is higher than the density of the ice. Therefore, it tends to drain from the pores and gradually percolate through the permeable ice by gravity.

In the early spring, densification of the ice is accelerated and the ice pack becomes heavy with gravitational water. The ice is relatively free of pollutants except at the top and bottom. However, as the melting of the ice pack begins at the surface, the melt water permeates downwards, and the pollutants are flushed out along with those concentrated at the surface (Ellmore, 1968).

The results of analyses on ice pack samples taken during 1976 and 1977 at Thayne support the contention that the pollutants concentrate in the upper and lower parts of the ice pack as occurred in Ellmore's desalination experiments (Ellmore, 1968). It should be noted that during the 1977 winter season the ground surface froze preventing movement of ice pack percolates into the soil. In addition, the ice pack during the winter of 1977 (by observation) had a density similar to water frozen in a freezer while the ice pack during the 1976 winter season had the appearance of a snow drift. The permeability of the soil and ice pack in 1976 was such that there was no surface runoff from the soil or the top of the ice pack. In 1977, there was considerable surface runoff from the top of the ice pack indicating a much denser ice with a lower permeability.

<u>Biochemical Oxygen Demand</u>

The BOD_5 in the top 25 percent and the bottom 25 percent of the ice pack was higher than that of the middle portions of the pack (see Tables 15 and

16). A comparison of sprayfield effluent data with BOD_5 data from the ice pack indicates that there was a reduction of BOD_5 within the ice pack itself during the winter months. The high BOD_5 during April, 1977 can be attributed to an apparent discharge of high strength whey by the cheese factory--a material not normally applied to the field.

There are two possible explanations for the reduction of BOD_5 in the ice pack. First, biological degradation of oxygen demanding organic matter could be occurring. While biological activity within an ice pack may seem improbable, it should be pointed out that active microorganisms have been isolated from polar ice caps. Activity may be reduced in scale under extreme cold conditions but can continue as long as free water remains available to the microorganisms (Brock, 1969). The fact that ammonification of organic nitrogen, a process generally due to biological action, also occurred in the ice pack, lends support to the contention that the observed BOD_5 reduction could be due to biodegradation. A similar reduction in the BOD_5 was observed in a snow pack made from municipal sewage (Wright, 1976). A second possibility is that the decrease in BOD_5 could be for ammonia nitrogen. Levels of ammonia nitrogen in the ice were found to be several times greater (up to 30 mg/l) than any level measured in the wastewater (up to 4.9 mg/l). Furthermore, the high levels occurred during April, near the time of ablation, when the possibility of surface runoff and/or groundwater pollution would have been the greatest.

The nitrogen data suggests two very important points. First, ammonification of organic nitrogen was taking place in the ice pack. Ammonification of organic nitrogen can occur by simple hydrolysis but this is generally limited to amides and imides. Ammonification generally occurs biologically with oxidative deamination being the most frequent mode of microbial attack (Thimann, 1963). While deamination can occur by other pathways in the absence of oxygen, these routes for degradation of organic nitrogen are energetically less favorable. Thus, the occurrence of ammonification in the ice pack is suggestive of a biological process occurring aerobically.

Secondly, it would appear ammonia nitrogen was more mobile in the ice pack than organic nitrogen (TKN less the ammonia nitrogen). This was evidenced by the greater percentage of ammonia nitrogen which migrated to the bottom of the ice pack in most cases where comparative data exists compared to the percentage of organic nitrogen which migrated. For example, 48 percent of the ammonia nitrogen reached the bottom quarter of the ice pack as compared to 20 percent of the organic nitrogen in April 1976. This may have been due to the physical size or the relative solubility of the organic nitrogen matter in comparison to the ammonia nitrogen. The ammonia nitrogen would be found in a soluble state while at least a portion of the organic nitrogen was associated with suspended matter. Due to the permeability of the ice pack (or lack of it), the ammonia nitrogen would be expected to migrate more easily. According to Fick's First Law, large particles have a slower diffusion velocity and lower rate of leaching (Morawetz, 1965). This may help to explain the increased migration rate of ammonia nitrogen compared to the organic nitrogen.

Phosphate

No observable trend in phosphate levels with depth in the ice pack was noted for 1977 data. Concentrations throughout the ice pack were in excess of levels desirable for direct discharge to streams.

Fecal Coliforms

Since it is possible for pathogens to leave the sprayfield by deep percolation or as aerosols or mist, fecal coliforms were included in the analysis program as indicators of potential travel distances for bacterial pathogens. Bacterial drift in the atmosphere was not monitored but samples were taken from the ice pack itself.

The fecal coliform levels in the ice pack (Tables 15 and 16) show a considerable reduction over effluent coliform densities. It is likely that the cold temperatures combined with exposure to ultraviolet radiation as the wastewater is sprayed onto the field could account for a high mortality in the bacteria. During the winter of 1976, ice pack coliform densities increased with increasing depth while in 1977 no trend with depth was observed and, in addition, observed coliform levels were generally much lower throughout the ice pack than in 1976. During 1976, a thick ice layer was formed over unfrozen soil. The insulating effect of the ice layer allowed drainage of soluble pollutants from the ice as has been previously discussed. However, in the case of bacteria, being the size of suspended matter, it is likely that the coliforms would not drain completely from the pack due to physical impedance of movement. During 1977, the ice formed was less permeable and the bacteria were immobilized at the surface and exposed to the elements, resulting in a high mortality. Die-off is a complicating factor since the process is time dependent and the bottom ice is the oldest. The trend toward increasing numbers near the bottom of the ice pack in 1977 would be even stronger without die-off.

Two other factors should be noted. In no case were large concentrations of bacteria found at the ice surface. It is likely that this is due in part to a higher die-off rate at the surface. As the bacteria drained in 1976, they became "Protected" from radiation, dessication, etc., by the ice layer itself. It should also be noted that the increase with depth seen in 1976 could be due to reproduction within the pack. The bacteria would be surrounded by small cells of liquid, high in nutrients, which might be a suitable growth medium. It has been shown that at low temperatures (4°C) coliform die-off rates are reduced under controlled laboratory conditions in sewage (in the absence of UV radiation) compared to death rates at higher temperatures (Hanes et al., 1965). However, no growth phase was observed at 4°C as was seen at higher temperatures. In ice, where water is less available than in 4°C liquid, it is not likely that significant reproduction rates are occurring.

FATE OF ICE PACK MELT WATER

To determine the fate of the ice pack melt water, two types of groundwater samples were taken. They were: (1) water trapped by bucket lysimeters that contained 15, 30, and 45 cm of soil, and (2) wells that extended into the water table. Samples of water taken from these sources have shown that after three consecutive years of spraying wastewater on the field and with a buildup of the ice pack each winter, no significant amounts of pollutants have reached the groundwater.

An examination of the water samples from wells at the edge of the sprayfield did indicate that the total dissolved solids (TDS) increased from approximately 300 mg/l above the field to 1200 mg/l below the field. Better than 90 percent of the increase could be accounted for by increases in calcium, magnesium, and bicarbonate ions. This increase was not unexpected since passage of water through similar soils would be expected to increase the TDS by leaching in approximately the same magnitude. A definite calcareous layer of soils exists in the sprayfield at depths of 45 to 60 cm, which may account for the build-up of calcium, magnesium and bicarbonate in the groundwater. All pollution parameters studied (BOD_5, nitrate, ammonia, COD, total phosphate, and fecal coliforms) were either absent or were approximately at the same concentrations as the groundwater from wells upstream from the sprayfield. It should be noted that the groundwater samples from the wells were taken from the top of the aquifer and were not homogeneous water samples from the aquifer. Also the results do not preclude the possibility that pollutants may reach the wells at some time in the future or that other pollutants, not studied, are already reaching them. However, since the pollutants examined encompass both conservative and nonconservative materials and living matter, none of which reached the wells in levels significantly above background, the possibility of pollution occurring seems remote. Other sites would require a case-by-case examination.

The lysimeter study was carried out during the winter of 1975-76 with the purpose of gaining some insight into the renovation of the wastewater in the soil matrix during the winter months. Additional studies are needed for definitive statements but the preliminary results are of interest as they relate to the renovation of the wastewater in the ice pack.

Nitrite nitrogen and ammonia nitrogen were found in small quantities in the drain water (maximum of 1.8 mg/l of NH_3 and 0.1 mg/l of NO_2) at soil depths up to 45 cm in the soil. No change in TKN was found by the well data over background groundwater samples. Thus, while TKN was decreasing with depth, nitrate nitrogen was increasing. This suggests quite strongly that the process of nitrification was taking place in the soil especially in the upper soil strata. Nitrification is an aerobic, thermally sensitive, process which might lead to the conclusion that it is unlikely to occur in soil covered by several feet of ice. The presence or absence of oxygen in the water in the lysimeters or soil was not examined but it should be recalled that ammonification did occur in the ice pack and the process was most likely due to oxidative deamination. This would lend evidence that the ice pack, at least, was aerobic. Air was able to reach the storage cell of the bucket lysimeter in small quantities during sampling which might have allowed nitrification to occur in the bucket itself. However, limited use of suction lysimeters during the winter of 1977 showed similar results. This type of lysimeter samples the soil directly by suction of pore water and does not provide sufficient contact time with air to permit nitrification to occur.

Samples from wells and springs adjacent to the field showed that neither nitrite nor nitrate were reaching the wells or springs (Table 17). In addition, an agronomic study of the soils in the sprayfield showed that nitrogen was being depleted from the soil. Also, the decline in soil ammonia nitrogen in the lysimeters could not be accounted for by observed increases in nitrate concentrations. This would suggest that denitrification may also have been occurring simultaneously with nitrification in anaerobic microenvironments within the soil matrix. This is not surprising since soil environments are typically nonhomogeneous on a micro scale (Stevens, 1972).

Even during the winter there were significant reductions of BOD_5 and COD in the upper 45 cm of the soil mantle. An 80 percent reduction was found for BOD_5, while COD had a 45 percent reduction. These decreases were probably contributable to filtration of the organic matter by the soil as well as an indication that some biological processes were occurring during the winter.

CONCLUSIONS

Knowledge of the changes taking place in an ice pack formed by the winter application of wastewater to land using spray irrigation, will enable better management of these types of systems. However, the data base for this study is very limited and the results should be taken as cursory. From the study at Thayne, Wyoming, the following conclusions can be made:

1. Formation of an ice pack can be used as a means of liquid storage during the winter months as an alternative to the use of large holding lagoons. This not only provides year-round use of the disposal facilities, but also provides additional treatment.

2. It has been shown that ammonification occurred in the ice pack. At the same time, nitrification was taking place in the soil mantle. Thus, organic nitrogen was oxidized as it travelled from the surface of the ice down into the soil, finally becoming nitrate nitrogen, its most oxidized state. Although different reactions occurred in the ice and soil, they were working in harmony to provide a further treatment of the wastewater.

3. For the predominately cheese plant wastewater and this type of land treatment system, there is little cause for concern of nitrate nitrogen contamination of groundwater. Nitrate values during the test period were well below federal drinking water standards (10 mg/l).

4. Ammonia nitrogen appears to be more mobile in the ice pack than organic nitrogen.

5. The severe leaching of the soil by the applied wastewater will increase TDS but will not increase BOD_5 or COD in the groundwater.

6. Due to differences in ice pack structure, particularly permeability,

changes in water quality and in the soil mantle did not demonstrate the same patterns from one year to the next.

SECTION 8

MANAGEMENT AND DESIGN RECOMMENDATIONS FOR SPRAYFIELD

INTRODUCTION

To successfully treat wastewater, the process of planning, system design and analysis, process design, construction, and operation and maintenance must all be performed in a satisfactory manner. Unfortunately, this was not the case at Thayne. With respect to this study, it was not the task of the principal investigators to manage, manipulate, design, or plan the system, but simply to monitor the system and give advice and suggestions when appropriate. Neither was it their task to pass judgement on any failure of the Thayne system not directly related to the experimental aspects of the system. Contained in this section are the recommendations on design and management of the sprayfield based on research findings. The principal investigators advise that these recommendations be considered for any land treatment system operating on a year-round basis under high altitude conditions.

RECOMMENDATION FOR SYSTEM DESIGN

The sprinkler system is a buried solid set system with 24.4m by 24.4m spacing. The pump was designed to deliver 47.3 liters/sec at a pressure of 483 Kpa at the sprinkler heads. Conventional horizontal impact sprinklers were selected (Aqua Dial No. 53 with 0.48 cm X 0.64 cm nozzles). For the given design pressure and spacings the application rate calculates to be 0.86 cm per hour. To determine the sprinkler systems uniformity of application, the Christiansen Uniformity Coefficient (UCC) was determined at two locations. The UCC was 61 percent in the first test and 73 percent in the second test.

According to Karmeli (1977) systems with a UCC less than 70 percent are generally unsatisfactory for agricultural irrigation purposes (see Fig. 14). The low UCC also means that approximately 40 percent of the area irrigated received 1.1 times the average application rate or more and that 40 percent of the area received approximately 60 percent of the volume of wastewater applied. Given the low UCC and the high operation pressure of the system, it is not recommended to operate the system anytime the average wind speed exceeds 6.5 Km/hr.

There were no areas within the sprayfield not having sufficient moisture for plant growth because of the sprinkler distribution pattern. However, dry areas are unlikely to occur when the amount of wastewater being applied

Figure 14. Sprayfield covered with ice, April 1977. (Note the circles cut by the sprinkler pattern--a symptom of poor uniformity of application).

exceeds by 2 or 3 times the amount needed to bring the soil to field capacity. The one area that did lack water from time to time was the upper end of the field. The end sprinklers were often plugged. This problem could be prevented by adding cleanout valves at the end of the lateral and periodically flushing out the lines.

From monitoring the system at Thayne and comparing it to the sprinkler systems used on irrigated farms, the following recommendations are made with respect to sprinkler system design:

1. An economic optimization should be made between operational costs (mainly energy) and capital cost in order to select optimum lateral and sprinkler head spacings and operating pressure.

2. An analysis of wind speed should be made to make sure the system can operate in all months with an acceptable uniformity of application. If closer lateral and sprinkler spacings are required because of the wind, an economic optimization should be made between sprinkler system cost and cost

of additional storage needed to store water during prolonged periods of high wind.

3. A cleanout valve should be placed at the end of each lateral.

4. All laterals and mains should be buried a sufficient depth to prevent freezing. Soil should not be piled up over the pipes in lieu of a deep trench. The piled soil prevents normal farming operations and the plants that grow in these piles can cause odor and weed problems.

5. All laterals and mains should drain back to the pump wet well to prevent any water in risers and sprinkler heads after the stoppage of spraying.

6. All systems should meet existing agricultural standards for an irrigation system, especially in terms of uniformity of application.

MANAGEMENT OF SPRINKLER SYSTEM

Management of the sprinkler during warm weather should be conducted similar to the agricultural sprinkler system. However, during the winter months the system must contend with extremely cold weather. For example, during January at Afton, Wyoming, there is a 0.43 probability that the minimum daily temperatures will be below -18°C and the 0.06 probability that the maximum daily temperature will be below -18°C, while the mean is -9°C. The mean temperature at the sprayfield was -9°C for January, 1976 and -7°C for January, 1977. Despite these cold temperatures only minor problems occurred (see Fig. 15). The main reason for the successful winter time operation was the relatively warm effluent temperatures. During January, 1976 water temperature at the bottom of the holding lagoon was 5°C. The effluent is pumped from the bottom of the holding lagoon.

As can be seen from Figure 16, ice will build up as high as the top of the risers. The relatively warm water, however, will cut through the ice. If a sprinkler head stops turning due to freezing, as they often do, the stationary jet of water will hit the ice pack and spread as surface flow before it freezes. The distribution of water on the ice pack when 50 percent of the sprinkler heads were not turning appeared to be as good as when all sprinkler heads were turning.

As was stated in Section 7, there were some problems with runoff from the surface of the ice pack during the 1976-77 winter. This problem was solved by the operator. Using the automatic controls, the water was switched to a different part of the sprayfield every 15 minutes. During ablation solution channels did develop through the ice pack due to the frozen soil (see Fig. 17). This problem can only be solved by preventing the soil from freezing in the fall.

Figure 15. Severe build-up of ice around sprinkler head.

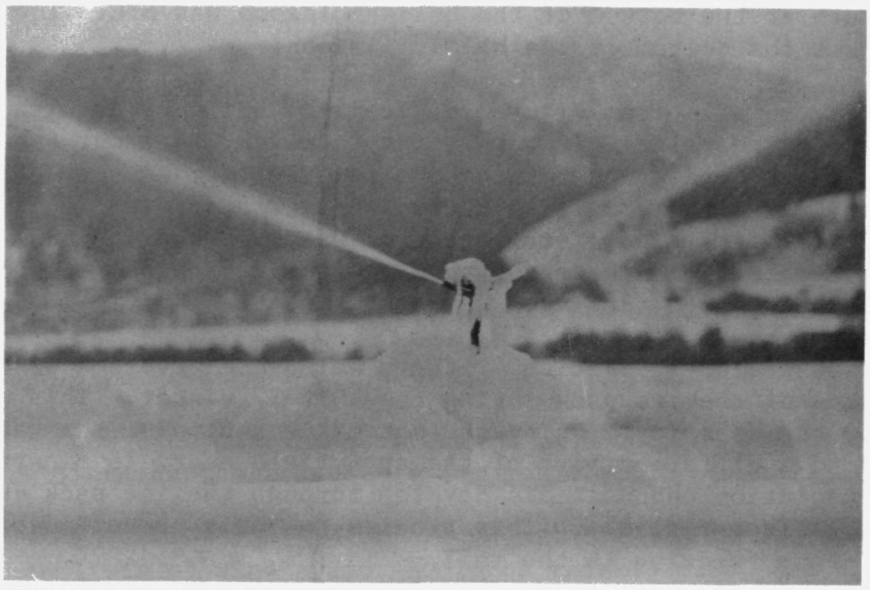

Figure 16. Ice build-up to top of riser.

Figure 17. Solution channel in ice pack.

Based on two winters of observation, the following recommendations are made with regard to winter management of the sprayfield:

1. The water in the holding lagoon should be maintained at 4°C or above to prevent any serious build-up of ice on the sprinkler heads.

2. The set times should be 30 minutes or less to avoid excess melting of the ice pack by the warm water and to prevent any possible runoff.

3. If cones of ice do develop around the sprinkler head, the head can be removed temporarily allowing the warm water to melt the ice immediately adjacent to the riser (see Fig. 18).

4. An ice pack should be forced to form by spraying during the night hours during the late fall when night-time temperatures are well below freezing.

5. No more than two-thirds of the sprayfield should be used during the winter. The remaining one-third of the sprayfield should be saved and used in the spring at the time of ablation of the ice pack. If this procedure is followed, no additional water will be added to the area under the ice pack and water logging of the soil at the time of ablation can be minimized.

6. Following ablation of the ice pack, the irrigation schedule should be returned to a summer-time mode. Any section of the sprayfield should not be irrigated more than once per week. More frequent irrigations will keep soil temperature low and retard plant growth.

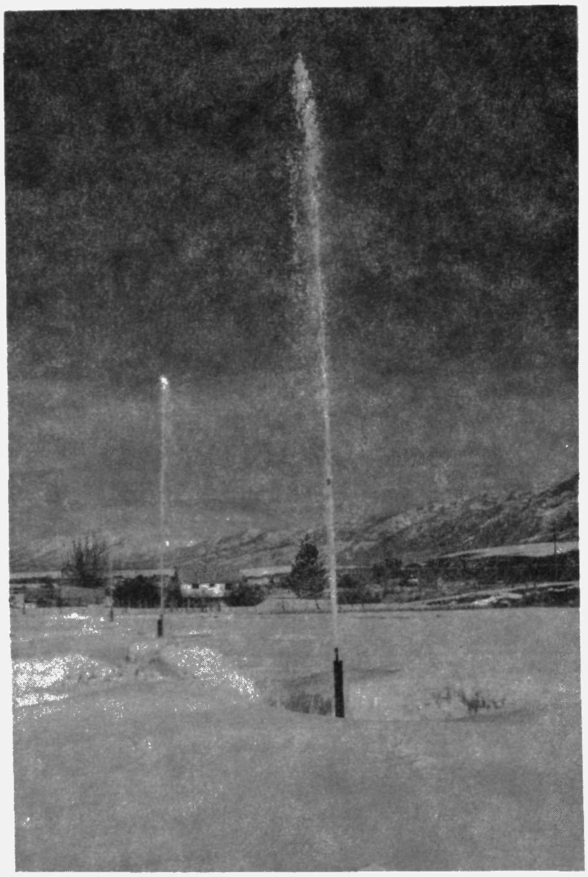

Figure 18. Melting of ice from around riser by removal of sprinkler head.

SECTION 9

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APPENDIX

I. RESULTS OF WATER QUALITY MONITORING

TABLE 17. NUTRIENT AND BIOLOGICAL DATA FOR FOURTEEN WATER SAMPLING POINTS

Location: Influent	NO_3 mg/l	NO_2 mg/l	NH_3 mg/l	TKN mg/l	TOC mg/l	BOD_5 mg/l	COD mg/l	TSS mg/l	Total PO_4 mg/l	pH	Spec. Cond. µ mhos/cm	Fecal Coli. No/100 ml
6-4-75	0.5								2.53	6.5	2,637	
10-25-75	5.1	0.5	0.0	0.7	44		23	12	0.19			
1-25-76						18				6.8	380	
2-24-76	2.0	0.5	0.0	1.1		30	24			5.6	400	900
3-15-76		<0.1	12	97		336	19,000			4.4	2,500	17,500
4-14-76	0.2	<0.1	0.0	2.5		60	12,000			4.2	2,600	14,000
5-25-76 composite		1.0	6.9	34			16,000					
5-26-76 9am -8 pm		0.5	11	62		1,290	18,000					
5-26 5-27-76 9pm - 8am	2.3	1.0	0.0	3.4		42	38					
5-27-76 9am - 8pm		0.5	5.1	30		2,070	3,300					
5-27 5-28-76 9pm - 8am	2.7	1.0	0.0	2.1		6	1,600					
5-28-76 9am - 8pm	3.9	1.0	0.0	1.8		1,890	4,500					
5-28 5-29-76 9pm - 8am		0.2	5.3	22		6	1,400					
5-29-76 9am - 8pm		0.1	7.1	33			1,900					
5-29 5-30-76 9pm - 8am	6.9	1.0	0.0	0.9			1,800					

(continued)

TABLE 17. (continued)

Location: Influent (cont.)

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
9-9-76	3.6	0.5	0.0	82	1,723	>1,500	17,000	616	2.53			>16,000
10-9-76	6.5	5.0	0.0	2.0	10	1,500	15,000	28	0.57			1,300
11-8-76	0	0	0	1.9	20	5	21,000	20	0.96	7.5	458	16,300
12-21-76	4.8	.5	0	130		570	5,600		2.09			40,000
1-7-77	0.1	0.6	0	27	483	620	1,200	160	2.9			65,000
2-12-77	0.6		0	1.4		320	0	12	0.4			4,600
3-6-77	4.4		0.9	8.2		211	2,600		1.01	4.8	1,100	0
4-12-77	4.5	1.0	0	35		295	1,900		1.76			TNTC[a]
5-13-77	N O S A M P L E											
6-18-77	4.6	<0.1	16	72		1,500	13,000	1,200				$1.3x10^6$
7-15-77	3.2	<0.1	1.8	17		165	610		1.37		320	980,000
8-18-77	0	<0.1	53	250		1,170	57,000		*	5.2	2,400	$1.3x10^6$
9-19-77	0	<0.1	5.4	90		1,560	18,000		*	5.8	2,200	$1.1x10^6$

* Not run due to interferences

a >50,000

(continued)

TABLE 17. (continued)

Location: Aerated Lagoon

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal Coli.
10-25-75	0.2	0.1	0.0	0.9	44		1,500	72	2.0			
1-25-76						615				6.4	475	
7-7-76	5.5			1.2					0.2	7.5	460	
9-9-76	2.9	1.0	0.0	24	665	>1,600	2,700	264	2.29			<2
1-7-77	.9	0.8	0	7.5	828	620	190		NA			TNTC[a]
4-12-77	3.3	0.1	1.6	69		155	4,300					TNTC[b]
5-13-77					N O S A M P L E							
6-8-77	3.2	<0.1	1.6	120		1,600	6,500	660				198,000
7-15-77	2.3	<0.1	0.2	48		705	0		1.69		700	178,000
8-18-77	0	<0.1	1.8	77		1,440	10,000		*	4.6	750	1.0×10^6
9-19-77	0.2	<0.1	3.0	28		1,410	15,000		2.56	5.2	440	1.4×10^6

NA-* Not run due to interferences

a Too numerous to count, actually greater than 50,000, bottle froze and broke in transit, sample may have been subject to contamination.

b >50,000

(continued)

TABLE 17. (continued)

Location: Effluent

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal Coli.
9-15-75	0.3			19			180		2.4	6.5	693	
10-18-75	0.6			31			370		3.1	5.1	989	
10-25-75	0.6	0.1	1.6	14	386		8,000	100	2.7			
1-25-76						617				2.8	775	
2-24-76	0.6	0.1	0.0	8.4		330	18,000			7.3	375	18,200
3-15-76	1.2	<0.1	4.9	28		324	19,000			4.1	925	17,500
4-14-76	0.4	<0.1	0.0	7.2		330	13,000			4.2	1,100	
5-25-76 composite		<0.1	5.1	19			2,500					
5-26-76 9 am - 8 pm		<0.1	0.0	3.5		1,350	2,900					
5-26-76 9 pm - 8 am		0.1	5.3	41		1,170	2,800					
5-27-76 9 am - 8 pm		0.1	3.9	21		1,290	2,900					
5-27-76 9 pm - 8 am		0.5	4.4	25		1,830	2,900					
5-28-76 9 am - 8 pm		0.1	3.5	30		1,350	3,000					
5-28-76 9 pm - 8 am	3.4	2.0	0.0	1.8		1,860	2,900					
5-29-76 9 am - 8 pm		0.1	2.8	15			29,000					
5-29-76 9 pm - 8 am		1.0	1.8	12			24,000					

(continued)

TABLE 17. (continued)

Location: Effluent (continued)

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal Coli.
9-9-76	3.0	1.0	3.0	34	807	1,390	18,000	52	2.34			>16,000
10-9-76	0.0	0.1	1.8	31	682	1,200	16,000	136	2.52			700
11-8-76	0	0	0	19	228	10	22,000	194	2.8	7.0	1,080	1,800
12-21-76	0.9	0.5	0	62		580	4,000		2.08			<10,000[a]
1-7-77	0.3	<0.1	4.2	87	1,254	610	280	220	NA			3,000
2-12-77	2.3		0	42		1,252	2,200	120	2.1			12,800
3-6-77	4.4		0.9	8.5		640	2,600		1.48	4.5	1,300	100,000
4-12-77	7.1	<0.1	0	5.1		565	43					0[b]
5-13-77	N O S A M P L E											
6-8-77	2.4	<0.1	11	120		...[c]	6,800	240				45,000
7-15-77	1.2	<0.1	39	81		1,230	0		2.27		1,250	21,500
8-18-77	0	<0.1	31	100		1,470	45,000		*	4.2	1,000	1.1×10^5
9-19-77	0.1	<0.1	29	43		1,950	1,500		2.93	5.0	320	1.0×10^5

[a] Too high a dilution was used and no colonies appeared, actual value is less than 10,000

[b] Colonies were uncountable due to water leakage

[c] Insufficient dilution was made

* Not run due to interferences

(continued)

TABLE 17. (continued)

Location: Under drain

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
10-25-75	3.7	<0.1	0.0	5.8	42		0.0	8.0				
1-25-76						2				6.9	400	0
2-24-76	2.9	<0.1	0.0	0.7		3	13			7.4	375	0
3-15-76	2.4	<0.1	0.0	1.8		2	6.9			7.5	400	4
4-14-76	4.8	<0.1	0.0	0.7		0	1.3			7.5	400	0
6-23-76	5.5	<0.1	0.0	1.4	5	1.3	840	0.0	0.12	7.3	481	11
9-9-76	0.8	<0.1	0.0	0.7	8	9.5	190		0.33			2
10-19-76	0.5	<0.1	0.0	0.5	19	5.9	130		0.61			196
11-8-76	3.6	<0.1	0.0	0.9	16.5	6.2	65		0.44			102
12-21-76	1.2	<0.1	0.0	2.4		7.3	56		0.03			38
1-7-77	2.1	0.1	0.0	0.7	15	5.9	35		NA			56
4-12-77	0.1	<0.1	0.0	4.1		4.6	140					
5-13-77	0.1			1.7		7.0	380		0.02	7.4	965	0
6-8-77	0.0	<0.1	1.4			6.4	2,000		0.03			0
7-15-77	0.0	<0.1	0.0	1.3		6	200		0.13		360	1
8-18-77	0.0	<0.1	0.0	1.1		2.2	39		0.11	6.8	180	1
9-19-77	0.1	<0.1	0.0	0.2		6.5	19		0.01	7.2	500	0

(continued)

TABLE 17. (Continued)

Location: Flat Creek

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
10-25-75	4.5	<0.1	0.0	0.4	31		0.0	0.0	0.05			
1-25-76						2				7.6	360	25
6-23-76	5.5	<0.1	0.0	0.0	5	2.4	980	40	0.10	7.4	458	44
9-9-76	2.1	<0.1	0.0	0.3	7.5	6	170		0.03			2
10-9-76	3.7	<0.1	0.0	0.6	1.0	1.5	36		0.22			11
11-8-76	3.1	<0.1	0.0	0.4	2.5	2.2	6.4	26	0.05	8.0	416	46
12-21-76	4.7	<0.1	0.0	0.4		2.6	0.0		0.09			2
1-7-77	7.0	<0.1	0.0	0.0	8	1.4	84		0.06			10
4-12-77	4.7	<0.1	0.0	0.7		3.2	7.4					9
5-13-77	4.8			0.0		0.0	1.8	6	0.02	7.9	412	40
6-8-77	3.8	<0.1	0.0	3.7		0.2	1,900		0.01			52
7-15-77	3.2	<0.1	0.0	0.9		...[a]	130		0.05		280	28
8-18-77	0.0	<0.1	0.0	0.4		1.4	4.2		0.03	7.4	265	99
9-19-77	0.9	<0.1	0.0	0.9		2.0	3.1		0.02	7.2	300	10

[a] Lab error

(continued)

TABLE 17 (Continued)

Location: Spring #1 (North)

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
10-25-75	4.3	<0.1	0.0	1.0	38		1.0	4.0	0.06			
1-25-76										7.3	350	2
2-24-76	4.0	<0.1	0.0	1.0		4.2	66			7.6	325	0
3-15-76	3.3	<0.1	0.0	0.4		1.8	0.2			7.6	400	2
4-14-76	4.3	<0.2	0.0	1.2		2.5	4.1			7.6	400	0
6-23-76	6.6	<0.1	0.0	0.0	4	2	1,400	4.0	0.05	7.4	463	0
9-9-76	1.2	<0.1	0.0	0.0	0	12	420		0.01			5
10-9-76	1.5	<0.1	0.0	0.7	2.5	0.7	43		0.21			148
11-8-76	3.6	<0.1	0.0	1.1	3.0	0.0	6.5		0.01			0
12-21-76	0.0	<0.1	0.0	0.6		2.3	2.1		0.06			3
1-7-77	0.1	<0.1	0.0	0.0	22	3.3	46		NA			0
4-12-77	2.1	<0.1	0.0	7.1		7.0	130					7
5-13-77	0.1			0.0		3.2	52	10	0.01	7.8	621	0
6-8-77	0.5	<0.1	0.5	3.9		7.3	320		0.04			3
7-15-77	0.3	<0.1	0.0	1.8		5.5	20		0.06		365	26
8-18-77	0.0	<0.1	0.0	0.4		3.2	15		0.09	7.1	300	2
9-19-77	0.0	<0.1	0.0	1.1		11.7	5.7		0.04	6.8	430	0

(continued)

TABLE 17. (Continued)

Location: Spring #2 (South)

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
10-25-75	4.7	<0.1	0.0	0.0	31		0.0	4.0	0.09			
1-25-76						2				7.3	350	2
2-24-76	4.0	<0.1	0.0	1.0		4.2	66			7.6	325	0
3-15-76	3.3	<0.1	0.0	0.4		1.8	0.2			7.6	400	2
4-14-76	4.3	<0.2	0.0	1.2		2.5	4.1			7.6	400	0
6-23-76	6.6	<0.1	0.0	0.0	4	2	1,400	4.0	0.05	7.4	463	0
9-9-76	1.0	<0.1	0.0	0.0	1	12	380		0.03			13
10-9-76	3.3	<0.1	0.0	0.7	8.0	2.4	84		0.20			391
11-8-76	5.4	<0.1	0.0	0.4	2.5	0.7	6.8		0.07			0
12-21-76	4.6	<0.1	0.0	0.6		1.7	9.2		0.39			0[a]
1-7-77	6.4	<0.1	0.0	0.2	5	4.4	12		NA			29
4-12-77	4.7	<0.1	0.0	0.7		3.35	3.7					0
5-13-77	0.1			0.0		2.5	10		0.01	7.8	682	0
6-8-77	0.5	0.1	0.0	3.3		8.0	280		0.00			0
7-15-77	0.4	<0.1	0.0	0.9		7.3			0.10		340	10
8-18-77	0.0	<0.1	0.0	0.4		1.0	1.8		0.04	7.0	300	43
9-19-77	0.1	<0.1	0.0	0.6		9	4.7		0.05	7.0	420	0

[a] Too high a dilution was used, actual value is less than 10,000

(Continued)

TABLE 17. (Continued)

Location: Well #1

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
6-23-76	9.1	<0.1	0.0	0.9	9.5	10	1,400	240	0.17	7.2	462	0
9-9-76	2.2	<0.1	0.0	0.0	0	25	220		0.07			22
10-9-76	3.4	<0.1	0.0	0.9	6.0	2.5	36		0.38			3
11-8-76	4.0	<0.1	0.0	0.2	4.5	0.3	12		0.04			0
12-21-76	4.1	<0.1	0.0	0.6		2.5	1.8		0.07			8
1-7-77	4.7	<0.1	0.0	0.3	8	4.8	13		0.08			0[a]
4-12-77	0.1	<0.1	0.0	1.4		6.25	680					4
5-13-77	0.0			1.3		5.8	41		0.11	7.7	930	0
6-8-77	0.3	<0.1	0.0	3.7		6.7	260		0.02			8
7-15-77	2.0	0.1	0.0	1.8		7.3	570		0.08		305	0
8-18-77	0.0	<0.1	0.0	0.8		1.7	65		0.13	7.6	280	0
9-19-77	0.1	<0.1	0.0	0.6		4.2	1.8		0.01	7.2	340	0

[a] Bottle froze and broke in transit, may be subject to contamination

(continued)

TABLE 17. (continued)

Location: Well #2

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
6-23-76	9.6	<0.1	0.0	0.0	6.5	45	1,300	760	0.96	7.1	565	0
9-9-76	0.0	<0.1	0.0	0.0	0	135	240		0.05			<2
10-9-76	0.0	<0.1	0.0	0.6	22	36	100		0.13			0
11-8-76	4.5	<0.1	0.0	0.4	13.5	3.2	26		0.04			1
12-21-76	0.1	<0.1	0.0	0.4		5.8	23		0.01			0
1-7-77	0.3	0.1	0.0	1.9	2	4.2	120		0.02			0
4-12-77	0.8	<0.1	0.0	3.7		6.7	180					0
5-13-77	0.0			1.5		6.7	65		0.02	7.2	1,840	0
6-8-77	0.3	<0.1	0.9	5.1		4.9	810		0.01			0
7-15-77	0.4	<0.1	3.2	6.4		4.3	810		0.26		1,000	0
8-18-77	0.0	<0.1	0.0	2.1		4.1	4.5		0.13	7.0	550	3
9-19-77	0.0	<0.1	4.8	6.4		3.9	52		0.01	7.0	610	0

(continued)

TABLE 17. (continued)

Location: Well #3

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
6-23-76	0.2	<0.1	0.0	0.9	32	62.5	1,700	224	0.39	7.0	643	0
9-9-76	15	<0.1	0.0	0.7	0	45	180		0.03			5
10-9-76	2.1	0.1	0.0	0.7	4	3.5	39		0.08			0
11-8-76	3.9	0.1	0.0	0.2	1.3	0	4.7		0.03			0
12-21-76	4.1	<0.1	0.0	0.2		1.5	0.3		0.01			0
1-7-77	4.9	<0.1	0.0	0.0	0	2.8	8.0		0.00			1
4-12-77	0.1	<0.1	0.0	1.8		7.45	1,100		0.01			0
5-13-77	0.0			0.9		9.8	25		0.03	7.7	796	0
6-8-77	0.4	<0.1	0.0	7.0		8.4	140		0.02			0
7-15-77	0.3	<0.1	0.0	2.8		3.6	480		0.10		330	0
8-18-77	0.0	<0.1	0.0	0.6		3.5	3.0		0.07	7.2	300	0
9-19-77	0.1	<0.1	0.0	0.7		5.1	6.5		0.01	7.4	450	0

(continued)

TABLE 17. (continued)

Location: Well #4

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
6-23-76	0.0	<0.1	0.0	0.9	98	225	1,400	276	0.72	6.9	802	0
9-9-76	0.1	<0.1	0.0	0.0	0	120	160		0.04			<2
10-9-76	0.0	<0.1	0.0	0.7	12.5	8.5	74		0.08			0
11-8-76	4.6	<0.1	0.0	0.4	3.0	0.5	8.7		0.03			0
12-21-76	0.0	<0.1	0.0	0.6		7.1	24		0.01			0
1-7-77	0.1	<0.1	0.0	1.7	16	2.4	56		0.08			0
4-12-77	0.0	<0.1	0.0	3.2		2.5	1,300		0.10			0
5-13-77	0.1			1.5		6.3	68		0.01	7.3	1,880	0
6-8-77	0.6	<0.1	0.2	5.1		6.5	1,000		0.01			0
7-15-77	0.2	<0.1	0.0	3.7		...[a]	1,300		0.19		1,100	0
8-18-77	0.0	<0.1	0.0	2.3		2.7	1,745		0.13	6.8	785	0
9-19-77	0.1	<0.1	0.0	1.7		4.0	46		0.26	7.0	800	0

[a] Lab error

(continued)

TABLE 17. (continued)

Location: Well #5

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
6-23-76	5.5	0.2	0.0	1.8	6	24	1,200	28	0.11	7.6	281	55
9-9-76	3.3	<0.1	0.0	0.0	0	30	160		0.03			< 2
10-9-76	3.4	0.1	0.0	0.4	3.0	3	36		0.17			1
11-8-76	4.6	0.1	0.0	0.6	2.0	1.0	8.7		0.04			0
12-21-76	3.9	<0.1	0.0	0.7		1.5	10		0.37			0
1-7-77	3.3	0.2	0.0	2.4	10	3.0	3.3		0.07			[a]
4-12-77	DRY FOR THIS SAMPLING											
5-13-77	6.8			0.6		5.2	5.8		0.05	7.9	503	0
6-8-77	4.6	<0.1	0.0	4.0		2.3	49		0.03			0
7-15-77	2.1	<0.1	0.0	1.4		0.6	1,100		0.11		350	0
8-18-77	0.0	<0.1	0.0	0.6		1.2	14		0.09	7.1	335	0
9-19-77	NO SAMPLE											

[a] No sample, bottle froze and broke in transit

(continued)

TABLE 17. (continued)

Location: Well #6

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
6-23-76	0.1	0.1	0.0	3.5	11	43	1,500	32	0.07	8.6	261	0
9-9-76	0.0	0.1	0.0	0.0	0	40	160		0.09			2
10-9-76	0.0	0.1	0.0	2.1	5.5	14	26		0.20			0
11-8-76	4.9	0.1	0.0	0.9	1.5	1.1	9.1		0.06			0
12-21-76	1.8	0.1	0.0	0.4		1.3	0		0.06			0
1-7-77	4.2	0.5	0.0	0.2	7	2.3	15		0.00			0
4-12-77	0.7	0.1	0.0	0.5		2.4	9.5		3.56			0
5-13-77		NO SAMPLE FROM HERE ON DRY WELL										

(continued)

TABLE 17. (continued)

Location: Well #7

Date	NO_3	NO_2	NH_3	TKN	TOC	BOD_5	COD	TSS	Total PO_4	pH	Spec. Cond.	Fecal. Coli.
6-23-76	0.3	0.2	0.0	1.8	5.5	23	1,500	44	0.10	8.7	141	0
9-9-76	0.1	<0.1	0.0	0.0	2	4	160		0.04			<2
10-9-77	0.6	0.1	0.0	1.0	3.0		32		0.08			1
11-8-76	4.3	<0.1	0.0	0.0	1.0	0.6	7.3		0.05			0
12-21-76	1.3	<0.1	0.0	0.2		0.9	0		0.02			0
1-7-77	1.0	<0.1	0.0	0.2	6.0	6	11		0.00			0
4-12-77	0.3	<0.1	0.0	0.5		4.1	7.8		0.022			0
5-13-77	5.8			0.7		1.6	5.4		0.02	7.5	415	0
6-8-77	1.9	<0.1	0.9	3.7		1.3	41		0.02			0
7-15-77	0.3	<0.1	0.0	1.4		2.4	1,100		0.04		160	0
8-18-77	0.0	<0.1	0.0	1.6		1.7	13		0.04	8.2	135	0
9-19-77	0.0	<0.1	0.0	0.6		5.6	8.8		0.01	7.2	170	0

TABLE 18. HEAVY METAL DATA FOR FOURTEEN WATER SAMPLING POINTS

Location	Date	Cu*	ZN	Cd	Pb	Ni
Influent	9-9-76	<0.01	<0.01	<0.01	<0.1	<0.1
Effluent	9-9-76	<0.01	0.07	<0.01	<0.1	<0.1
Well #1	6-23-76	<0.01	0.14	<0.01	<0.1	<0.1
Well #1	9-9-76	<0.01	<0.02	<0.01	<0.1	<0.1
Well #2	6-23-76	<0.01	0.08	<0.01	<0.1	<0.1
Well #2	9-9-76	<0.01	0.04	<0.01	<0.1	<0.1
Well #3	6-23-76	<0.01	0.06	<0.01	<0.1	<0.1
Well #3	9-9-76	<0.01	<0.02	<0.01	<0.1	<0.1
Well #4	6-23-76		0.08			
Well #4	9-9-76		0.02			
Well #5	6-23-76		0.05			
Well #5	9-9-76		<0.02			
Well #6	6-23-76		0.06			
Well #6	9-9-76		<0.02			
Well #7	6-23-76		0.05			
Well #7	9-9-76		<0.02			
Under drain	6-23-76		0.04			
Under drain	9-9-76		<0.02			
Spring #2	6-23-76		0.02		0.1	
Spring #2	9-9-76		<0.02		0.1	
Spring #1	6-23-76		0.02		0.1	
Spring #1	9-9-76		<0.02		0.1	
Flat Creek	6-23-76		0.03		0.1	
Flat Creek	9-9-76	<0.01	<0.02	<0.01	<0.1	<0.1

* All parameters are measured in mg/1.

TABLE 19. CHEMICAL ANALYSIS FOR FOURTEEN WATER SAMPLING POINTS

Location	Date	Para	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl_2	NO_3	Fl	Total CO_3	% Na	Boron	Silica
Influent	6-4-75	meq/1	3.28	1.63	18.92	0.36	0.0	5.93	0.24	17.98	0.10	0.07				
		mg/1	66	20	435	14	0.0	362	12	634	0.5	1.3				
Effluent	9-15-75	meq/1 mg/1	3.39	1.68	1.47	0.51	0.0	5.5	0.0	1.15	0.0	0.08	160	21	0.05	
		mg/1	68	26	34	20	0	240	0	41	0.3	1.5				
	10-18-75	meq/1	5.09	2.10	2.51	1.55	0	4.05	0.67	1.89	0.01	0.08	120	22	0.08	
		mg/1	100	26	58	61	0	250	32	67	0.6	1.6				
Water tap men's room	6-4-75	meq/1	2.6	1.6	0.05	0.01	0	3.42	0.67	0.05	0.01	0.01				
		mg/1	52	19	1.1	0.2	0	207	32	1.8	0.6	0.2				
South lagoon SW corner	7-7-75	meq/1	3.62	1.84	0.23	0.04	0	4.25	0.62	0.9	0.09	0.01	130	4.3		
		mg/1	73	24	5.4	1.6	0	260	30	32	5.5	0.2				
Spring above transit pipe	6-4-75	meq/1	2.75	1.51	0.05	0.01	0	3.63	0.70	0.10	0.01	0.01				
		mg/1	55	18	1.1	0.2	0	222	34	3.6	0.6	0.2				
Transit pipe from lagoons	6-4-75	meq/1	3.26	1.60	0.19	0.05	0	4.39	0.58	0.21	0.01	0.01				
		mg/1	65	20	4.3	2.1	0	268	28	7.3	0.5	0.2				
	7-7-75	meq/1	3.55	2.50	0.21	0.03	0	4.75	0.50	1.18	0.11	0.01				
		mg/1	71	30	4.8	1.2	0	290	24	42	7.0	0.2				

(continued)

TABLE 19. (continued)

Location	Date	Para	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl_2	NO_3	Fl	Total CO_3	% NA	Boron	Silica
North lagoon NE Corner	10-15-76	meq/l	3.99	1.93	3.05	1.47	0	3.6	0.75	1.73	0.01	0.08	110	17	0.02	20
		mg/l	80	24	70	57	0	220	36	61	0.5	1.5				
	1-25-76	meq/l	3.14	1.73	3.08	0.87	0	0	0.69	--	0.01	0.18	0	18	0.03	16
		mg/l	63	21	71	34	0	0	33	--	0.6	3.4				
	2-21-76	meq/l	2.91	1.37	2.05	0.49	0	1.60	0.74	1.23	0.01	0.08	48	17	0.01	11
		mg/l	58	17	47	19	0	98	35	61	0.8	1.5				
	7-7-76	meq/l	3.29	2.21	0.30	0.07	0	4.65	0.60	0.72	0.0	0.01	140	4.3		
		mg/l	66	27	7.0	2.8	0	280	29	25	0.1	0.2				

APPENDIX

II. RESULTS OF CLIMATIC MONITORING

TABLE 20. DEPTH TO WATER TABLE IN SPRAYFIELD (METERS)

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
9-26-75	4.87	2.61	2.52	3.52	3.97	1.43	3.59
8-12-76	3.69	3.12	3.02	4.20	3.26	1.41	3.76
10-976	4.73	3.86	4.19	5.65	6.31	3.06	5.64
11-19-76	4.99	4.03	4.47	5.91	6.99	3.87	6.00
12-20-76	4.65	4.19	4.75	6.13	7.33	4.60	8.17
1-4-77	5.29	4.28	5.85	6.25	7.45	4.97	6.95
5-12-77	4.66	4.72	4.95	4.92	4.71	--	5.90
6-8-77	4.48	3.75	4.04	5.25	5.27	--	5.62
8-16-77	4.65	3.96	4.24	5.43	6.06	--	6.28
9-16-77	5.06	3.52	4.73	6.26	Dry	--	7.04

TABLE 21. HOURS PER MONTH OF IRRIGATION FOR EACH SECTION OF SPRAYFIELD

Month	Year	Set #2	Set #3	Set #4	Set #5	Set #6	Set #7	Total # of hrs.
December	1975	8	8			52	52	120
January	1976					90	81	171
February	1976					78	98	176
March	1976					112.5	126	238.5
April	1976					147.5	116.5	264
May	1976					83	229.5	312.5
June	1976	33	33			319.5	306.5	692
July	1976	80	94.5	105.5	98	42	40	460
August	1976	91	91	115	49	93	76	515
September	1976	78	86	74	66	54	16	374
October	1976	59	44	45	60	58	70	336
November	1976	44	34	50	45	45	46	264
December	1976	52	51	56	54	62	44	319
January	1977	56	56	60	54	56	52	334
February	1977	34	47	58	49	50	43	281
March	1977	47	47	52	49	50	57	302
April	1977	67	63	75	50	46	45	346
May	1977	66	72	61	62	54	61	376
June	1977	30	54	64	64	41	60	313
July	1977			Operator sick, no data				
August	1977	72	96	42	83	51	56	400
September	1977	30	55	32	46	58	50	271

Note: The average output per hour of operating time was 170 cubic meters.

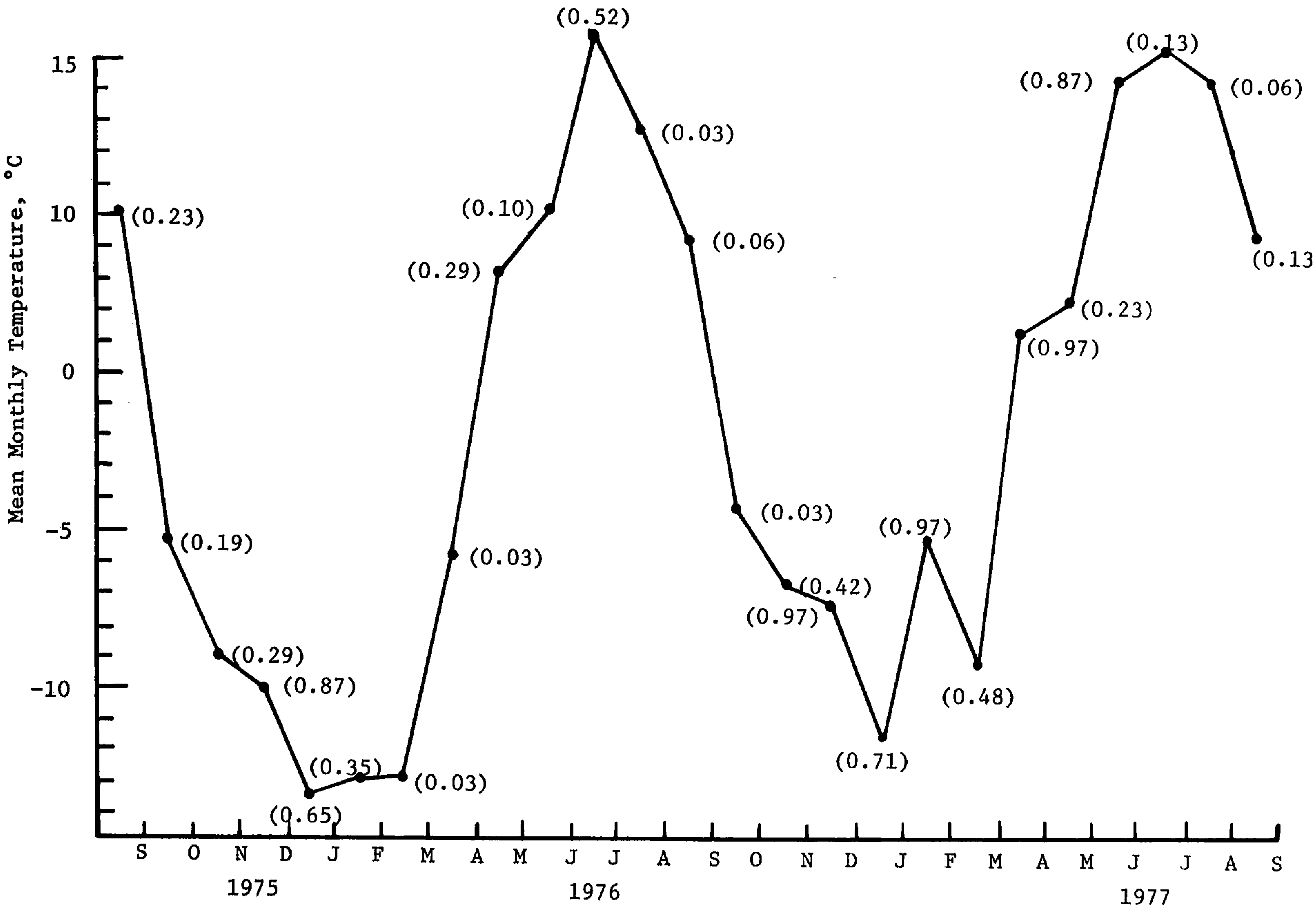

Figure 19. Mean Monthly Temperatures for Thayne, Wyoming. () Empirical probabilities of observing mean monthly temperatures less than or equal to the specified values.

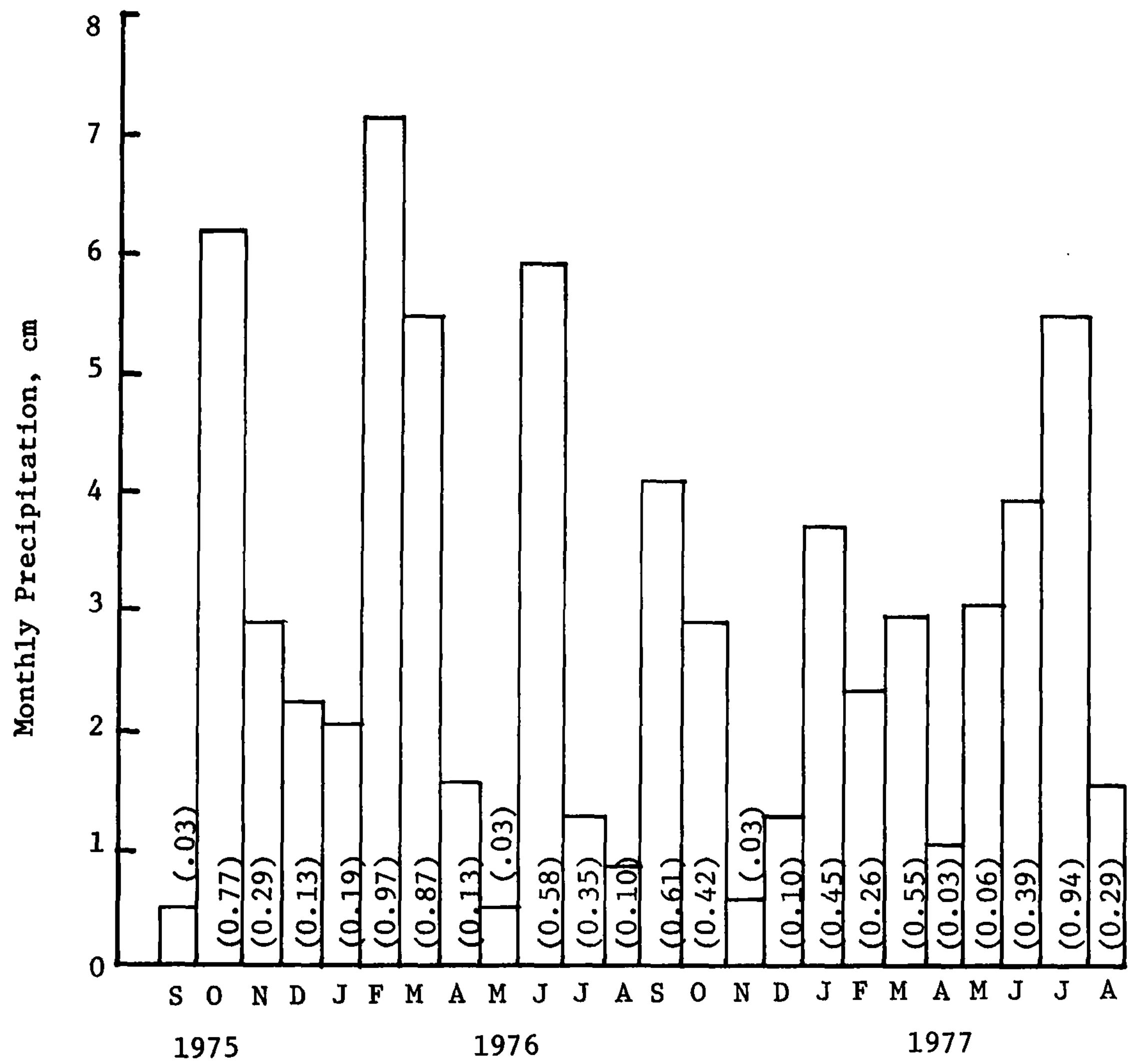

Figure 20. Monthly precipitation for Thayne, Wyoming. ( ) Empirical probabilities of observing monthly rainfall less than or equal to the specified values.

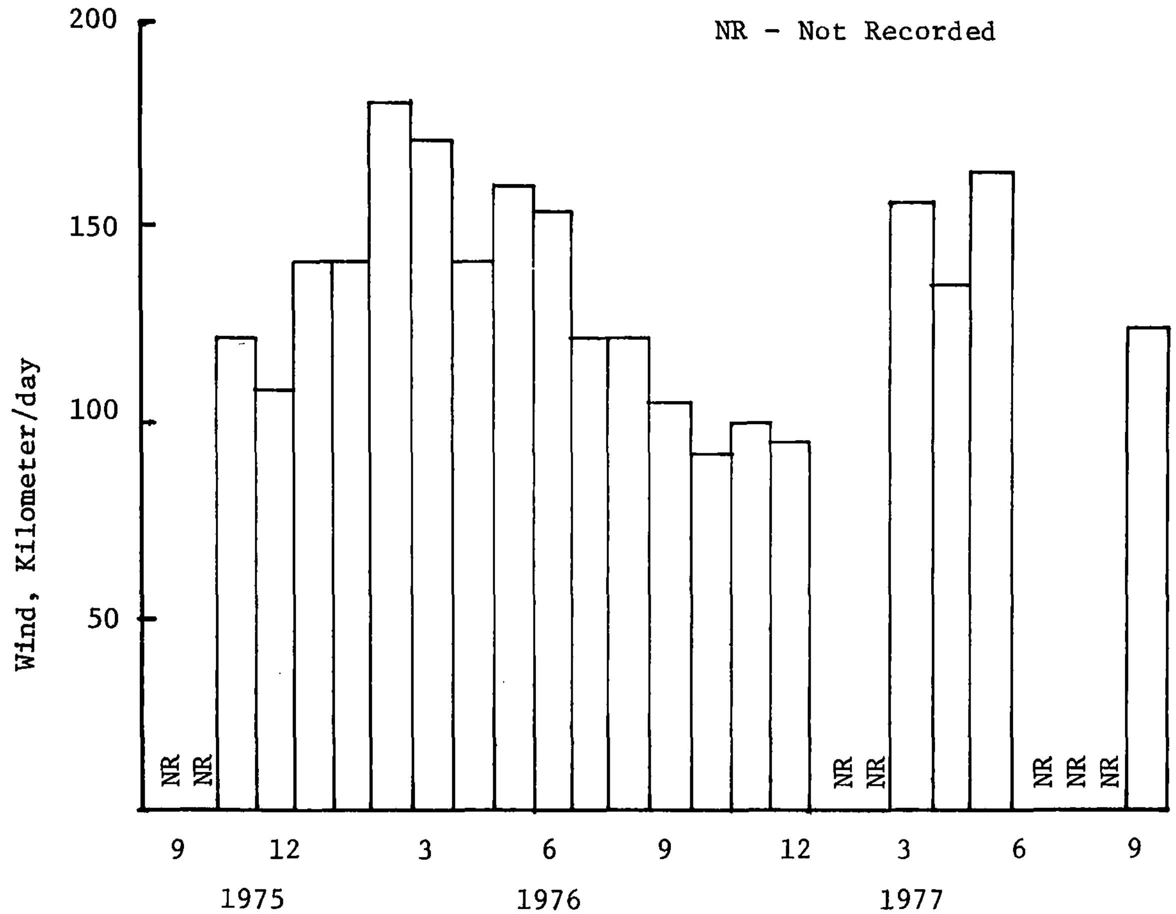

Figure 21. Mean wind speed for Thayne, Wyoming.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-78-139	2.	3. RECIPIENT'S ACCESSION NO.
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7. AUTHOR(S) John Borrelli, Robert D. Burman, Ronald H. Delaney, Joseph L. Moyer, Hugh W. Hough, Barron L. Weand		8. PERFORMING ORGANIZATION REPORT NO.
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16. ABSTRACT

The objectives of this study were to monitor and evaluate the nutrient, crop, and hydrologic parameters affecting the Thayne, Wyoming, wastewater treatment system. Cheeseplant wastewater and municipal sewage were mixed, pretreated, and applied to a 15 hectare sprayfield on a year-round basis. An ice pack formed during November or December, depending on weather conditions, and lasted through the middle of April. Samples of groundwater and water from adjacent springs have shown that after three consecutive years (1975-77) of spraying wastewater on the field and with a build-up of the ice pack each winter, no significant amounts of pollutants have reached the groundwater. Organic nitrogen was oxidized as it traveled through the ice pack and upper part of the soil mantle during the winter. Reduction of BOD_5, COD, and nitrogen forms to migrate in the ice pack was observed, clearly showing the concentration of these parameters at the surface and bottom of the ice pack. Garrison creeping foxtail appeared to be most adapted to the sprayfield of those species tested. Reed canarygrass, smooth bromegrass, and western wheatgrass were also able to survive the harsh environment of the sprayfield. The forages studied could, at specific stages of growth, contain sufficient NO_3-N to be toxic to livestock.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Land use/ Sewage treatment/water reclamation Environmental engineering/waste disposal/ Water quality/ Soil water/ Ground water/	Land treatment/ sewage effluents Land pollution abatement Land management/ environmental management High altitude spray irrigation	68D 68C 48G 48B 48E

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