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Meeting Wastewater Discharge Standards by Use of High-Rate Infiltration-Percolation Basins

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MEETING WASTEWATER DISCHARGE STANDARDS BY USE OF HIGH-RATE INFILTRATION-PERCOLATION BASINS

BY

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HIGH-RATE INFILTRATION-PERCOLATION BASINS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Major Adviser   Date

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INTRODUCTION

Protection and management of the nation's natural resources, although not a recent concept, has become a priority policy in the United States. The importance of water as a natural resource can be demonstrated by examining statistics on water use in this country. The Water Resource Council estimates that in 1975 the United States used 370 billion gallons per day. The projected water use in 1985 of 350 billion gallons per day reflects the increasing use of recycled, treated effluents and cooling waters by industrial water users and steam electric utilities (1).

Two fundamental problems have been associated with the use of large quantities of water -- depletion and deterioration in quality. Present advanced wastewater treatment technology has shown that tertiary treatment of wastewater can produce high quality effluents, but large amounts of energy and chemicals must be sacrified. An alternative to these costly systems is the land treatment system, which utilizes the soil mantle as a multiprocess "living filter" (2). Infiltration-percolation, a land treatment method, can be used for the reclamation of large quantities of wastewater. The infiltration-percolation advanced treatment system has been investigated extensively by the Civil Engineering Department at South Dakota State University.

South Dakota's predominantly rural environment makes land treatment a conducive method of advanced wastewater treatment. Initial investigations that considered the soil matrix as a treatment system began with research conducted by Druyvestein (3). Examination of water leaking through the bottom of the Volga, Milbank and Beresford, South Dakota stabilization ponds resulted in the conclusion that good quality water could be obtained by passing stabilization pond effluent through the soil. Further studies using soil lysimeters to treat stabilization pond effluent were performed at Brookings and Madison, South Dakota. The soil lysimeters produced a good quality effluent, but infiltration rates were too low to make the system practical (4,5).

After these initial investigations, it became apparent that if small communities were to use land treatment of wastewater to meet the stringent effluent standards imposed by PL 92-500 (6), a pilot plant study of an infiltration-percolation system would be required to demonstrate the process. Aided by the City of Brookings and the South Dakota Water Resources Institute, the Civil Engineering Department at South Dakota State University began construction of an infiltration-percolation pilot unit in 1974. The location of the pilot basins with respect to the Brookings sewage treatment plant and stabilization pond is shown in Figure 1. Full-scale operation of the pilot unit

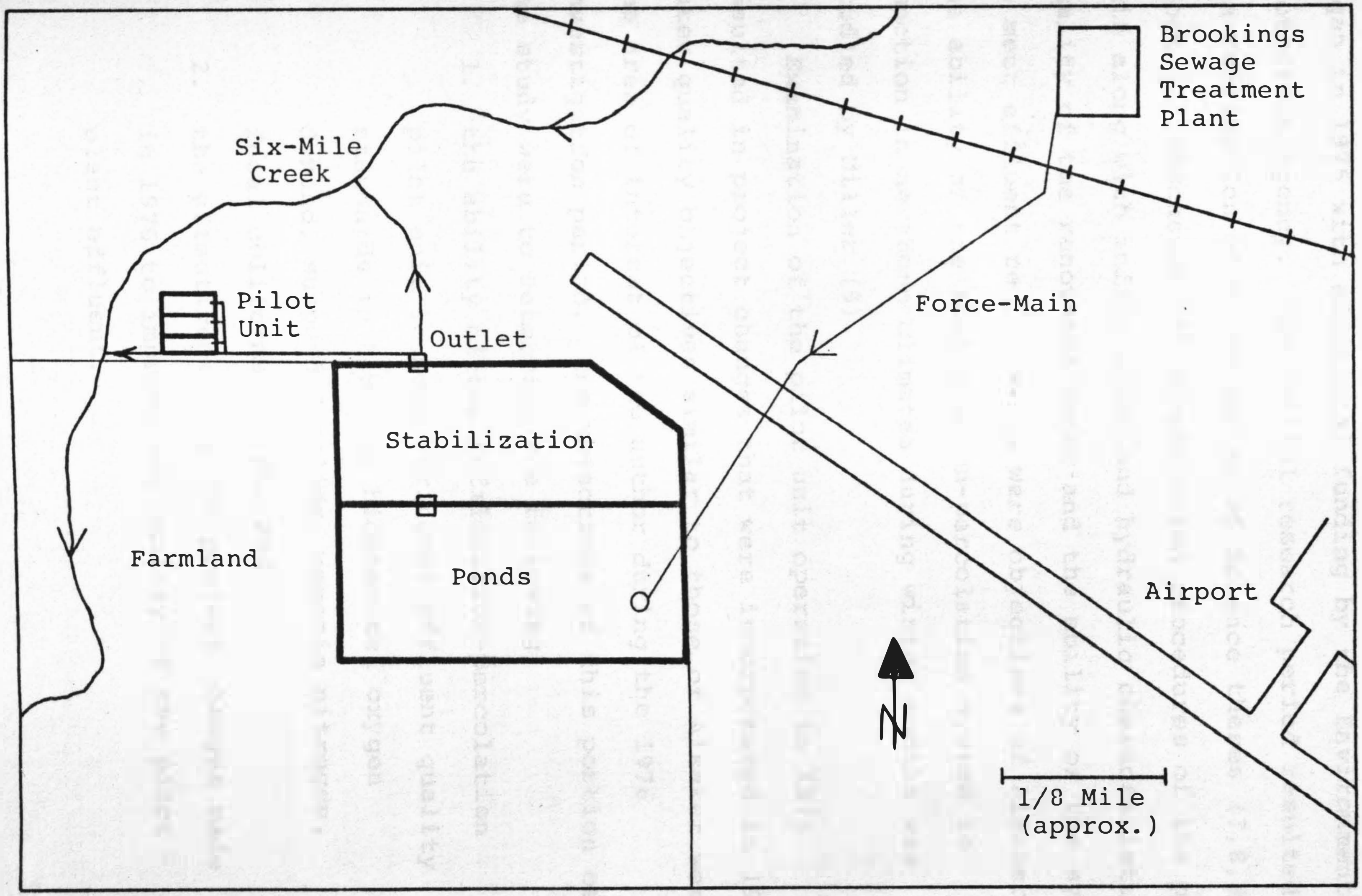


Figure 1. Overview of area showing sewage treatment plant, stabilization ponds, pilot unit, and Six-Mile Creek (9).

began in 1975 with additional funding by the Environmental Protection Agency. The initial research period resulted in the publication of three Master of Science theses (7,8,9). Voogt (7) discussed the construction procedures of the pilot unit along with infiltration and hydraulic characteristics. Quality of the renovated water and the ability of the system to meet effluent requirements were objectives of Alsaker (8). The ability of the infiltration-percolation system to function in northern climates during winter months was studied by Miller (9).

Examination of the pilot unit operation in 1975 resulted in project changes that were incorporated in 1976. Water quality objectives similar to those of Alsaker were the area of interest of the author during the 1976 investigation period. The objectives of this portion of the study were to determine the following:

1. the ability of the infiltration-percolation pilot unit to meet stringent effluent quality standards in terms of biochemical oxygen demand, suspended solids, ammonia nitrogen, fecal coliforms and pH, and
2. the effectiveness of the project changes made in 1976 to improve the quality of the pilot plant effluent.

LITERATURE REVIEW

The infiltration-percolation method of land treatment involves the controlled spreading of wastewater onto the land at a rate measure in feet per week. The applied wastewater infiltrates the soil surface and percolates through the soil pores (2,10). The objective of an infiltration-percolation system can usually be cited as one of the following: (a) groundwater recharge, (b) natural treatment followed by pumped withdrawal or underdrains for recovery or, (c) natural treatment with renovated water moving vertically and laterally in the soil and recharging a surface water-course (11).

The treatment-unit, soil, is a mixture of mineral particles, organic material, air and water. The pore space occupied by air or water may be as much as 50 percent of the total volume, and the pathway of movement through these pores is a maze of varying sized channels (12). As the wastewater infiltrates the soil surface and percolates through the soil pores, various physical, chemical and biological mechanisms inherent in the system remove the pollutants.

Soil Treatment

The land treatment approach to wastewater treatment regards nature as a complex of systems which must be taken into account if the wastewater treatment is to be a success. In this view, the land is not merely a dumping site, it is a matrix of several different processes which, if approached properly, may provide an ultimate purification system for wastewater (13).

Biochemical Oxygen Demand. The presence of oxygen-demanding organic matter in wastewater is indicated by the biochemical oxygen demand (BOD). BOD is removed from wastewater by a combination of physical and biological processes occurring in the soil. The soil acts as an effective filter in removing particulate matter, where the major removal occurs in the upper 5 to 6 inches. Physical removal can also occur by adsorption of the dissolved organic compounds. The BOD physically removed is readily converted by soil organisms to carbon dioxide, water, and other inorganic substances under aerobic conditions (14,15).

To maintain these aerobic conditions in an infiltration-percolation system, a rest period of at least 50 percent of the total time should be allowed for year-round operations with a minimum of several days between applications (16). After infiltration has ceased, the potential for reaeration of the active biological zone at the soil surface is influenced by the unsaturated depth. A minimum critical depth of unsaturated zone exists somewhere between 2 and 4 feet (16,17).

The BOD removal efficiency of the soil can be affected by the amount of vegetative cover and the infiltrative capacity. Anything that adds surface area at the soil-air interface will increase biological decomposition capacity whether it be litter or living plants. At very high rates of wastewater infiltration, residence time of the dissolved or particulate BOD may not be great enough for complete biological decomposition to occur and a sizable fraction of undecomposed BOD may reach the groundwater (14).

Suspended Solids. The major mechanism for the removal of suspended solids (SS) is filtration at the soil surface. High concentrations of some solids may coat the soil surface to the extent that infiltration rates are reduced. Providing a rest period between applications allows organic material to dry and oxidize, thus restoring infiltration rates. If mineral suspended solids are applied, periodic tilling of the soil may be necessary (16).

Algae growth in stabilization ponds can contribute significantly to the SS concentration of the pond effluent. The use of holding ponds prior to infiltration at Hemet, California resulted in a tenfold increase in SS concentration due to heavy algae growth (10). *Chlorella*, an algae species with a 3 to 5 micron diameter, can be difficult to remove in filtration systems because of its small size. Experimental results involving the use of stabilization pond effluent for groundwater recharge at Tel Aviv, Israel show the presence of algae in the water after moving 8 meters through dune sand. Further testing at the 25-meter level revealed the absence of algae cells. The major removal mechanism in the soil for small algae cells is adsorption onto charged soil particles (18,19).

Ammonia Nitrogen. Natural chemical and biological reactions in soils can be used to remove nitrogen from wastewater. Reactions can be divided into two groups: (a) removal of nitrogen from the soil system and (b) storage of nitrogen in the soil. Nitrogen may be immobilized in the soil by adsorption of the ammonium ion (NH_4^+) on the soil cation exchange sites, fixation by clay minerals, adsorption by organic matter and incorporation into microbial tissue. Nitrification occurs in the soil by the biological oxidation of ammonium, first to the nitrite, then to the nitrate form. Nitrogen can be transferred from the soil to the atmosphere in the gaseous form by denitrification, volatilization of ammonia, and chemodenitrification. Nitrogen incorporated into vegetation is removed when the crop is harvested. Denitrification is the only reaction capable of removing most of the nitrogen applied at rates characteristic of the infiltration-percolation system (2,20).

Fecal Coliforms. The greatest removal of bacteria occurs at the top surface mat (2 to 6 millimeters). Removal is largely accomplished by mechanical straining at the soil surface and sedimentation of bacterial clusters. Adsorption can also be a factor in the removal of bacteria by soil (21). Although most organisms are removed in the shallow film of soil at the surface, several feet of soil appear necessary for near complete removal of bacteria (14,22).

Total Dissolved Solids. The fate of total dissolved solids applied to the land is usually the surface water through underdrainage or the groundwater through percolating soil water. The soil has little capacity to retain most soluble salts commonly found in treated wastewater. Evaporation from basin surfaces or evapotranspiration due to heavy plant growth on basins could cause an increase in total dissolved solids of the renovated water (22,23). A drop in solution pH, due to carbon dioxide production by soil organisms, can result in the dissolution of minerals and subsequently increase the total dissolved solids (24).

Treatment Efficiency

Pound and Crites (25) reviewed selected infiltration-percolation installations, and their summary on treatment efficiencies appears in Table 1. Consistently good removals of BOD and SS are evident among the selected sites. In the two instances where SS removals appear, corresponding BOD removals are slightly less than the SS removals. Total nitrogen removal varies from 0 percent at Whittier Narrows to 80 percent at Flushing Meadows. The high removal of nitrogen at Flushing Meadows is mainly the result of biological denitrification. At Whittier Narrows, however, short frequent loading lead to excellent nitrification but essentially no denitrification, and therefore, no nitrogen removal. Generally, enteric coliforms are almost completely removed in the soil.

TABLE 1
REMOVAL EFFICIENCY AT SELECTED INFILTRATION-PERCOLATION SITES (25)

Location	Depth Sampled (ft)	Removal Efficiency (%)			
		BOD	SS	N	E.Coli
Flushing Meadows, Arizona	30	98	100	30-80	100
Hyperion, California	7	90	--	--	98
Lake George, New York	10	96	100	43-51	99.3
Santee, California	200[a]	88	--	50	99
Westby, Wisconsin	3	88	--	70	--
Whittier Narrows, California	8	--	--	0[b]	0[c]

[a]Lateral flow.
[b]Short frequent loading promotes nitrification but not denitrification.
[c]Coliforms regrow in the soil.

PROJECT DESCRIPTION

The wastewater treatment scheme for the City of Brookings consists of grit removal, primary clarification, high-rate trickling filtration and additional stabilization through a two-cell polishing pond. The discharge from the stabilization ponds serves as the influent for the infiltration-percolation pilot unit shown in Figure 2. Diverted stabilization pond effluent flowed by gravity through 8-inch irrigation pipe to the research site, where a valving system allowed flow to the distribution system or to Six Mile Creek. Individual flooding of each basin was accomplished by a 6-inch irrigation distribution pipe complete with values and flow meter. The individual basins were surrounded by 3-foot-high earth dikes sealed with plastic to prevent leaking and to define the basin area. During initial construction of the pilot unit the south and north basins were scarified, while the middle basin was left with the original brome-alfalfa cover. The alfalfa in the middle basin died during the winter following the 1975 investigation period.

A collection system composed of 4-inch perforated plastic drain is buried approximately 30 inches below the ground surface in the middle of each basin. A perimeter drain also follows the east and south sides of the pilot

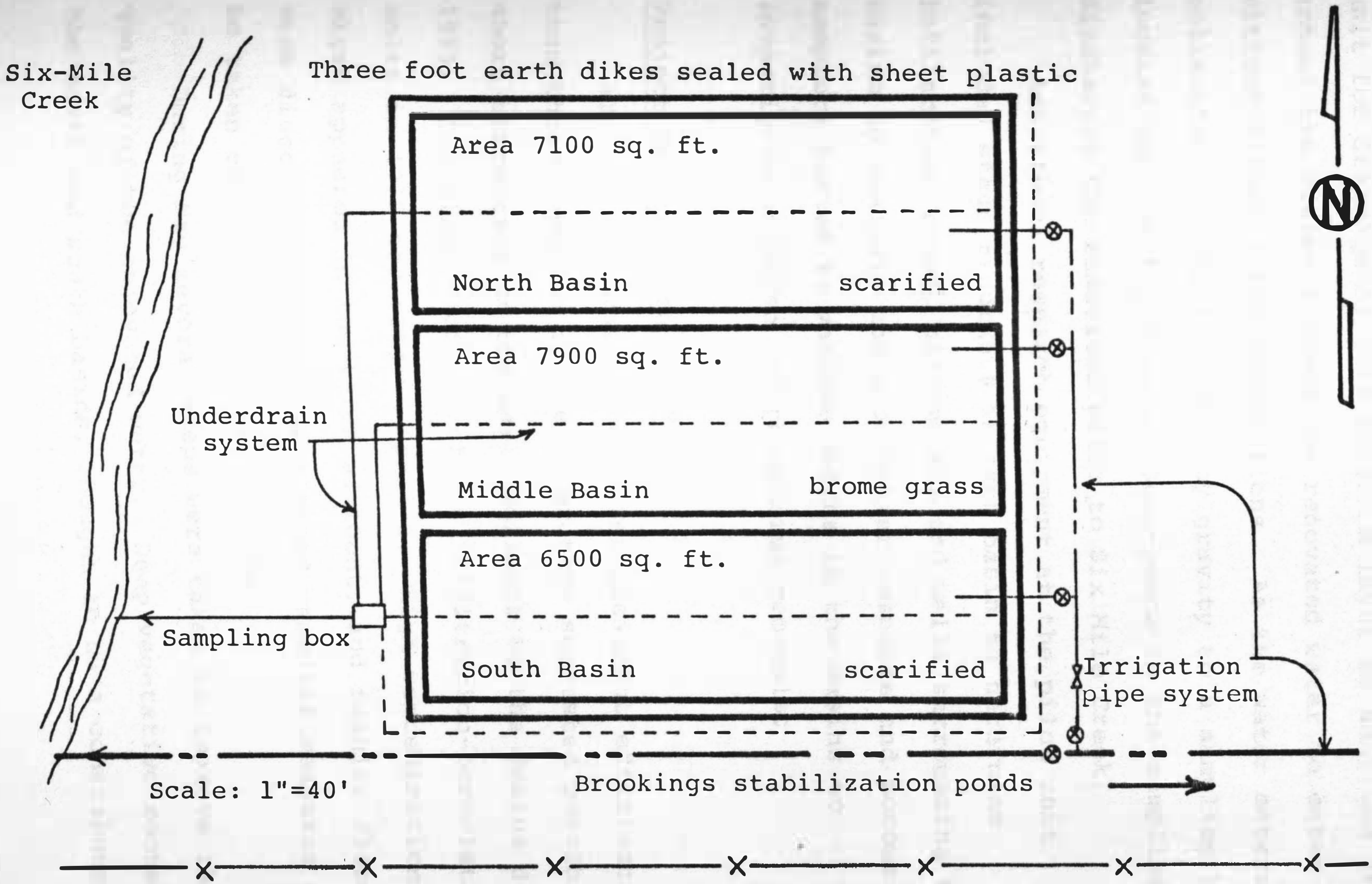


Figure 2. Diagram of pilot infiltration-percolation basins (9).

unit for drainage of this area. A layer of sand and gravel around the drains allowed the renovated water to enter without plugging the perforations. As the water entered the collection system, it flowed by gravity to a sampling box located outside the basins. Sump-pumps in the sampling box discharged the renovated water to Six Mile Creek.

Additional research equipment at the pilot unit included stage recorders in each basin to determine infiltration rates, piezometers and wells surrounding the basins to evaluate the groundwater response and porous cup samplers buried at various depths in the basins to investigate nitrogen and phosphorus removals.

Project Construction in 1976

Alsaker (8) stated that lower treatment efficiencies than those reported in the literature suggested possible short circuiting of the basin influent to the drains during 1975. The first flooding of the infiltration-percolation units in 1976 occurred on April 6. High concentrations of algae appeared in the basin effluent, and regular floodings were discontinued until the planned remedial measures could be taken to end the short circuiting.

During May several steps were taken to improve the quality of the renovated water. Deep vegetative roots in the north and south basins, thought to be a contributory factor to short circuiting, were removed from the basin surfaces. A frost ripper, chisel and roto-tiller used in the north and south basins disturbed the soil to an approximate combined depth of 18 inches. These measures assured a well mixed upper strata and basin surfaces free from plant growth.

To further prevent short circuiting directly over the drains, a large tractor-mounted compactor tamped the soil over the approximated location of the drain lines, leaving a depression 4 to 6 inches deep. Widths of 3 feet over the north and south drains and 1 foot over the middle drain were compacted. A clay-fill material placed in the compaction depressions resulted in a semi-impervious layer over the drains. Compaction of the clay layer with a mechanical hand tamper finalized the preparatory work on the basin surfaces.

Deteriorating effluent quality during the latter part of 1975 was thought to be related to the installation of sump-pumps in the sample box (8). After the installation of the sump-pumps and the subsequent free flow from the drains, the percolation rate into the drains may have increased, causing the formation of low channels. This increased flow rate meant less detention time in the soil, and consequently, less treatment of the percolating water. To counter this trend, elbows were placed on the drains in the sample box. The resulting submergence approximated the condition of the drains prior to the addition of sump-pumps. After twelve flooding periods, the elbows were removed before the August 17 flooding so that any changes in effluent quality could be noted.

Pilot Unit Operation and Monitoring

The first regular flooding of the infiltration-percolation basins occurred on May 26. A regular schedule of 1 day flooding followed by 6 days rest continued through November.

Table 2 displays the loading rates applied to the individual basins during this investigation period. The flooding sequence consisted of flooding the south basin with 24 inches followed by the middle basin with 24 inches and the north basin with 18 inches. The selection of these loading rates and cover types permitted inquiry into the effect of hydraulic loading and basin cover on effluent quality.

Three to five grab samples of the basin influent (stabilization pond effluent) and north, middle, south and perimeter drain effluents were taken during the flooding and drainage periods. Collection of three influent samples proceeded during flooding, while sampling of the renovated water continued during the time the drains flowed (approximately 24 hours).

TABLE 2
LOADING RATES, COVER TYPE, AND FLOODING VOLUMES
INFILTRATION-PERCOLATION PILOT UNITS 1976

Basin	Cover Type	Loading Rate* (inches/week)	Gallons Applied*
North	Scarified	18	79,740
Middle	Brome Grass	24	118,700
South	Scarified	24	96,900

*The loading volumes were monitored using a Badger magnetic flow meter

Collection of water samples for fecal coliform analysis followed a similar pattern with the exception of the influent sample. One day of storage of the influent samples collected during the day of flooding resulted in low bacterial counts. The storage period before analysis allowed high concentrations of protozoa in the samples to feed on bacteria; consequently, fecal coliform samples of the influent were taken the day after flooding.

Continued weekly flooding of the basins with the nutrient-rich influent created a lush plant growth on all basins. The presence of plant growth on the basins during winter operations could be a hindrance to the formation of floating ice covers thought necessary for cold-weather flooding (9). During the week prior to the September 15 flooding, the basins were mowed and the growth was partially removed.

To allow the formation of a floating ice cover on the basins, it was thought that a longer flooding period would be required. Consequently, beginning on November 21 a 2-day flooding period with application every 2 weeks began. The increased gallons applied to the basins eventually resulted in an ice cover formation, but the longer drying period between floodings caused the soil to freeze and infiltration rates decreased to negligible amounts. The only data obtained from the new flooding schedule were on November 21-22.

WATER QUALITY STANDARDS

With the enactment of PL 92-500 municipalities have been issued permits for the discharge of treated effluents into navigable waters. These discharge permits require a certain quality effluent described by various physical, chemical and biological parameters. The importance of the water quality parameters involved in this investigation and their method of analysis in the laboratory are discussed in the following sections.

Biochemical Oxygen Demand

Sawyer and McCarty (26) define biochemical oxygen demand (BOD) as "the amount of oxygen required by bacteria while stabilizing decomposible organic matter under aerobic conditions". The most widely used method for estimating the organic pollution load of wastewater is the 5-day BOD test. Efficient biological degradation of organic materials requires dissolved oxygen, and an overload of wastewater in receiving waters can result in oxygen depletion and secondary effects such as objectionable odors, plant and animal deaths, and generally decreased rates of biological degradation (27).

A method of BOD analysis similar to the method described in _Standard Methods for the Examination of Water and_

Wastewater (28) was used in the laboratory. The procedure consisted of making serial dilutions of the sample and using the standard 5-day incubation period and 20°C incubation temperature.

Suspended Solids

The suspended solids (SS) of a water sample is that material retained on a standard glass-fiber filter after drying at 103-105°C (26). The composition and concentration of SS in surface water are important because of their effects on light penetration, temperature, solubility products and aquatic life. The mechanical or abrasive action of particulate material is of importance to the higher aquatic organisms, such as mussels and fish. Blanketing of plants and sessile animals with sediment as well as the blanketing of important habitats, such as spawning sites, can cause drastic change in aquatic ecosystems. If sedimentation, even of inert particles, covers substantial amounts of organic material, anaerobic conditions can occur and produce noxious gases and other objectionable characteristics, such as low dissolved oxygen and decreases in pH (27).

The method of SS analysis described in Standard Methods was used in the laboratory. The prepared glass-fiber filters were weighed on a Mettler balance prior to filtering and after drying to constant temperature.

Ammonia Nitrogen

Nitrogen, in various forms, can deplete dissolved oxygen levels in receiving waters, stimulate aquatic growth, exhibit toxicity towards aquatic life, affect chlorine disinfection efficiency, present a public health hazard and affect the suitability of wastewater for reuse (29).

When ammonia is present in water, un-ionized ammonia (NH_3) exists in equilibrium with the ammonium ion (NH_4^+) and the hydroxide ion (OH^-). The principal toxicity problem is from the un-ionized ammonia form. It appears that fish are the critical organisms when establishing in-stream limitations. A slight increase in pH may cause a great increase in toxicity as the NH_4^+ is transformed to NH_3. Factors which may increase ammonia toxicity at a given pH include: (a) lower concentrations of dissolved oxygen and carbon dioxide, (b) elevated temperature and (c) bicarbonate alkalinity (29). Willingham (30) related the pH and temperature of the water to the fraction of NH_3 present. Research conducted on fish toxicity showed that the highest concentration of un-ionized ammonia which apparently will not cause any adverse effects is 0.02 mg/l (30).

Dickinson (31) performed the laboratory analysis of ammonia nitrogen using a Technicon Auto Analyzer. The method of analysis for the test is described in Technicon Auto Analyzer Methodology (32).

pH

Addidtions of either acids or alkalies to water may be harmful not only for producing acid or alkaline conditions, but also by increasing the toxicity of various components in the water. A joint study conducted by the Academy of Science and the Academy of Engineering recommends that for protection of the most sensitive organisms the pH should not be less than 6.5 nor more than 8.5. There should also be no change greater than 0.5 pH units above the estimated natural seasonal maximum, nor below the estimated natural seasonal minimum (27).

Determinations of pH were made on influent and renovated water samples using a Fisher pH meter. The pH meter was standardized with 6.86 buffer at 25^{o}C before monitoring the samples.

Fecal Coliforms

Coliform bacteria have been used as indicators of sanitary quality in water since 1880 when *Eschericia coli* and similar gram negative bacteria were shown to be normal inhabitants of fecal discharges. Any occurrence of fecal coliforms in water is, therefore, prime evidence of contamination by wastes of some warm-blooded animals, and as the fecal coliform densities increase, potential health hazards become greater and the challenge to water treatment more demanding (27).

The membrane filter technique was used by Hesla (33) for the determination of fecal coliforms in the influent and renovated water samples. Serial dilutions were made of the samples, and the procedure followed Standard Methods.

Total Dissolved Solids

Total dissolved solids (TDS) is a general term used in describing the concentration of dissolved materials in water. Typical constituents of total dissolved solids in natural surface waters include carbonates, sulfates, chlorides, phosphates and nitrates. These anions occur in combination with such metallic cations as calcium, sodium, potassium, magnesium and iron to form ionizable salts (27). A major change in quantity or composition of total dissolved solids alters the structure and function of aquatic ecosystems. Such changes are difficult to predict.

The effect of salinity, or total dissolved solids, on the osmotic pressure of soil solutions is one of the most important water quality considerations (27). Crops vary considerably in their tolerance to soil salinity in the root zone, and the factors affecting the soil solution and crop tolerance are varied and complex.

Although effluent discharge standards seldom exist for total dissolved solids, it is an important parameter to monitor when considering the end-use of the renovated water.

Laboratory analysis for TDS was not performed, but specific conductance readings on the basin influent and effluent were taken. Specific conductance is frequently used in water analysis to obtain a rapid estimate of TDS (26). This method relates to the ability of salts in solution to conduct a current and results are expressed as micromhos per centimeter (µmhos/cm) at 25^{o}C (27).

Dissolved Oxygen

Any reduction of dissolved oxygen (DO) in water can reduce the efficiency of oxygen uptake by aquatic animals and hence reduce their ability to meet demands of their environment. There is evidently no concentration level or percentage of saturation to which the oxygen content of natural waters can be reduced without causing or risking some adverse effects on the reproduction, growth, and consequently, the production of fishes inhabiting those waters. The selection of the level of protection is a socioeconomic decision, not a biological one (27).

Measurement of dissolved oxygen of the renovated water occurred only once during the investigation. The azide modification of the Winkler Method described in Standard Methods was used in the laboratory.

EVALUATION OF RENOVATED WATER QUALITY

Evaluation of the data from the 1976 infiltration-percolation pilot study is approached in four different sections. Section one discusses the analytical data obtained from the study in terms of maximum, minimum, median and mean values. Treatment efficiencies with respect to BOD_5, SS, ammonia nitrogen and fecal coliform removal are also examined. Graphs that compare the flooding data to the various parameter values of the influent and effluent obtained for that date appear in the second section. In this case, trends that appear during the investigation are discussed. The ability of the renovated water to meet effluent discharge standards is covered in the third section by use of frequency distribution graphs. The last section deals with the statistical analyses conducted to interpret the results concerning basin cover type and hydraulic loading effects on water quality.

Analytical Data

The quality of the renovated water from the infiltration-percolation pilot unit appeared quite good from visual observation of samples taken during the investigation. The pilot unit effluent was continually free from odor and usually low in turbidity, except for the period when algae appeared in the renovated water. A complete set of data for each of the flooding periods appears in Appendix A, and a summary of this data is shown in Table 3.

The mean influent BOD_5 concentration of 23.9 milligrams per liter (mg/l) decreased to 4.3, 5.1 and 1.8 in the north, middle and south effluents respectively. These reductions represent treatment efficiencies ranging from 79 to 92 percent, which compares closely to those reported in the literature (10,14,25). The 1976 data also showed improved BOD_5 reductions when compared to the 63 to 77 percent treatment efficiencies of 1975. The results indicate that the best removals occurred in the south basin, while removals in the middle and north basins existed at a somewhat lower level.

The pilot basins proved very effective in the removal of SS from the pilot plant influent. The SS of the influent (stabilization pond effluent), consisting largely of algae and daphnia, had a mean concentration of 38.3 mg/l during the investigation. Since a certain amount of SS can also contribute to BOD_5, it follows that the removals of both would be similar for the pilot basins. The south basin, achieving the best SS removal, had a mean concentration of 2.3 mg/l in the effluent, which resulted in a 94 percent treatment efficiency. The north and middle basins, were

TABLE 3
ANALYTICAL DATA FOR
PILOT INFILTRATION-PERCOLATION BASINS
BROOKINGS, SOUTH DAKOTA

May 26 - November 22, 1976

Determination	Number of Floodings Evaluated	Concentration - mg/l Max.	Min.	Median	Mean	Treatment Efficiency (%)
BOD_5						
Influent	27	58.6	4.6	21.4	23.9	
N-Effluent	27	11.1	0.4	4.3	4.3	82.0
M-Effluent	27	10.2	0.6	6.2	5.1	78.7
S-Effluent	27	8.0	0.4	1.8	1.8	92.5
Perimeter Drain	3	1.7	1.0	1.8	1.2	
SS						
Influent	27	71.0	15.8	34.2	38.3	
N-Effluent	27	10.8	0	2.8	4.0	89.6
M-Effluent	27	14.0	0.4	3.8	5.8	84.9
S-Effluent	27	6.0	0	2.2	2.3	94.0
Perimeter Drain	19	7.4	0	2.2	2.4	
Ammonia Nitrogen						
Influent	26	18.76	0.85	5.50	7.30	
N-Effluent	27	3.15	0.08	1.27	1.41	80.7
M-Effluent	26	5.46	0.13	0.83	1.46	80.0
S-Effluent	27	1.84	0.22	0.58	0.65	91.4
Perimeter Drain	21	0.86	0	0.13	0.21	
pH (units)						
Influent	26	9.16	7.80	8.30	----	
N-Effluent	26	7.42	6.92	7.24	----	
M-Effluent	26	7.61	7.12	7.34	----	
S-Effluent	26	7.45	6.90	7.20	----	
Perimeter Drain	20	7.61	7.19	7.40	----	
Fecal Coliform (#/100ml)*						
Influent	15	14420	129	3020	1980	
N-Effluent	20	2383	2	246	168	91.5
M-Effluent	20	3268	4	196	215	89.1
S-Effluent	20	338	1	79	47	97.6
Perimeter Drain	14	202	1	2	4	
Specific Conductance (μmhos/cm)						
Influent	23	1994	1518	1808	1789	
N-Effluent	23	2176	1818	2062	2033	
M-Effluent	23	2236	1722	1887	1910	
S-Effluent	23	2371	1818	2211	2163	
Perimeter Drain	16	2248	1818	2102	2072	
Dissolved Oxygen						
Influent	1				2.60	
N-Effluent	1				2.20	
M-Effluent	1				7.75	
S-Effluent	1				2.55	

*Fecal coliform results are geometric mean values of three to five grab samples obtained during the flooding period.

not as proficient in removing SS, having treatment efficiencies of 90 and 85 percent respectively. Almost complete removal of SS by land treatment systems is reported (10,14,25), but method and depth of sampling can affect the results. Although some short circuiting may have occurred during the investigation, comparison with the 1975 treatment efficiencies of 78 to 87 percent indicates that the incidence of short circuiting was much less.

The mean influent ammonia nitrogen concentration of 7.30 mg/l was reduced to 1.41 mg/l by the north basin, 1.46 mg/l by the middle and 0.65 mg/l by the south. Treatment efficiencies of 80 to 91 percent demonstrate improved ammonia reductions over the 66 to 78 percent range obtained in 1975. Treatment by the north and middle basins appears to be similar, while the average effluent ammonia level of the south basin was less than half the level of the other effluents. Research conducted by Dickinson (31) on the nitrogen transformations that occur at the infiltration-percolation pilot unit reveals that a major portion of the nitrogen applied was converted to nitrates in the effluent by nitrification. Although limited removal of total nitrogen takes place, the removal mechanisms are not completely understood at the pilot unit.

Since by definition pH values are logarithmic functions, the median values for the influent and renovated water appear in Table 3. The median pH of 8.30 for the influent decreased by approximately one unit in the renovated water. Median effluent pH levels ranged from 7.20 to 7.34. A major cause for the pH drop in the soil-treated water relates to the reaction with carbon dioxide produced from the aerobic decomposition of organic matter (24). pH and temperature monitoring are important when dealing with ammonia nitrogen toxicity (30). Temperature data were not collected during this study; further research should include monitoring of this parameter.

Average fecal coliform concentrations for the investigation period are presented by geometric means due to the nature of bacteriological testing. The pilot unit influent had a geometric mean concentration of 1980 organisms per 100 milliliters (organisms/100ml). This level declined to 168 organisms/100ml in the north effluent, resulting in a 92 percent treatment efficiency; 215 organisms/100ml in the middle effluent, resulting in an 89 percent efficiency; and 47 organisms/100ml in the south effluent, resulting in a 98 percent efficiency. The effluent fecal coliform concentrations are slightly higher than those reported in the literature, but for complete removal to take place, longer travel distance and detention time in the soil may be necessary (14,22). During the 1975 investigation low removal efficiencies and several effluent concentrations larger than influent concentrations caused Alsaker (8) to question the results from that portion of the study. The most probable number (MPN) method of determining fecal coliforms was used in 1975.

Since total dissolved solids is most readily evaluated by determining the electrical conductivity of a solution (27), specific conductance measurements of the influent and renovated water were obtained during the study. The average specific conductance for the influent during the investigation of 1789 micromhos per centimeter (μmhos/cm) increased to levels of 2033, 1910 and 2163 μmhos/cm for the north, middle and south effluents respectively. These values correspond to 12.0, 6.3 and 17.3 percent increases in specific conductance by the basin effluents. Specific conductance readings for the influent and effluent during 1976 were slightly higher than those reported during 1975. Extensive plant growth on the basin surfaces during 1976 probably contributed to high evapotranspiration rates and subsequent concentrated TDS levels in the renovated water (22,23). Another possible contributing factor to increased TDS would be the pH drop in the renovated water, which could result in mineral dissolution (24).

Regular monitoring of dissolved oxygen (DO) levels of the reclaimed water was not made during the infiltration-percolation study. Testing for effluent DO concentrations occurred during the October 27 flooding. Prior to this date the elbows had been removed; consequently, the drains were flowing partially full at the time of sampling. The method of sampling involved acquiring duplicate samples from the basin drain lines, while taking care to avoid air entrainment in the dissolved oxygen bottles. The north, middle and south effluents showed DO levels of 2.20, 7.75 and 2.55 mg/l respectively. Sampling in 1975 when the drain lines were completely inundated revealed DO levels below 1 mg/l in all cases. The flow condition in the corregated drains together with the tile gradient may have contributed to air entrainment in the renovated water during the October 27 testing. Before meaningful conclusions can be made concerning DO concentrations in the renovated water, more extensive DO monitoring should be conducted. It is anticipated that the percolate would be too low in DO to meet the discharge standards the majority of the time. Knowledge concerning oxygen solubility also requires that temperature data be taken at the time of sampling.

Quality data in Table 3 demonstrate that the south basin continually achieved better removals than the north and middle basins. Removal efficiency of pollutants in the soil can be affected by infiltration capacity (14). Mean infiltration rates of the basins for 1976 were reported by Larson (34). The south basin had the lowest infiltration rate of 0.45 inches/hour followed by the north with 0.57 inches/hour and the middle with 1.34 inches/hour. Lower infiltration rates contribute to longer detention times in the soil, which allow the physical, chemical and biological treatment mechanisms to better treat the wastewater. Larson hypothesized that differences in soil type rather than hydraulic loading accounted for the differences in the infiltration rates in the north and south basins. Dissimilarity between basin soils would also contribute to differences in renovated water quality.

Water samples collected from the perimeter drain revealed an extremely good quality water. Water quality from the perimeter drain may have been influenced by groundwater dilution, but applied wastewater also had a longer detention time and travel distance before entering the drain. The excellent water quality from the perimeter drain suggests that the location of drains for renovated water collection can greatly influence the quality of the water obtained.

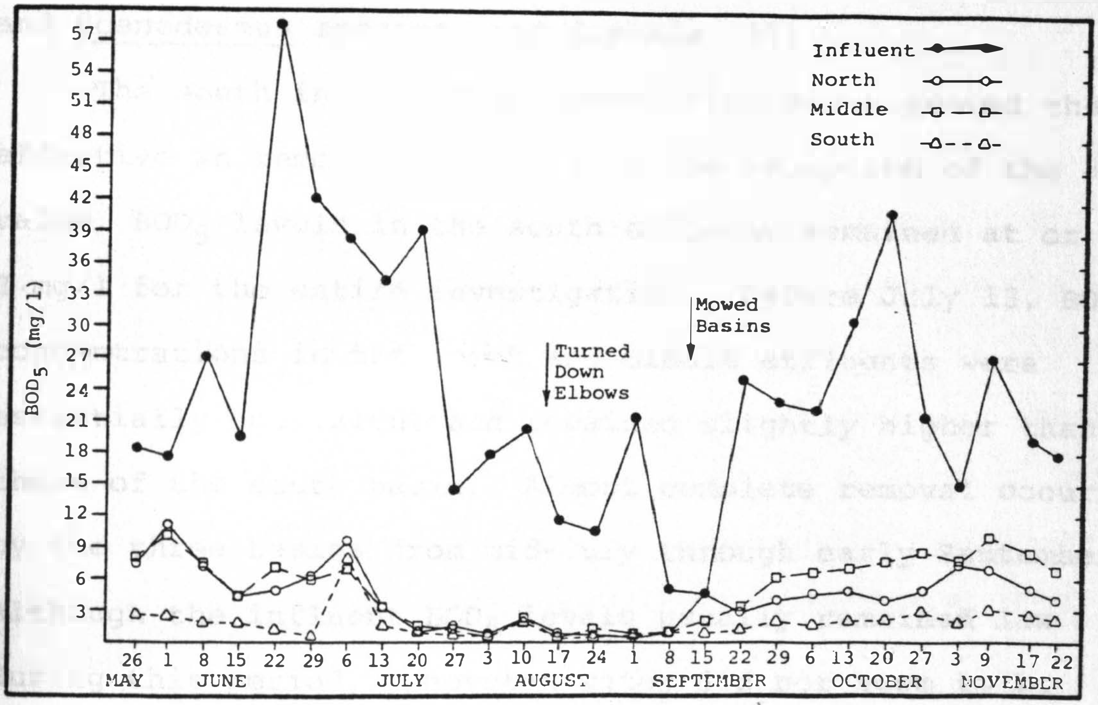
Quality Trends

The Brookings stabilization pond effluent serves as the influent for the infiltration-percolation pilot unit.

The quantity of pollutants discharged in this effluent varies throughout the year, depending on the removal efficiency of the wastewater treatment plant, seasonal temperature changes, pond detention time, pond fauna and flora and other undefined factors. This changing influent concentration resulted in a varying strength waste being applied to the basins during each flooding.

Quality parameter values of the pilot-plant influent and effluent from weekly floodings reveal various trends when plotted for the entire research period. Figures were plotted to graphically represent these influent and effluent quality trends. Trends in influent quality and an in-depth discussion on renovated water variations appears in the following six sections: (a) biochemical oxygen demand and suspended solids, (b) ammonia nitrogen and pH, (c) fecal coliforms, (d) specific conductance, (e) basin mowing effects and (f) drain elbow effects.

Biochemical Oxygen Demand and Suspended Solids. Quality trends for BOD_5 and SS appear in Figure 3. Influent BOD_5 concentrations ranged from 4.6 mg/l to 58.6 mg/l during the May 26 through November 22 research period. Higher BOD_5 levels appeared in the early summer and fall seasons. A similar range in influent SS levels during the investigation showed a spread in values from 15.8 to 71.0 mg/l, with consistently high levels appearing in October. SS in the



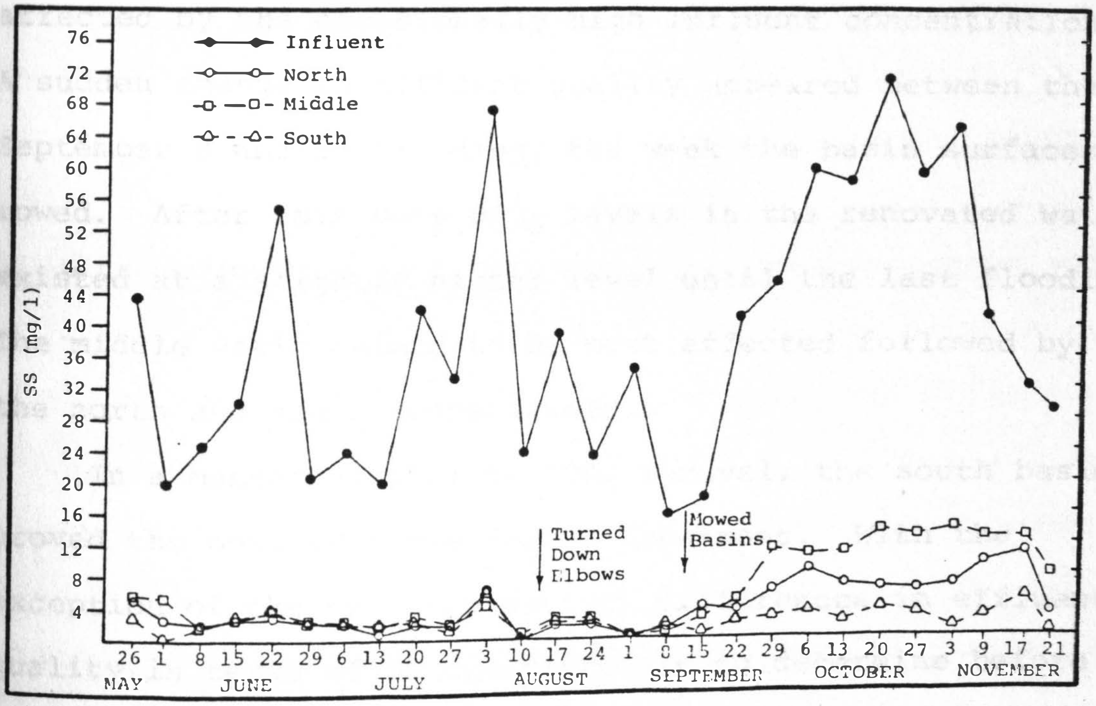


Figure 3. BOD_5 and SS Data for Infiltration-Percolation Pilot Unit Operation - 1976.

influent consisted largely of algae, including _Chlorella_ and _Scenedesmus_ species, and daphnia (31).

The south infiltration-percolation basin proved the most effective in removing BOD_5. With the exception of the July 6 value, BOD_5 levels in the south effluent remained at or below 3 mg/l for the entire investigation. Before July 13, BOD_5 concentrations in the north and middle effluents were essentially equivalent and remained slightly higher than those of the south basin. Almost complete removal occurred by the three basins from mid-July through early September. Although the influent BOD_5 levels usually remained low during this period, renovated water did not seem to be affected by the occasionally high influent concentrations. A sudden change in effluent quality appeared between the September 8 and 15 flooding, the week the basin surfaces were mowed. After this date BOD_5 levels in the renovated water existed at a slightly higher level until the last flooding. The middle basin seemed to be most affected followed by the north and south respectively.

In a manner similar to BOD_5 removal, the south basin proved the most reliable for SS treatment. With the exception of the start-up period, differences in effluent quality in terms of SS are difficult to determine before September 15 (Figure 3). After this date, definite trends in SS quality showed the best treatment achieved by the south basin followed by the north and middle respectively. During the period of higher SS in the renovated water, high SS levels also appeared in the basin influent. High concentrations of filimentous algae noted in the influent on August 3 apparently affected the renovated-water SS slightly. Correlation coefficients, which measure the strength of the linear relationship between two variables (35), were calculated for influent and effluent SS levels. Highly significant coefficients for all three basins indicate that influent SS levels affect the renovated water levels. Correlation coefficient computations can be found in the Appendix B.

Although short circuiting could have been taking place to some extent in the north and middle basins, other factors may also have contributed to the higher SS in the effluent. Observations indicated that algae present in the renovated water contributed to the SS levels. Some species of algae, such as Chlorella, may be difficult to remove because of their extremely small size. Studies conducted in Israel with the spreading of stabilization pond effluent on sand dunes showed that algae moved 8 meters through the sand, but that complete removal of algae did occur before filtration through 25 meters. Since the major removal mechanism for algae of this size is by adsorption onto charged particles, presence of algae in the renovated water may not necessarily indicate short circuiting (18,19).

Ammonia Nitrogen and pH. Figure 4 shows that higher ammonia nitrogen levels appeared in the influent prior to July 20 and after October 13. Values ranged from 0.85 mg/l on August 10 to 18.76 mg/l on November 21. Alsaker (8) reported an inverse relationship between suspended solids and ammonia nitrogen levels due to algae consuming ammonia as food, but this trend was not apparent in 1976. Influent pH levels, ranging from 7.80 to 9.16, showed two peaks during the investigation (Figure 4). One peak occurred around July 27 followed by the second around October 6. High pH levels in the stabilization pond were probably due to the algae utilizing carbon dioxide in their photosynthetic activity (26).

Ammonia nitrogen levels in the south basin effluent remained below 1 mg/l throughout the 6-month period with minor exception, thus giving the south basin the best overall ammonia nitrogen treatment of the three basins. From the period between July 6 and September 15 ammonia levels in the renovated water remained quite low, with the middle basin usually giving better treatment than the north. Apparent differences in renovated water quality from the different basins appeared in the period prior to July and after September. In the May/June period the middle basin effluent had lower ammonia levels than the north, but during the October/November period the north effluent had lower

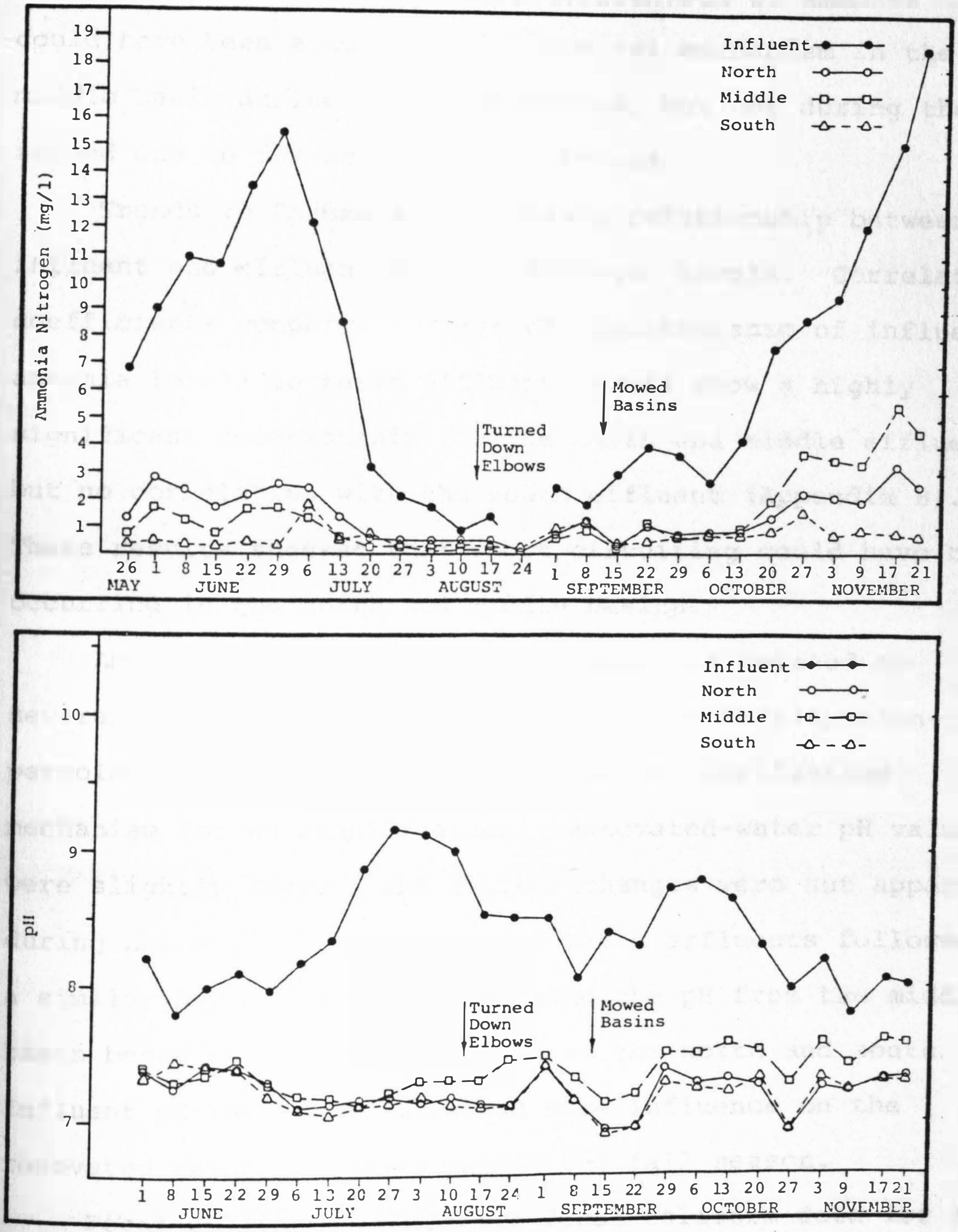


Figure 4. Ammonia Nitrogen and pH Data for Infiltration-Percolation Pilot Unit Operation - 1976.

levels than the middle. Plant utilization of ammonia could have been a contributing removal mechanism in the middle basin during the first period, but not during the second due to the mowing of the basins.

Trends in Figure 4 also show a relationship between influent and effluent ammonia nitrogen levels. Correlation coefficients computed to test the relationship of influent ammonia levels to basin effluent levels show a highly significant relationship for the north and middle effluent, but no correlation with the south effluent (Appendix B). These results suggest that short circuiting could have been occurring in the north and middle basins.

Ammonia nitrogen toxicity in water is related to several factors including pH levels. The infiltration-percolation system appears to act as an equalization mechanism for pH stabilization. Renovated-water pH values were slightly above 7 and extreme changes were not apparent during the study. The pH of the basin effluents followed a similar pattern until August when the pH from the middle basin began to deviate from that of the north and south. Influent pH levels may have had some influence on the renovated water pH levels during the fall season.

Fecal Coliforms. Reliable fecal coliform data for the influent began with the August 17 flooding. Levels prior to this date were low because the protozoa utilized the coliform bacteria as a food source during the storage of samples prior to analysis. The trend of the influent fecal coliform levels shows a gradual increase through September and October followed by a slight decrease in November (Figure 5). Geometric mean concentrations varying from 129 to 14,420 organisms/100ml were applied to the infiltration-percolation basins.

Geometric means for fecal coliform concentrations in the south effluent, although quite variable, usually remained below 100 organisms/100ml. The north and middle basins, not achieving as efficient removals as the south, appeared to be more affected by the influent concentrations. Highly significant correlation coefficients for the north and middle basins also suggested this influence.

Specific Conductance. Specific conductance values of the stabilization pond effluent (influent) during the research project varied from the low of 1518 μmhos/cm to the high of 1994 μmhos/cm (Figure 6). Specific conductance readings from July 20 through August 10 do not appear on the graph due to instrumental error in analysis.

Specific conductance readings for the basin effluents were similar during the initial period of the investigation, but a gradual spread in values developed later. The largest increase in specific conductance occurred in the south effluent followed by the north and middle effluents

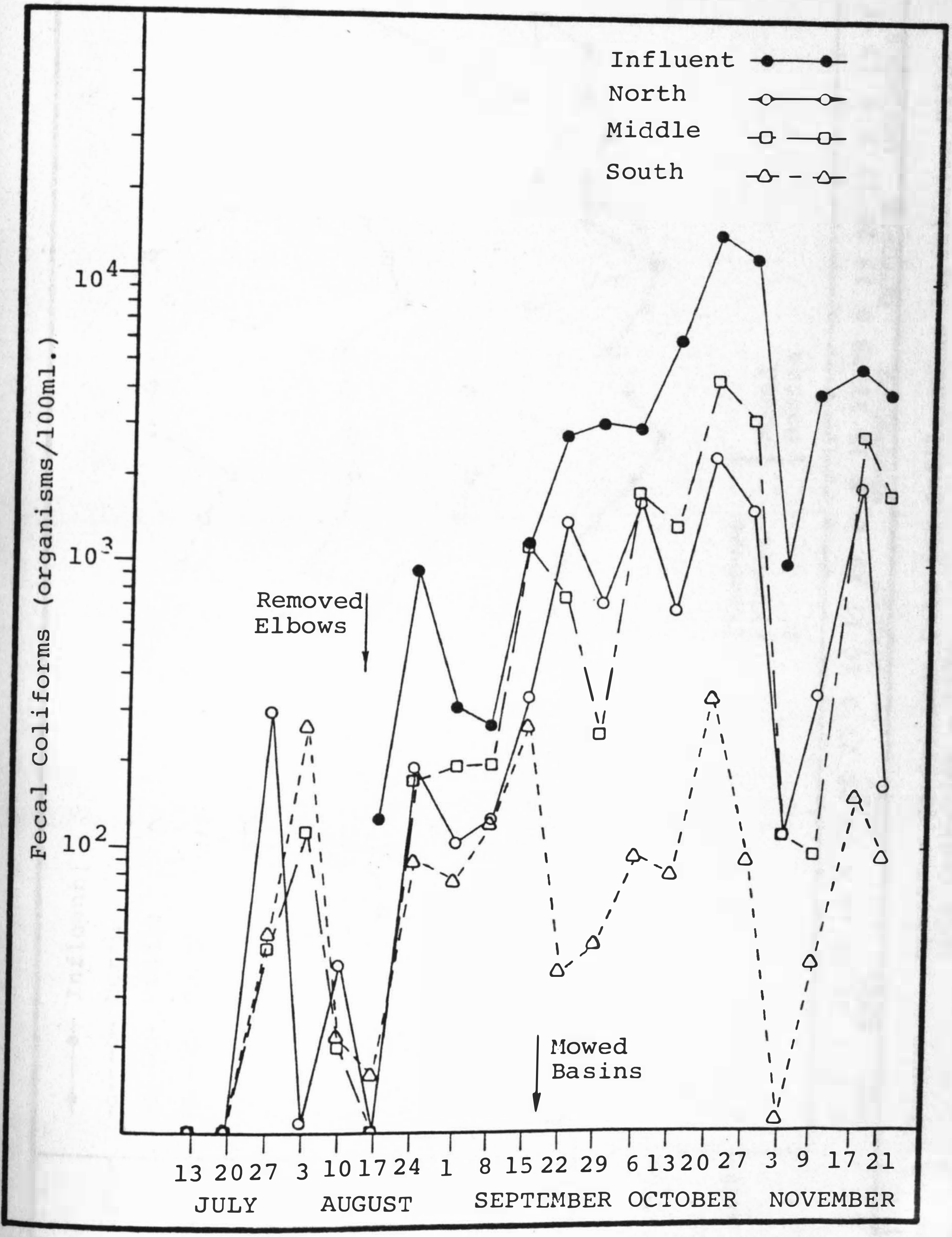


Figure 5. Fecal Coliform Data for Infiltration - Percolation Pilot Unit Operation - 1976.

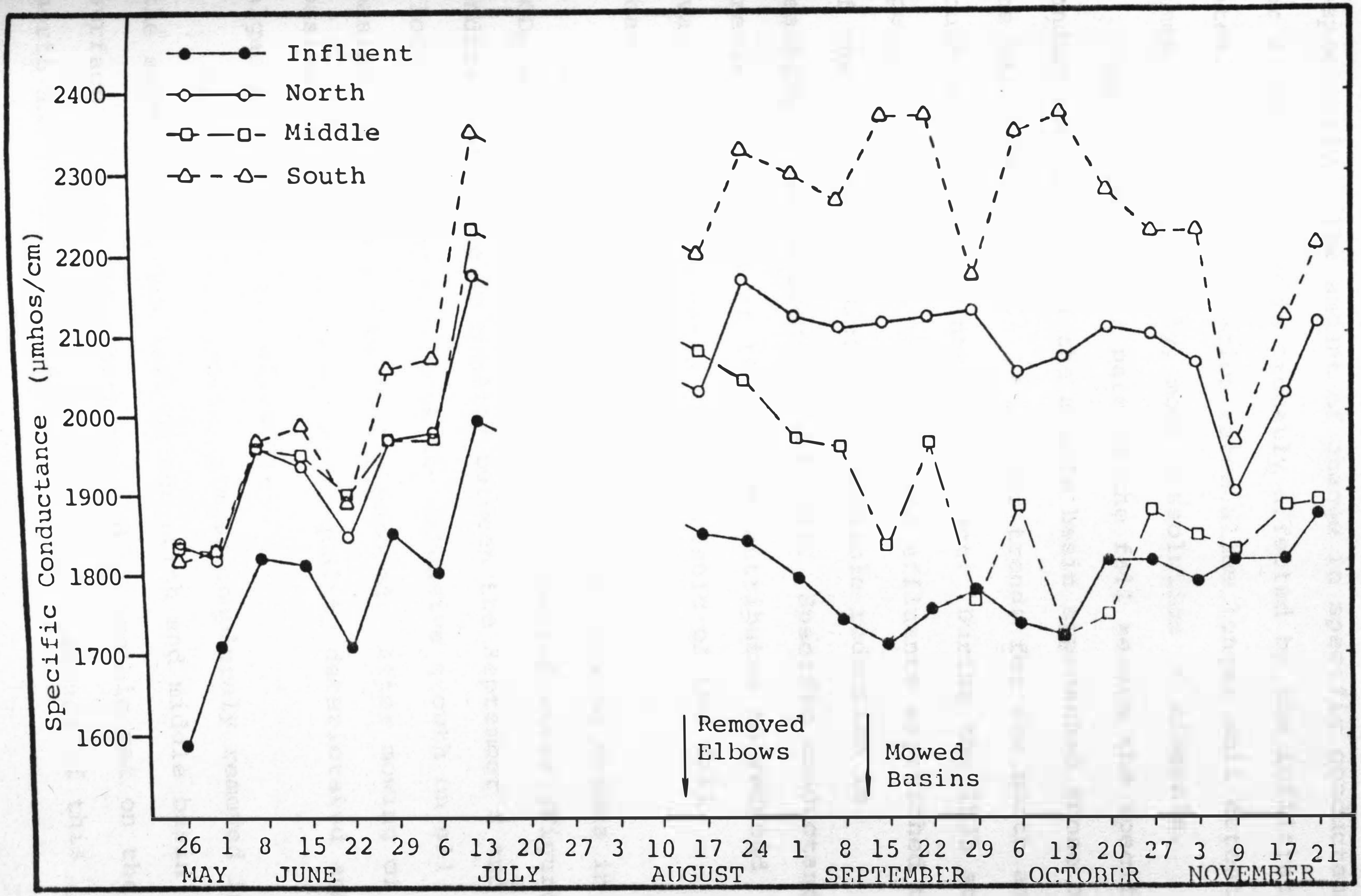


Figure 6. Specific Conductance Data for Infiltration-Percolation Pilot Unit Operation - 1976.

respectively. The amount of change in specific conductance for a certain basin is probably affected by the infiltration rates. Lower infiltration rates allow longer soil detention times, and consequently, more dissolution of minerals.

During the latter part of the fall season the specific conductance levels of the middle basin approached those of the basin influent, while similar trends for the north and south effluents were not as apparent. During the 1975 study specific conductance levels of the effluents approached those of the influent, indicating a possible reduction in leaching of salts from the soil (8). Specific conductance trends in the fall of 1976 may be attributed to reduced evapotranspiration rates characteristic of the fall season (34).

Basin Mowing Effects. The graphs showing trends in BOD_5 and SS concentrations of the renovated water (Figure 3) indicate a change in quality between the September 8 and 15 flooding. During this week the extensive growth on all basins was mowed and partially removed. After mowing of the basins occurred, renovated water quality deteriorated and algae appeared in the effluent.

The mowed basin growth, almost completely removed in the south basin, was left on the north and middle basin surfaces. This old growth created an organic mat on the north and middle basin surfaces. The presence of this organic mat could have resulted in two conditions: (a) the organic decomposition of the mat exceeded the assimilation capacity of soil microorganisms and (b) reduced aeration through the soil profile resulted in less oxidation capacity (2,14). Both of these conditions could have affected BOD_5 and SS removals in the basins. Complete removal of old plant growth after mowing, or burning of the plant growth during the late fall, could have eliminated the organic matting conditions.

Other factors could have contributed to the deteriorating BOD_5 and SS quality during this time. High levels of these pollutants in the influent during this period may have caused short circuiting. The fall season is also characteristic of lower air temperatures, which would contribute to decreased microbiological activity in the soil. Consequently, although the weekly data would suggest that mowing of the basins influenced the removal efficiencies of BOD_5 and SS, these other factors that changed about the same time prevent a definite conclusion.

Drain Elbow Effects. The placement of elbows on the drain lines in the sample box allowed the drains to be completely inundated. It was thought that the inundated drains decreased the velocity of the percolating water in the vicinity of the drains; consequently, improving effluent quality. The removal of these elbows between the

August 10 and 17 floodings did not appear to affect the renovated water quality (Figures 3, 4, 5). Although water quality changes became apparent later on, these changes could not necessarily be attributed to the elbow removal.

Comparison with Effluent Discharge Standards

The Federal Water Pollution Control Act requires that secondary treatment and/or compliance with state water quality standards shall be attained by all publicly owned treatment works by July 1, 1977 (6). In order to determine the consistency with which the effluent from the infiltration-percolation pilot basins could have met effluent discharge standards, frequency distribution graphs were compiled for BOD_5, SS, ammonia nitrogen and fecal coliforms. The frequency distribution graphs reveal the percent of time that specific values of these parameters were equalled or exceeded during the investigation. Given an effluent discharge standard, the amount of time that standard was violated by the effluent of the pilot basins could be determined.

The effluent quality standards from the proposed discharge permit for the City of Brookings appear in Table 4. These standards will be used in the following sections as an example to determine the ability of the pilot basins to meet stringent discharge requirements.

Biochemical Oxygen Demand. The frequency distribution graph for BOD_5 values obtained during the study is shown in

TABLE 4
PROPOSED WASTEWATER DISCHARGE STANDARDS
FOR SECONDARY TREATMENT[1]
BROOKINGS, SOUTH DAKOTA

Parameter	30-Consecutive Day Period	7-Consecutive Day Period
BOD_5 - mg/l	8[a]	12[b]
SS - mg/l	30[a]	45[b]
Fecal Coliform - #/100ml	1000[c]	--
Ammonia Nitrogen - mg/l		1.1[d] (Maximum)
Dissolved Oxygen - mg/l		6.4[d] (Minimum)
pH - units		Shall remain between 6.3 and 9.0[d]

[a]This limitation shall be determined by the arithmetic mean of a minimum of three (3) consecutive samples taken on separate weeks in a 30-day period.

[b]This limitation shall be determined by the arithmetic mean of a minimum of three (3) consecutive samples taken on separate days in a 7-day period.

[c]Fecal coliform values shall not exceed a geometric mean of 1000 organisms per 100 ml in any five (5) consecutive grab samples taken on separate days in a 30-day period, nor shall any grab sample exceed 2000 organisms per 100 ml.

[d]Any single analysis and/or measurement beyond this limitation shall be considered a violation of the conditions of the permit.

[1]NPDES permit # SD 0023388 for the City of Brookings, South Dakota.

Figure 7. BOD_5 concentrations are located on the left axis, while the percent of samples equalling or exceeding the stated BOD_5 concentration can be read off the bottom axis. The effluent draining from the south basin seldom exceeded a BOD_5 level of 3 mg/l. The north and middle, being similar to each other in concentrations, seldom exceeded 10 mg/l.

The ability of an effluent to meet the standards shown in Table 4 for BOD_5, SS and fecal coliforms is determined by averaging a minimum of three values over a selected time period. When using the constructed frequency graphs to determine pilot unit violations of standards, it should be remembered that the standard can be exceeded by individual samples, since the average of three consecutive values may fall below the standard. The 8 mg/l monthly BOD_5 standard, exceeded by 94 percent of the influent samples, was violated 13 percent by the north effluent, 22 percent by the middle and 2 percent by the south during the investigation. The influent was in non-compliance with the weekly 12 mg/l standard 88 percent of the time, but the renovated water continually met the weekly standard. Minor problems encountered in meeting the monthly standard occurred during the spring and fall seasons.

Suspended Solids. Figure 7 reveals that the majority of the SS values from the south basin were less than 5 mg/l, while the north values usually stayed below 10 mg/l and the

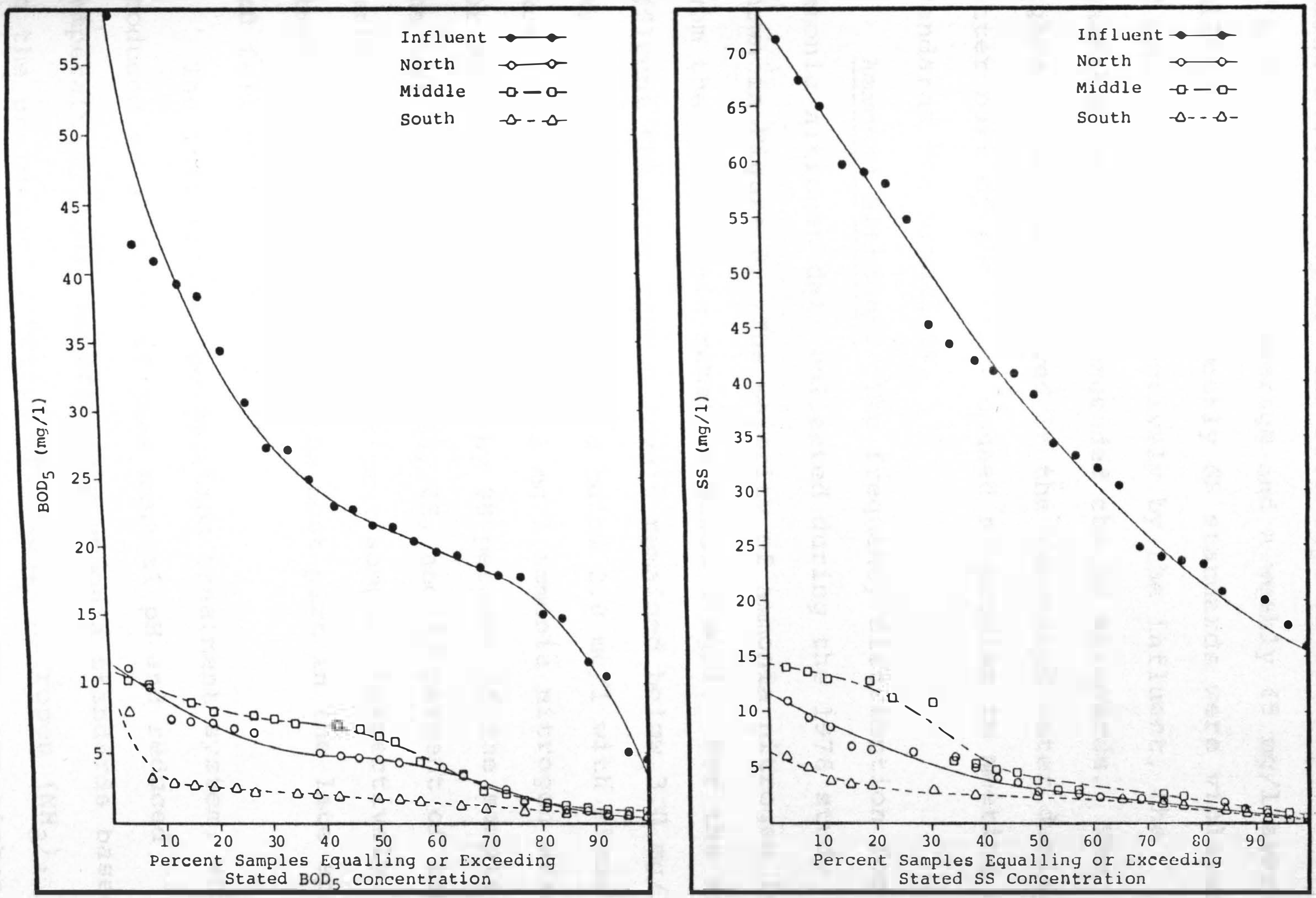


Figure 7. Frequency Distribution Graphs Indicating Percent Samples Equalling or Exceeding Stated BOD_5 and SS Concentrations.

middle below 14 mg/l. The Brookings SS standard consists of a monthly 30 mg/l average and a weekly 45 mg/l average. While the monthly and weekly SS standards were violated 62 and 38 percent respectively by the influent, the renovated water never exceeded the SS standards. The higher SS levels observed in the renovated water during the latter part of the study caused no problem in meeting SS standards for Brookings.

Ammonia Nitrogen. The frequency distribution for ammonia nitrogen data collected during the 1976 study is shown in Figure 8. The majority of ammonia nitrogen levels from the south basin remained below 1 mg/l. For the north effluent the most common levels remained below 3.0 mg/l and the middle effluent remained below 2.0 mg/l with minor exception. The proposed 1.1 mg/l ammonia nitrogen standard for Brookings was violated by 98 percent of the samples of the basin influent and by 54, 45, and 13 percent of the north, middle and south effluent samples respectively. The standard was violated for the most part in the late spring and fall seasons (Figure 4).

The infiltration-percolation treatment system, which produced an effluent of near neutral pH and reduced temperature, could benefit from ammonia standards based on the un-ionized fraction of ammonia nitrogen (NH_3). Investigations into fish toxicity show that the highest

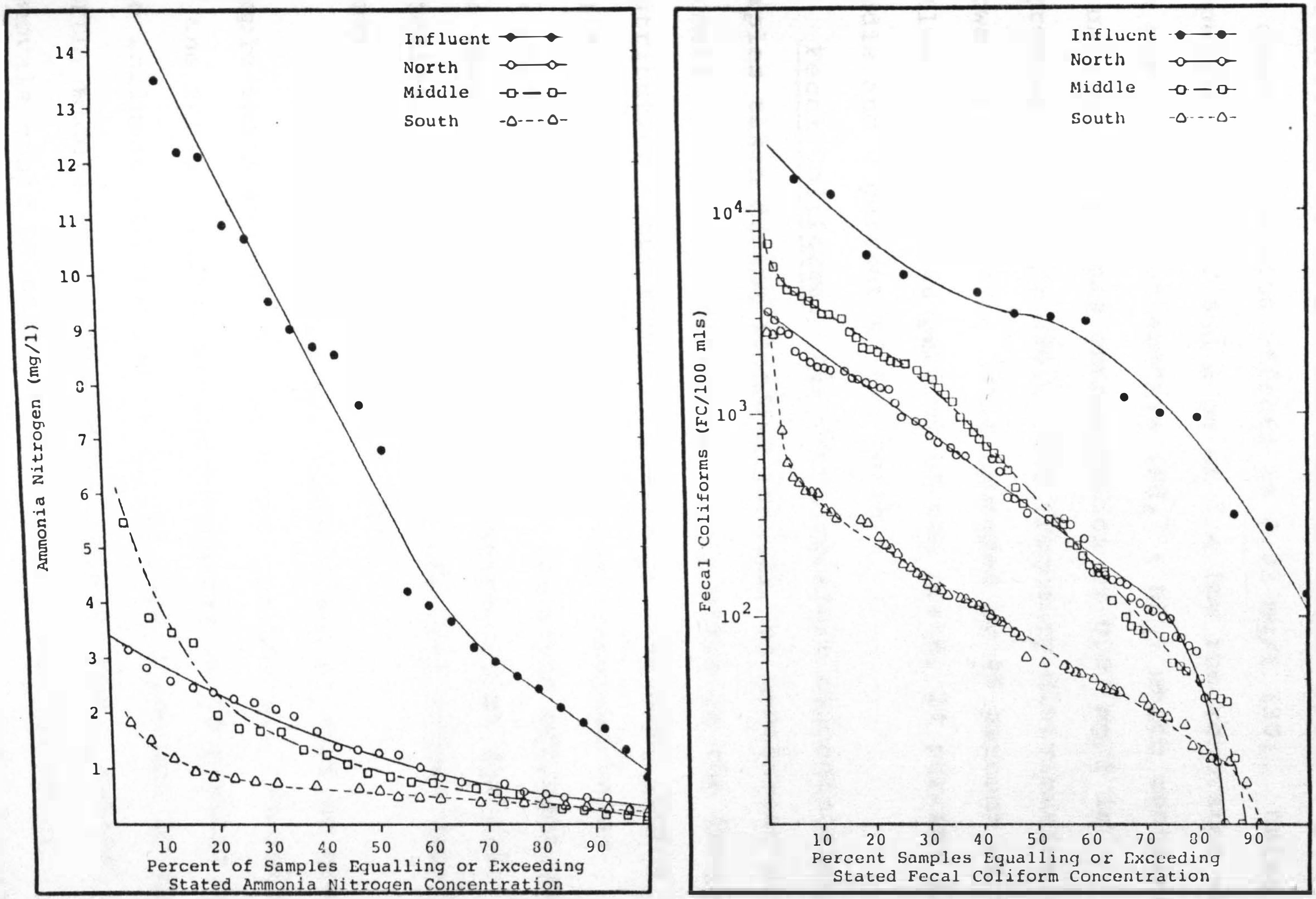


Figure 8. Frequency Distribution Graphs Indicating Percent Samples Equalling or Exceeding Stated Ammonia Nitrogen and Fecal Coliform Concentrations.

concentration of un-ionized ammonia which apparently will not cause any adverse effects is 0.02 mg/l (30). Using a temperature of 20°C and a pH of 7.4 for the renovated water, the concentration of ammonia ($NH_4^+ + NH_3$) which contained an un-ionized ammonia concentration of 0.02 mg/l is approximately 2 mg/l (30). The frequency distribution graph shows the 2 mg/l value being exceeded by 85 percent of the influent samples, 28 percent of the north, 24 percent of the middle and 0 percent of the south.

Fecal Coliforms. All fecal coliform concentrations of samples taken during flooding periods, as contrasted with geometric mean concentrations, are plotted in the frequency distribution graph shown in Figure 8. The most common fecal coliform values in the south effluent remained below 600 organisms/100ml. Results for the north effluent show the levels staying below 2000 organisms/100ml for all practical purposes and the middle effluent values usually remained below 5000 organisms/100ml.

The Brookings proposed standard states that no grab sample shall exceed 2000 organisms per 100 ml. Violation of the fecal coliform standard occurred in 63 percent of the influent samples and in 11, 23, and 2 percent by the north, middle and south samples respectively. Better removals could probably be achieved by the basins by allowing longer detention time and longer travel distances in the soil, as would occur with groundwater recharge by the effluent (14,22).

pH. pH levels of the renovated water during the infiltration-percolation study ranged from 6.90 to 7.61. The near neutral values obtained fall within the range for maximum protection determined by the National Academy of Science and the National Academy of Engineering (27). According to the proposed Brookings pH standard, the pH shall remain between 6.3 and 9.0. Renovated water levels never violated the proposed pH range while the influent samples violated the upper limit (pH of 9.0) about 12 percent of the time.

Dissolved Oxygen. The dissolved oxygen measurements of renovated water taken on October 27 suggest that some method of aeration will be required to meet most discharge standards, such as the proposed Brookings minimum level of 6.4 mg/l. An aeration mechanism, depending on the level of dissolved oxygen to be attained, will probably be required prior to discharge to a stream.

Compliance - 1975 versus 1976. The data shown in Table 5 characterize the ability of the infiltration-percolation unit to meet stringent discharge requirements. During 1976 the south basin produced an effluent capable of satisfying standards proposed for the City of Brookings except for DO. The north and middle basins encountered

TABLE 5
COMPARISON OF EFFLUENT QUALITY FROM PILOT BASINS TO THE PROPOSED DISCHARGE STANDARDS FOR BROOKINGS, SOUTH DAKOTA

(1975 and 1976 research periods)

Parameter	Limiting Standard (mg/l)	Percent Weekly Samples Meeting Standard							
		Influent		North		Middle		South	
		1975*	1976	1975*	1976	1975*	1976	1975*	1976
BOD_5	8	0	6	45	87	30	78	75	98
	12	7	12	80	100	69	100	90	100
SS	30	29	38	100	100	93	100	100	100
	45	48	62	100	100	100	100	100	100
Ammonia Nitrogen	1.1	2	2	29	46	29	55	39	87
	(2.0)**	16	15	45	72	39	76	55	97
pH (units)	6.3-9.0	--	88	--	100	--	100	--	100
Fecal Coliforms (#/100ml)	2000	54	37	68	89	63	77	81	98
Dissolved Oxygen	6.4	(inadequate data for evaluation)							

*From research data collected by Alsaker (8).

**Not included in proposed discharge permit for Brookings, South Dakota.

minor problems with the BOD_5 and fecal coliform standards, while the stringent ammonia-nitrogen standard posed a more serious problem. These discharge requirements were not met in 1975 with the exception of SS and probably pH.

Measures taken in 1976 to reduce the previous year's short-circuiting problem, appear to have improved the renovated water quality. The ability of the pilot basins to meet the proposed standards improved in 1976 with respect to BOD_5, ammonia nitrogen and fecal coliforms.

Conclusions drawn in 1975 assumed that at the present mode of operation, the pilot-plant effluent would not meet proposed dissolved oxygen levels and similar conclusions were also drawn in 1976. While quality data from the perimeter drain were not collected in 1975, analyses of the 1976 data revealed that the perimeter effluent was capable of satisfying all discharge requirements, with the exception of dissolved oxygen.

Hydraulic Loading and Basin Surface Effects

Differences in basin surface cover and hydraulic loading were established in the study to determine if water quality would be altered. Using the 1975 data, Alsaker (8), by use of a paired t-test, confirmed that the higher hydraulic loading and scarified basin cover of the south basin produced a better quality effluent. The paired t-test is used to determine whether there is a real difference in the responses to two treatments or, alternatively, whether the observed difference is small enough to be attributed to chance (35).

The same method of statistical analysis performed on the 1975 data was performed on the 1976 data. Comparison of the effluent of the south basin, which received 24 inches, to the effluent of the north basin, which received 18 inches, showed the south effluent quality in terms of BOD_5, SS and ammonia nitrogen removals to be better at the 0.01 level of significance. Effluent from the middle basin with the undisturbed surface when compared to the south effluent with the initial scarified surface revealed the south effluent also better at the 0.01 level of significance. The paired t-test computations used for the statistical comparison of the basin effluents can be found in Appendix C.

Although the initial intent of the statistical analysis was to determine whether hydraulic load and/or basin surface affected renovated water quality, it is the opinion of the author that quality differences could be attributed to other factors besides loading and cover. The t-test shows the south effluent to be superior in quality when compared to the north and middle, which is complementary with direct observations of the analytical data and trends during the investigation. Differences in basin soil type, variety of plant growth on the basins and other undefined factors could have affected renovation processes in the soil.

SUMMARY AND CONCLUSIONS

A pilot unit for the study of infiltration-percolation land treatment of stabilization pond effluent was constructed by research personnel at South Dakota State University during the 1974 summer. During the 1975 operational period, Alsaker (8) determined that the pilot system produced a treated water of highly improved quality having some potential for meeting discharge requirements. Conclusions also drawn in 1975 included the possibility of short circuiting in the pilot basins resulting in reduced treatment efficiency.

Remedial measures taken in 1976 to correct the possible short circuiting included thorough mixing of the north and south basin surfaces and compaction directly over the drains in all basins. The addition of a clay layer over the drains and additional compaction concluded the basin preparation. Elbows were attached to the sample box drain lines resulting in complete inundation of the drains. Removal of the elbows later in the investigation allowed inquiry into quality and infiltration changes.

Weekly flooding of the basins beginning on May 26 resulted in extensive plant development on all basin surfaces. Preparation for winter operation required the mowing of the basins in early September. Conclusions drawn during this investigation include the following:

1. Excellent removals of stabilization pond pollutants by the infiltration-percolation basins were achieved in 1976. Treatment efficiencies extended from 79 to 92 percent for BOD_5, 85 to 94 percent for SS, 80 to 91 percent for ammonia nitrogen and 89 to 98 percent for fecal coliforms.

2. The pilot-basin renovated water showed a 6.3 to 17.3 percent increase in specific conductance levels with respect to the applied influent. Substantial evapotranspiration rates and dissolution of minerals such as calcium carbonate probably contributed to this increase.

3. The soil matrix acted as a pH equalization mechanism, and influent pH levels decreased to values in the effluent of 6.9 to 7.6.

4. Dissolved oxygen levels of the renovated water, checked in October when the drains flowed partially full, were greater than those obtained in 1975 when the drains remained inundated. Air entrainment could have occurred as the renovated water flowed to the sample box.

5. The nutrient-rich influent to the basins resulted in extensive plant growth on the basin surfaces during the summer. Mowing of the basins in September appeared to coincide with increased BOD_5 and SS concentrations in the renovated water. The presence of an organic mat on the basin surface from mowing may have affected the removal mechanism.

6. The levels of SS, ammonia nitrogen and fecal coliforms in the influent appeared to have affected the levels in the north and middle basin effluents. Correlation coefficients computed for influent versus effluent levels also indicated the possibility of continued short circuiting.

7. The removal of the elbows from the sample box drain lines after twelve flooding cycles did not immediately affect renovated water quality. Although quality changes occurred later, these changes could not necessarily be attributed to the elbow removal.

8. Frequency distribution graphs plotted with the values obtained from BOD_5, SS, ammonia nitrogen and fecal coliform weekly analyses revealed that the south effluent had the lowest consistent level of pollutants of the three basins. The south effluent complied with the Brookings secondary treatment discharge requirements with minor expections. The north and middle effluents did not consistently meet the ammonia nitrogen and fecal coliform standards.

9. Based on the paired t-test, the south basin was more effective in removing BOD_5, SS and ammonia nitrogen than the north and middle basins. The superior treatment by the south basin may have been the consequence of other factors besides the higher hydraulic loading and initial scarified surface. Possibilities include differences in

basin soil type and variety of plant growth on the basin surfaces.

10. The infiltration-percolation system proved more effective in 1976 than in 1975 for removal of pollutants from the stabilization pond effluent. Project construction in 1976 appeared to have improved the quality of the renovated water.

RECOMMENDATIONS

The analysis of data and resulting conclusions from the 1976 operation of the infiltration-percolation pilot plant result in the following recommendations for consideration:

1. Annual tilling of the basin surfaces should be continued to allow soil aeration and to disrupt the formation of flow channels causing short circuiting.

2. Physical removal of basin growth after mowing, or burning of the growth in the late fall, should be practiced so that an organic mat does not form on the basin surfaces.

3. Temperatures of the basin effluent should be monitored during the sampling because of their importance to ammonia toxicity and oxygen solubility.

4. A more regular schedule of measuring dissolved oxygen is needed to determine the effect of flow conditions in the drains on the dissolved oxygen levels.

5. Lowering of the drains would allow longer travel distance and detention time in the soil for fecal coliform removal.

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Appendix A
Results of BOD_5 Analyses

Flooding Date	Influent	North	Middle	South	Drain
	Concentration - mg/l				
May 26	18.4	7.3	8.0	2.7	
June 1	17.7	11.1	10.2	2.5	1.7
8	27.1	7.2	7.4	1.8	1.0
15	19.6	4.3	4.4	1.8	1.0
22	58.6	5.0	7.1	1.2	
29	42.2	6.4	5.8	0.6	
July 6	38.4	9.7	7.0	8.0	
13	34.4	3.4	3.4	1.6	
20	39.2	1.1	1.6	1.0	
27	14.7	1.5	1.2	0.7	
Aug. 3	17.9	0.9	0.7	0.7	
10	20.3	2.4	2.3	2.1	
17	11.6	0.8	0.6	0.4	
24	10.5	0.7	1.3	0.5	
Sept. 1	21.4	0.4	0.9	0.6	
8	5.0	1.0	1.0	0.8	
15	4.6	4.7	2.1	0.8	
22	25.0	2.8	3.4	1.2	
29	23.0	4.0	6.2	2.0	
Oct. 6	22.8	4.6	6.7	1.7	
13	30.7	4.8	7.0	2.1	
20	41.0	4.0	7.7	2.2	
27	21.5	5.0	8.6	2.8	
Nov. 3	15.0	7.4	7.7	1.9	
9	27.2	6.8	9.9	3.1	
17	19.3	5.0	8.6	2.6	
21-22	17.8	4.1	6.8	2.2	

Appendix A (continued)
Results of SS Analyses

Flooding Date	Influent	North	Middle	South	Drain
	Concentration - mg/l				
May 26	43.5	5.0	5.6	3.0	
June 1	20.0	2.6	5.4	0.4	3.0
8	24.8	2.2	2.0	1.8	7.4
15	30.4	2.6	2.6	3.0	2.8
22	54.8	2.8	3.8	3.8	3.2
29	20.8	2.4	2.6	2.4	3.0
July 6	24.0	2.2	2.4	2.2	2.2
13	20.0	0.8	1.6	1.8	1.6
20	42.0	2.0	3.0	2.4	2.4
27	33.2	1.8	2.0	1.2	1.6
Aug. 3	67.2	6.4	4.6	6.0	4.8
10	23.6	0	0.8	0	0
17	38.8	1.8	2.8	2.4	3.0
24	23.4	1.8	2.6	2.2	1.6
Sept. 1	34.2	0.4	0.4	0	0.4
8	15.8	1.2	1.0	1.6	1.2
15	17.8	4.0	2.6	0.9	1.2
22	40.8	3.6	4.8	2.2	4.2
29	45.2	6.0	11.2	2.6	1.9
Oct. 6	59.6	8.6	10.8	3.4	0.6
13	58.0	6.8	10.8	2.2	
20	71.0	6.4	13.6	3.6	
27	59.0	6.0	13.0	3.0	
Nov. 3	65.0	6.6	14.0	1.2	
9	41.0	9.4	12.8	2.6	
17	32.0	10.8	12.8	5.0	
21-22	29.0	3.0	8.0	0.7	

Appendix A (continued)
Results of Ammonia Nitrogen Analyses(31)

Flooding Date	Influent	North	Middle	South	Drain
		Concentration - mg/l			
May 26	6.80	1.27	0.73	0.35	0.38
June 1	9.00	2.80	1.67	0.48	0.32
8	10.90	2.36	1.23	0.38	0.24
15	10.65	1.69	0.74	0.31	0.13
22	13.50	2.18	1.68	0.44	0.13
29	15.50	2.58	1.72	0.34	0.08
July 6	12.18	2.43	1.34	1.84	0.11
13	8.55	1.39	0.64	0.58	0.16
20	3.20	0.59	0.28	0.73	0.06
27	2.10	0.49	0.28	0.27	0.06
Aug. 3	1.70	0.47	0.13	0.33	0.06
10	0.85	0.53	0.17	0.37	0.07
17	1.35	0.50	0.14	0.24	0.03
24	----	0.08	----	0.22	0
Sept. 1	2.41	0.72	0.54	0.93	0.47
8	1.81	1.23	0.85	1.19	0.73
15	2.92	0.27	0.23	0.38	0.04
22	3.95	1.03	1.08	0.43	0.07
29	3.65	0.72	0.53	0.61	0.28
Oct. 6	2.65	0.79	0.64	0.67	0.86
13	4.20	0.83	0.92	0.64	0.14
20	7.62	1.32	1.94	0.82	
27	8.70	2.24	3.73	1.52	
Nov. 3	9.52	2.07	3.46	0.67	
9	12.11	1.93	3.29	0.84	
17	15.12	3.15	5.46	0.77	
21-22	18.76	2.52	4.48	0.64	

Appendix A (continued)
Results of pH Analyses

Flooding Date	Influent	North	Middle	South	Drain
		Concentration - pH units			
June 1	8.22	7.38	7.40	7.32	7.43
8	7.80	7.25	7.30	7.45	7.38
15	8.01	7.42	7.35	7.41	7.47
22	8.11	7.40	7.46	7.40	7.61
29	7.98	7.30	7.29	7.20	7.41
July 6	8.18	7.11	7.20	7.10	7.30
13	8.34	7.13	7.18	7.05	7.30
20	8.87	7.17	7.12	7.12	7.32
27	9.16	7.18	7.22	7.13	7.35
Aug. 3	9.12	7.14	7.31	7.18	7.34
10	9.01	7.18	7.31	7.12	7.42
17	8.53	7.13	7.31	7.10	7.38
24	8.51	7.12	7.46	7.12	7.43
Sept. 1	8.50	7.41	7.48	7.41	7.30
8	8.06	7.15	7.32	7.15	7.45
15	8.40	6.94	7.13	6.90	7.19
22	8.30	6.95	7.20	6.95	7.23
29	8.72	7.39	7.50	7.28	7.50
Oct. 6	8.78	7.28	7.50	7.24	7.50
13	8.65	7.31	7.58	7.21	7.54
20	8.30	7.26	7.52	7.32	
27	7.98	6.92	7.27	6.93	
Nov. 3	8.20	7.25	7.58	7.32	
9	7.80	7.22	7.51	7.23	
17	8.06	7.31	7.61	7.30	
21-22	8.02	7.33	7.57	7.30	

Appendix A (continued)
Results of Fecal Coliform Analyses(33)

Date/Time	Influent	North	Middle	South	Drain
	Concentration - organisms/100ml				
July 13-14					
1730	---	3	6	---	0
2245	---	0	58	0	0
0645	---	21	0	0	38
1030	---	0	---	1	0
July 20-21					
1400	---	---	5	---	---
1755	---	5	3	2	0
2245	---	7	10	0	0
0655	---	1	2	1	2
1020	---	0	---	0	0
July 27-28					
1440	---	---	290	---	---
1710	---	383	0	23	6
2240	---	87	55	284	120
0640	---	387	231	43	76
1020	---	631	---	23	2
Aug. 3-4					
1440	---	---	THTC*	113	---
1745	---	THTC*	83	THTC*	THTC*
2240	---	0	175	37	207
0640	---	78	39	58	THTC*
1030	---	0	---	101	THTC*
Aug. 10-11					
1330	---	---	89	---	---
1635	---	163	0	53	16
2235	---	THTC*	86	---	THTC*
0640	---	68	21	THTC*	1
1050	---	0	---	0	15
Aug. 17-18					
1405		---	102	2	35
1625		72	---	21	22
2255		108	0	---	3
0640		0	3	45	17
1030	129	0	5	33	1

* THTC = too high to count or greater than 200 colonies.

Date/Time	Influent	North	Middle	South	Drain
	Concentration - organisms/100ml				
Aug. 24-25					
1430		---	300+	300+	62
1750		300+	300+	300+	55
2235		300+	227	34	27
0645		100	42	36	100
0900	948+	---	---	---	---
0925		149	---	60	40
Sept. 1-2					
1335		---	284	144	4
1650		300	600+	64	8
2235		122	164	58	0
0640		164	50	94	8
1000	314	20	---	54	---
Sept. 8-9					
1350		---	434	176	0
1645		152	638	206	2
2240		142	522	124	0
0650		106	50	122	0
1010	272	116	42	50	0
Sept.16-17					
1400		---	1152	182	8
1615		620	1536	248	20
2250		600+	1260	226	56
0640		600+	744	418	4
0930		600+	---	328	53
0945	1200+	---	---	---	---
Sept.22-23					
1345		---	2384	248	12
1645		1456	2112	40	0
2245		---	688	16	0
0650		1344	96	16	4
0830		1424	---	24	0
0930	2864	---	---	---	---

Appendix A (continued)
Results of Fecal Coliform Analyses(33)

Date/Time	Influent	North	Middle	South	Drain
	Concentration - organisms/100ml				
Sept.29-30					
1425		---	1360	220	0
1615		520	960	50	0
2235		780	2040	20	0
0655		960	120	30	2
0930	3120	720	---	30	4
Oct. 6-7					
1520		---	2120	160	---
1800		1820	1820	84	1
2235		1660	1500	96	0
0700		1500	---	88	2
1000	3020	1720	---	60	1
Oct. 13-14					
1350		---	1800	306	---
1615		920	1680	138	0
2245		680	800	46	0
0650		240	---	58	0
0900		1520	---	30	1
0945	6120	---	---	---	---
Oct. 20-21					
1340		---	6900	---	---
1615		1660	4140	462	---
2240		2600	4540	420	---
0645		2540	2920	410	---
0910		2940	---	164	---
0920	14420	---	---	---	---
Oct. 27-28					
1355		---	5400	2500	---
1545		920	3880	2530	---
2250		1680	2960	580	---
0620		1960	1840	340	---
0915	12040	2080	---	490	---

Date/Time	Influent	North	Middle	South	Drain
	Concentration - organisms/100ml				
Nov. 3-4					
1320		---	80	---	---
1550		80	80	40	---
2250		320	320	0	---
0650		40	80	20	---
0910	1000	160	---	20	---
Nov. 9-10					
1310		---	180	---	---
1550		320	200	80	---
2245		280	40	40	---
0645		240	60	20	---
0905		680	---	40	---
0915	4000	---	---	---	---
Nov. 17-18					
1330		---	4100	---	---
1520		---	3520	836	---
2250		1740	1680	44	---
0700		1140	---	124	---
0910		3260	---	116	---
0925	4900	---	---	---	---
Nov. 21-23					
1920		---	3640	---	---
2215		---	3120	112	---
1300		---	360	---	---
1635		0	880	136	---
2255		600	2520	56	---
0700		1360	1920	64	---
1450	4000	900	3160	128	---

Appendix A (continued)
Results of Specific Conductance Analyses

Flooding Date	Influent	North	Middle	South	Drain
	Conductance - micromhos per centimeter				
May 26	1588	1838	1833	1818	
June 1	1710	1818	1828	1828	1818
8	1823	1960	1960	1970	1882
15	1813	1936	1950	1989	1882
22	1710	1847	1901	1891	1872
29	1852	1970	1970	2058	1994
July 6	1808	1980	1970	2073	2024
13	1994	2176	2234	2352	2239
20	----	----	----	----	----
27	----	----	----	----	----
Aug. 3	----	----	----	----	----
10	----	----	----	----	----
17	1850	2029	2080	2202	2095
24	1840	2167	2044	2330	2197
Sept. 1	1794	2124	1969	2299	2165
8	1742	2108	1959	2268	2083
15	1711	2114	1835	2371	2155
22	1753	2124	1964	2371	2155
29	1778	2129	1763	2175	2237
Oct. 6	1737	2052	1882	2351	2108
13	1722	2072	1722	2371	2248
20	1815	2108	1748	2279	
27	1815	2098	1876	2227	
Nov. 3	1784	2062	1845	2227	
9	1815	1900	1826	1968	
17	1815	2024	1883	2121	
21-22	1871	2114	1887	2211	

Appendix B. Correlation of Quality Parameter Variables (35).

Parameter	Variables Correlated	Number of Samples	Correlation Coefficient r	Significant Values 0.05*	Significant Values 0.01**
BOD_5					
	Influent x North	26	0.24	0.381	0.487
	Influent x Middle	26	0.35		
	Influent x South	26	0.26		
SS					
	Influent x North	26	0.59**	0.381	0.487
	Influent x Middle	26	0.68**		
	Influent x South	26	0.53**		
Ammonia Nitrogen					
	Influent x North	25	0.91**	0.388	0.496
	Influent x Middle	25	0.69**		
	Influent x South	25	0.18		
Fecal Coliforms					
	Influent x North	14	0.78**	0.514	0.641
	Influent x Middle	14	0.89**		
	Influent x South	14	0.50		
Specific Conductance					
	Influent x North	22	0.45*	0.413	0.526
	Influent x Middle	22	0.65**		
	Influent x South	22	0.31		

*Indicates significance at the 0.05 level **Indicates significance at the 0.01 level

Appendix C. Paired t-Test for Comparing the Quality of the Renovated Water (35).

Parameter	Comparison	Σd	Σd^2	$\bar{d}$	$s_{\bar{d}}$	d.f.	t
BOD_5	South and North Basins	64.9	281.05	2.50	0.428	25	5.84**
	South and Middle Basins	83.4	446.00	3.21	0.524	25	6.13**
Suspended Solids	South and North Basins	43.3	209.89	1.67	0.460	25	3.63**
	South and Middle Basins	88.7	777.57	3.41	0.855	25	3.99**
Ammonia Nitrogen	South and North Basins	19.3	31.37	0.74	0.162	25	5.10**
	South and Middle Basins	17.3	49.15	0.69	0.248	24	2.79**

**Indicates significance at the 0.01 level