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WINTER OPERATING CONSTRAINTS OF A HIGH-RATE INFILTRATION-PERCOLATION TREATMENT SYSTEM FOR WASTEWATER

BY

EUGENE A. MILLER

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
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1977

WINTER OPERATING CONSTRAINTS
OF A HIGH-RATE INFILTRATION-PERCOLATION
TREATMENT SYSTEM FOR WASTEWATER

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

Head, Civil Engineering Department Date

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INTRODUCTION

In order to comply with the Federal Water Pollution Control Act Amendments of 1972 (1), many small communities in South Dakota are faced with the probability of having to update the quality of wastewater that is being discharged. Many of these communities presently use low-cost lagoons or stabilization ponds that provide various degrees of wastewater treatment. With the lack of trained personnel for routine operation and maintenance and the inherent financial problems due to a limited tax base, small communities have a definite need for a simple and inexpensive form of wastewater treatment that will upgrade effluents from stabilization ponds to meet the more stringent discharge requirements.

Land application,which has been investigated by the Civil Engineering Department at South Dakota State University over the last several years (2,3,4,5), could be a form of treatment that might be feasible for the small communities in South Dakota. These studies have all shown that land application does have a potential use in South Dakota.

The Brookings Utilities Department was encouraged with the research by Tiltrum (4) using lysimeters to treat effluent from the Brookings stabilization ponds. With the more stringent discharge requirements to be met by Brookings by 1977 and 1983, the City Utilities Department expressed interest in exploring the use of an infiltration-percolation systems.

In 1974, an infiltration-percolation pilot unit was constructed with funds provided by the Water Resources Institute at South Dakota State University. The Civil Engineering Department at South Dakota State University provided research personnel; the City of Brookings supplied land and construction assistance. The pilot project began operation in 1975 with the Environmental Protection Agency providing financial assistance for the study.

In the first year of operation, Alsaker (6) investigated the treatment performance of the pilot plant with emphasis on the quality of effluents in relation to discharge requirements. Voogt (7) also studied the infiltration capacity and hydraulic characteristics of the site. Continuous studies are presently under investigation with several graduate students cooperating to evaluate the treatment and operation of the pilot units.

Infiltration-percolation systems are successfully used in the southern climates of the United States throughout the year. Concern has been expressed, however, about the feasibility of using infiltration-percolation basins in northern climates where severe winters are a common occurrence. It is imperative to verify the ability of infiltration-percolation basins to operate successfully under adverse winter conditions and still produce an effluent that meets discharge requirements. The objectives of this portion of the study were as follows:

1. Identify some of the major winter operating constraints for infiltration-percolation systems, and

2. Investigate the amount of required storage if continous operation of infiltration-percolation basins if impossible.

The infiltration-percolation pilot unit was operated during the winter of 1975-76 to obtain information to fulfill these objectives for a climatic condition similar to that of Brookings, South Dakota.

LITERATURE REVIEW

Presently, there is a multitude of wastewater treatments that are being utilized. One form of wastewater treatment is land disposal or application of domestic and industrial wastewaters to the earth's soil mantle (8).

One form of land disposal is infiltration-percolation. Infiltration-percolation can be defined as "an approach to land application in which large volumes of wastewater are applied to the land, infiltrate the surface, and percolate through the soil pores" (9-180).

Infiltration-percolation treatment is "similar to intermittent sand filtration in that application rates are measured in feet per week or gallons per day per square foot" (9-14). This method of treatment renovates the wastewater as it travels through the soil matrix by natural physical, chemical, and biological processes (9-69). Infiltration-percolation systems can supplement the underground water supply (10-39).

Reports on two known land application systems operating in northern climates were examined to obtain pertinent information which might be helpful in evaluating winter operation of the pilot unit. The literature was also reviewed for other information related to winter operation of the pilot unit.

Treatment Facilities at Westby, Wisconsin

One successful land application system operating in a northern climate is at Westby, Wisconsin. The system was installed in 1959 to avoid legal action from land owners downstream from the point of discharge from a two-stage high-rate trickling filter plant that served the City. Four terraced basins that cover a total area of 3.7 acres were constructed on a hillside. The area inside each basin is approximately 3/4 of an acre. There are ridges and furrows in the basin floor. The furrows isolate the sections within the basins. Vegetation in the basins consists of Reed Canary grass (11).

In 1964, engineers and scientists from the Robert A. Taft Sanitary Engineering Center at Cincinnati, Ohio began an evaluation of the Westby, Wisconsin system. It was concluded from the evaluation that "additional purification is afforded the infiltrating liquid even under adverse winter conditions". It was also concluded that a land disposal system such as "ridge and furrow liquid waste-treatment and disposal systems can be operated satisfactorily in northern latitudes" (11).

Past winter operations at Westby, Wisconsin have shown that a bridge of ice supported by the ridges would develop over the furrows which preserved a channel for the flow of wastewater. In 1965, no ice bridging occurred; the wastewater froze throughout the furrows. As a result of freezing, the wastewater randomly spilled over the dikes to the lower basins which caused an overload on the bottom basins (11). Winter operations of 1972 and 1973 were hampered by excessive quantities of rainfall that turned the basins into a series of holding ponds (9-80). Because of this, a definite need for winter storage facilities to handle rain water was demonstrated.

Treatment Facilities at Lake George, New York

Another successful infiltration-percolation system operating in a northern climate is at Lake George, New York. The system was initiated in 1936 due to efforts by the Lake George Association to preserve the aethestical value of the recreation lake. The Lake George treatment plant is a modified trickling filter process, which uses a covered trickling filter during winter, that utilizes natural, delta sand beds as an infiltration area for treated effluent. The combined area of the sand beds is 6.4 acres (12).

Summer flow for the summer resort community was about 1.2 million gallons per day (mgd); the winter flow was only 0.3 mgd. Consequently, during winter the infiltration-percolation system treated only about 25 percent of the flow for which the basins were designed (9-193).

In 1967, the Rensselaer Polytechnic Institute of Troy, New York became involved in the evaluation of the Lake George, New York treatment system. The Rensselaer Fresh Water Institute at Lake George was created to evaluate the ability of the wastewater treatment plant to remove nutrients to avoid possible contamination of Lake George (12). A portion of the research centers around seasonal variation in purification of the Lake George Village wastewater treatment plant.[1]

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[1] Personal letter from T. James Tofflemire dated March 25, 1976.

The normal operational procedure is to flood two beds in sequence each day to depths of eight to ten inches. The beds are then rested four to five days before the dried solids are scraped off and then the beds are flooded again. During winter operation, the hydraulic load to the beds is seven to fifteen inches of effluent each week. Flooding lasts for nine hours followed by a five-to ten-day rest period (9-194). The ice layer, which floats, serves to insulate the soil surface from the freezing temperatures (9-84).

Design Considerations

There are several factors that can influence the performance of soil-systems treating liquid wastes. Unfavorable soil and climatic conditions represent formidable design problems. The engineer is generally faced with two alternatives: select a favorable site where possible or modify the design to overcome disadvantages incurred at an unfavorable site (13). The remainder of the design can be established to take full advantage of the site. Before design principles can be established, the effects of the interaction between environmental and design factors must be evaluated (13).

The macroclimate at an infiltration-percolation site cannot be changed with present technology, therefore, the climate must be evaluated with respect to its influence upon the system (9-30). Factors such as temperature, quantity of snow, and wind speed are all important in site evaluation.

Lower liquid temperatures affect the viscosity of the wastewater. Infiltration rates are inversely proportional to viscosity; a decrease in temperature will cause a decrease in infiltration rates. For example, a temperature drop of the wastewater from 80°F to 50°F would cause the infiltration rate to be reduced by 34 percent as a result of the change in the viscosity (14).

Temperature also effects the rates of biological and chemical reactions; reaction rates are reduced 50 percent for each drop of 10°C. Also, denitrification rates may be reduced more than nitrification rates when temperatures drop below 10°C. Therefore, the system would remove less nitrogen from the wastewater when temperatures are low (14).

The influence of snow depths on land application is more difficult to assess than temperature (15-134). In regions where snow accumulates during winter, the effect of snow should be evaluated. Information needed for this purpose includes the total amount of snowfall, maximum expected depth, and period of snow cover (16-103).

The wind directly or indirectly influences several factors such as: drifting of snow, air temperature and rates and intensity of evaporation (15-138). Wind might also be responsible for excessive loss of heat from the applied wastewater during periods of cold temperatures.

As reported, the normal operation of the Lake George, New York treatment system allows four to five days for the beds to be rested between floodings; winter operations normally provide five to ten days between floodings (9-194). This rest period or restoration provides for the reaeration of the basin bottom. This restoration is carried out by aerobic microorganisms whose activity may be significantly hampered during periods of cold temperatures. Therefore, longer periods of time are necessary for microbial restoration during winter months. But with extended restoration periods, the basin bottom could freeze forming an impermeable boundry for the next flooding (15-16).

Storage Facilities

The amount of storage affects the feasibility and design of land disposal systems. In most land-application systems, storage facilities of some type will be required (16-70). Design of holding ponds for winter flow is not an insurmountable problem but adds to the cost and acreage requirements for land application systems.

The winter design period is that period of operation where some modification will have to be made due to winter conditions. Examples of modifications include complete storage of wastewater or partial storage with partial operation of the system. There have been several criteria set forth for the determination of the winter design period. Analysis of the suggested criteria does not differentiate between full and partial winter storage (16-103).

In storage facilities design, an analysis of the historical winter weather data should be made to obtain the maximum required winter design period (16-70). The range of temperatures which should be expressed in terms of monthly or seasonal averages may be important in selecting storage time periods (16-103). Frost dates, periods of frozen ground, and snow cover should also be considered when determining the winter design period (16-103). However, for northern climates, the date of probable ground freezing would appear to be more critical (15-134). One estimation for storage calls for a time period of 180 days in northern climates (15-42).

One publication prepared under government contract recommends that 10 to 25 percent of the total design area be allocated for emergency situations (9-81). The magnitude of the factor-of-safety employed will vary with the system and will depend on a number of factors, such as severity of potential adverse effects and degree of certainty of design assumptions (16-111). A larger factor-of-safety or a greater percent of design area for emergencies might be in order for areas with severe winters.

DESCRIPTION OF PILOT STUDY

The infiltration-percolation system under investigation is located at the west end of the Brookings airport. The utilized land, which the City of Brookings owns, is located between the stabilization ponds and Six-Mile Creek (Figure 1). The site for the pilot unit was selected in part to utilize soil similar to that where a full-scale system would possibly be located (7). The present wastewater treatment facilities for the City of Brookings consist of a conventional trickling filter plant which provides secondary treatment. Two stabilization ponds which have a total detention time of 25 to 30 days then provide additional treatment. The daily average flow to the ponds is 1.2 to 1.3 mgd.[2]

The infiltration-percolation pilot unit, which consists of three 50-foot by 150-foot basins, is supplied with wastewater from the stabilization pond by gravity through a funnel connected to eight-inch aluminum irrigation pipe that discharges into Six-Mile Creek. A bypass system of six-inch irrigation pipe, along with valves, tees, and elbows allows the basins to be flooded singly or simultaneously (7) (Figure 2).

The underdrain system for collecting effluent samples is a series of four-inch corrugated, perforated plastic drains "laid longitudinally under each basin at a depth of about 30 inches

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[2] Interview with John Wirtz, Brookings Chemist September 24, 1976

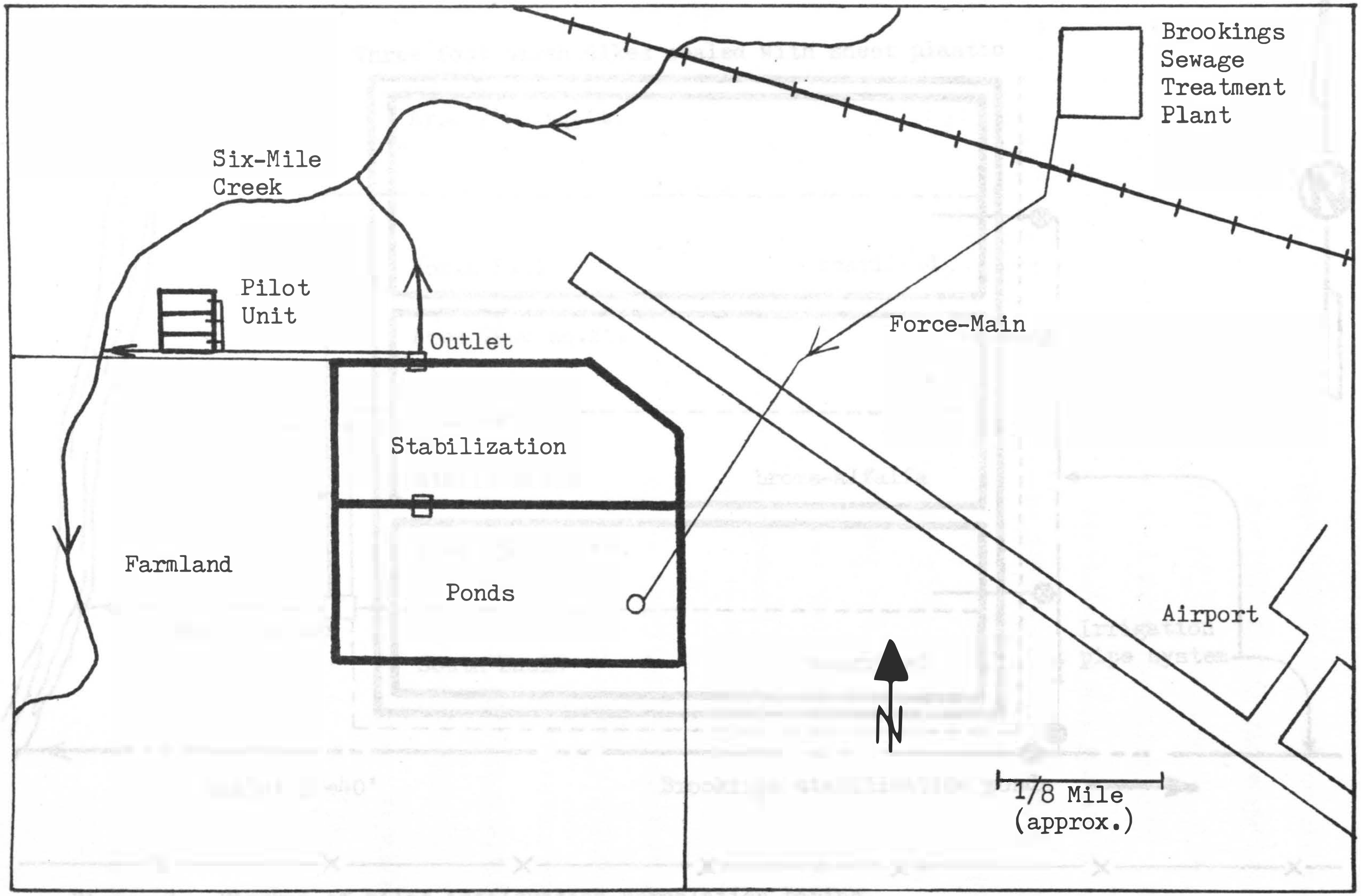

Figure 1. Overview of area showing sewage treatment plant, stabilization ponds, pilot unit, and Six-Mile Creek.

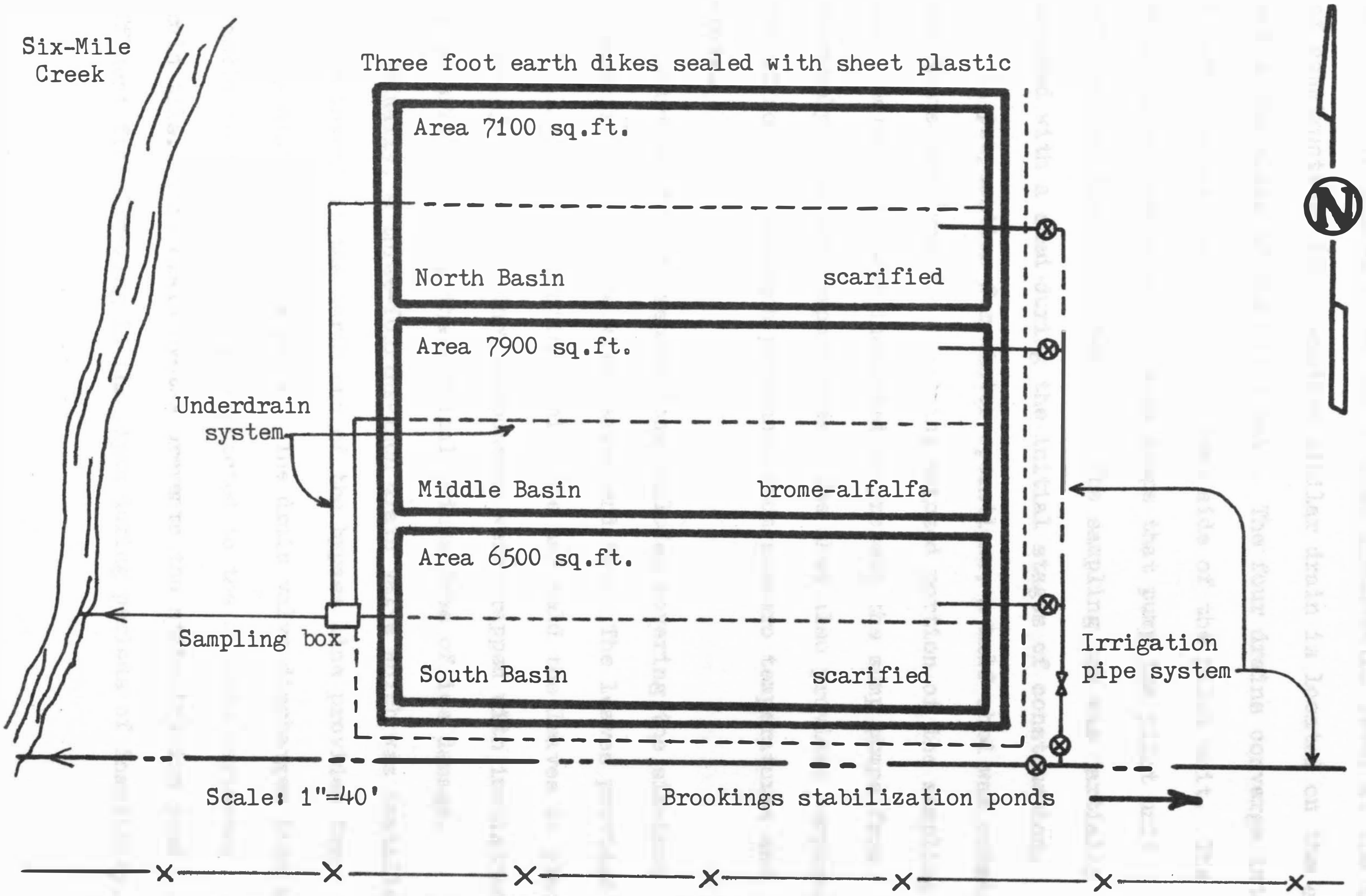

Figure 2. Diagram of pilot infiltration-percolation basins.

and about 12 inches above the natural groundwater level at the time of construction" (7). Another similar drain is located on the east and south sides of the pilot unit. The four drains converge into a sampling box that is on the west side of the pilot unit. The sampling box contains two sump pumps that pump the pilot unit effluent to Six-Mile Creek (6). The sampling box was partially covered with a shed during the initial stages of construction.

In preparation for winter operations, a half shed was constructed and installed over the remaining exposed portion of the sampling box. Both sheds were insulated to protect the sump pumps from extremely cold air temperatures. The shed also provided temporary relief for the research personnel from subzero temperatures and winds.

Further winter preparations included covering the six-inch bypass irrigation pipe with leaves and hay. The leaves provided the bulk of the insulation, while the hay held the leaves in place. Valves, joints, and other components were wrapped with insulation in an effort to keep the critical points free of ice damage.

Finally, a three-fourths-inch drain valve which was installed at the invert at the north end of the bypass line provides for gravity draining of the pipes. The drain valve discharges into a plastic drain tile which is connected to the outside perimeter drain tile. This drain system prevents the stabilization pond effluent from freezing in the pipes during periods of inactivity.

The infiltration-percolation pilot unit was first flooded on June 11, 1975 after the initial stages of construction (7). Normal operating procedure was to apply stabilization pond effluent to each basin at weekly intervals. The north basin, which was scarified, received 18 inches of stabilization pond effluent while the middle basin received 24 inches. The middle basin supported a native cover of brome grass and alfalfa. The south basin which was also scarified received 24 inches of stabilization pond effluent. Flooding was on a weekly basis except for the week of October 14- 21, 1975, when the basins were flooded every day in an attempt to decrease the infiltration rates by expanding the soil particles (7). Flooding continued on a weekly basis through December, 1975. During January, 1976, the south and north basin were each flooded once. In an attempt to expedite the removal of ice, the basins were flooded for the last time during winter on February 24 and 25, 1976. The next flooding was done on April 6, 1976.

Analyses performed on the composite effluent samples were ammonia, nitrate, and total Kjeldahl nitrogen; total and ortho phosphorous; biochemical oxygen demand; suspended solids; and specific conductance. The tests were performed in the Sanitary Engineering Laboratories at South Dakota State University by other graduate students involved with the project. Fecal coliform determinations were made by personnel of the Microbiology Department at South Dakota State University (6).

PRESENTATION AND DISCUSSION OF WINTER OPERATING CONSTRAINTS

The primary objective of this portion of the study was to identify some of the major winter operating constraints for the infiltration-percolation system. The identified constraints are based on the operation of the pilot unit during the winter of 1975-76.

With a multitude of possible winter conditions, it becomes necessary to briefly describe the type of winter conditions that prevail for the locality. Winters on the northern plains are characterized by about four months of subfreezing temperatures. Periods of subzero temperatures are not uncommon. The snowfall for the area generally averages about twenty-four inches (17). Strong, Arctic winds often accompany snowfall resulting in the formation of large drifts. In general, the most severe winter conditions for the locality occur during the months of January and February.

Initially, operation of the infiltration-percolation pilot unit during the winter was to utilize, as much as possible, the same methodology and equipment as was used in the fall. But due to low winter temperatures, the float recorders and piezometer tubes, used in the hydraulic study by Voogt (7), froze and became inoperable. Consequently, the infiltration rates and groundwater elevation under the basins could not be determined. The winter conditions also prevented collection of samples from ceramic cups installed at various depths within the basins. Such problems as these are common with winter operations of infiltration-percolation systems. For example, a letter[3] from Dr. Donald B. Aulenbach of the Rensselaer Polytechnic Institute pertaining to the Lake George, New York treatment facility states the following:

> "We are continuing to obtain data during operation in the winter. We frequently find difficulty in obtaining samples both from the standpoint of test wells freezing and sampling and measurement equipment suffering from malfunctions during freezing conditions."

The winter conditions limited the availability of data for the pilot unit. The data available for discussion consists of (a) personal observations, some of which are documented by photographs, (b) temperature data when flooding was accomplished, and (c) effluent quality data.

Blizzard Conditions

After an uneventful fall period of pilot unit operation, the weekly flooding on November 18, 1975, proceded as usual but a slight drizzle started in the evening. On November 19, 1975, the day after flooding, snow started falling in the afternoon. The snowfall increased in intensity and turned into a snow storm. By night, the snow storm had turned into a raging blizzard. Two days later, the blizzard subsided. Traffic was at a standstill throughout the area. Finally, on November 24, 1975, five days after the blizzard started, the research personnel inspected the pilot unit.

Thus, a blizzard condition was the first major operating constraint identified in the operation of the pilot unit. A blizzard

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[3] Personal letter from Dr. Donald B. Aulenbach dated April 2, 1976

will provide some of the most severe weather conditions during which an infiltration-percolation system will operate.

There were several problems that were a direct result of the blizzard. The first problem made apparent by the blizzard was the remoteness of the site. Street and highway traffic were restored long before research personnel could reach the site. Another problem demonstrated by the blizzard was the difficulty of operation and maintenance of the system during a severe storm. It would have been impossible for personnel to carry out normal assigned jobs during a blizzard of the magnitude that actually occurred in November, 1975.

Although blizzards are not a common occurrence, an infiltration-percolation system in northern climates should be designed for operation during such storms. Mechanical operation by remote control to allow flooding of individual basins is one viable solution for operation during severe blizzards. Diversion of wastewater flows to emergency storage might also be a satisfactory solution to operation during a blizzard.

Ice Formation

During winter operations, layers of ice were formed during each weekly flooding. Although low temperatures were the basic cause of ice formation, there were several factors that affected the degree of ice formation. One of these factors is the temperature of the applied stabilization pond effluent. Figure 3 displays the monthly

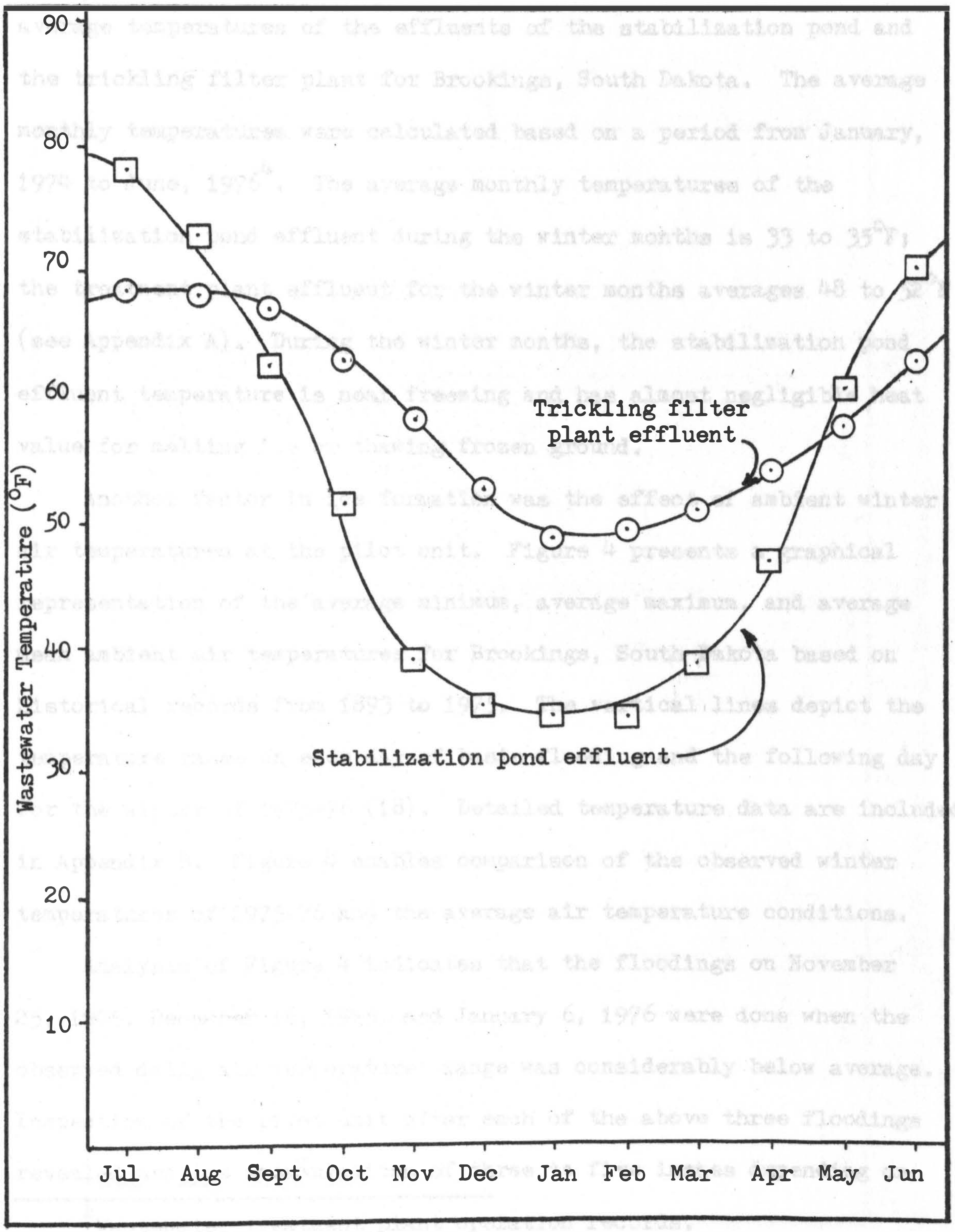

Figure 3. Monthly average wastewater temperature at Brookings, South Dakota.

average temperatures of the effluents of the stabilization pond and the trickling filter plant for Brookings, South Dakota. The average monthly temperatures were calculated based on a period from January, 1974 to June, 1976[4]. The average monthly temperatures of the stabilization pond effluent during the winter months is 33 to 35°F; the treatment plant effluent for the winter months averages 48 to 52°F (see Appendix A). During the winter months, the stabilization pond effluent temperature is near freezing and has almost negligible heat value for melting ice or thawing frozen ground.

Another factor in ice formation was the effect of ambient winter air temperatures at the pilot unit. Figure 4 presents a graphical representation of the average minimum, average maximum, and average mean ambient air temperatures for Brookings, South Dakota based on historical records from 1893 to 1975. The vertical lines depict the temperature range on each day of basin flooding and the following day for the winter of 1975-76 (18). Detailed temperature data are included in Appendix B. Figure 4 enables comparison of the observed winter temperatures of 1975-76 and the average air temperature conditions.

Analysis of Figure 4 indicates that the floodings on November 25, 1975, December 16, 1975, and January 6, 1976 were done when the observed daily air temperature range was considerably below average. Inspection of the pilot unit after each of the above three floodings revealed new ice accumulations of three to five inches depending on

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[4] Wastewater treatment plant operation records,
John Wirtz, City Chemist

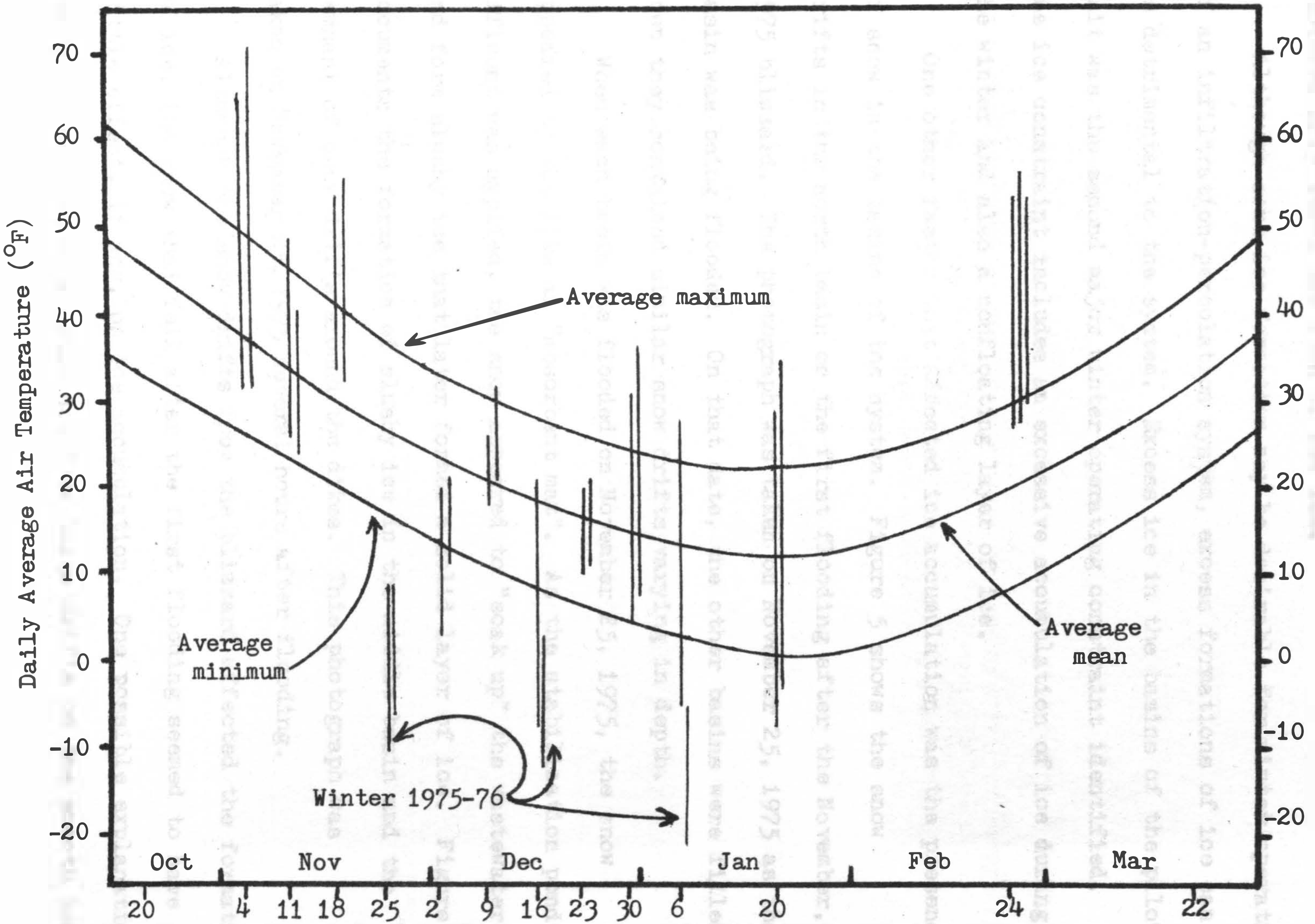

Figure 4. Average and 1975-76 observed ambient air temperatures for Brookings, South Dakota.

the basin and location within the basin. Other weekly floodings produced only about one inch of new ice.

Although some ice formation may be desirable for winter operation of an infiltration-percolation system, excess formations of ice can be detrimental to the system. Excess ice in the basins of the pilot unit was the second major winter operating constraint identified. The ice constraint includes an excessive accumulation of ice during the winter and also a nonfloating layer of ice.

One other factor that affected ice accumulation was the presence of snow in the basins of the system. Figure 5 shows the snow drifts in the north basin on the first flooding after the November, 1975 blizzard. The photograph was taken on November 25, 1975 as the basin was being flooded. On that date, the other basins were filled when they contained similar snow drifts varying in depth.

When each basin was flooded on November 25, 1975, the snow appeared to act like an "absorbent mat". As the stabilization pond effluent was applied, the snow appeared to "soak up" the wastewater and form slushy ice that later formed a solid layer of ice. Figure 6 documents the formation of slushy ice in the middle basin and the remnant of snow drifts around the dikes. This photograph was taken on November 25, 1975 several hours after flooding.

Although the snow drifts from the blizzard affected the formation of ice, the snow that fell after the first flooding seemed to have little effect, if any, on ice accumulation. One possible explanation would be that the snow could not form large drifts on the smooth ice

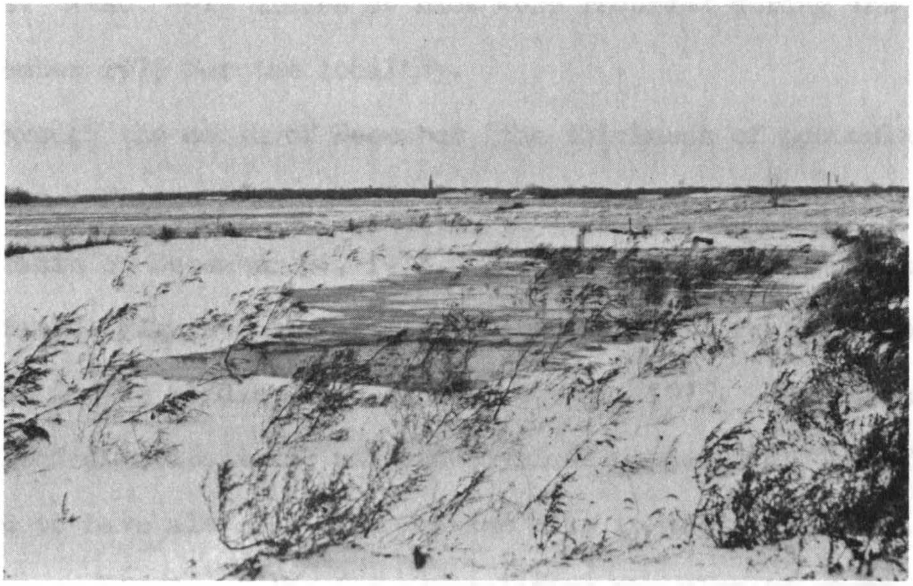

Figure 5. Filling the north basin after the November 19-21, 1975 blizzard.

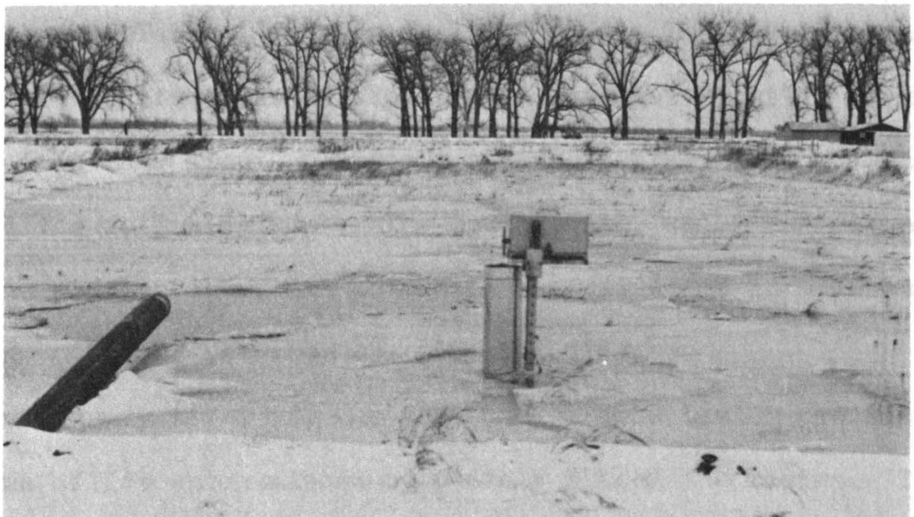

Figure 6. Middle basin showing slushy ice and vegetation after flooding on November 25, 1975.

surface. Also, only traces of snow were recorded during the month of December 1975 for the locality.

Through the month of December, the thickness of accumulated ice increased. Figure 7 shows multiple layers of accumulated ice in the south basin on December 31, 1975. The area shown is adjacent to the south bank. Figure 8 shows freshly applied stabilization pond effluent in the middle basin on December 31, 1975. The basin had been flooded to about the maximum physical capacity as the effluent appears to have almost overflowed the dike in the foreground.

The magnitude of the ice accumulation can also be shown by the inability of the basins to accept the desired weekly volume of applied wastewater which is termed the theoretical load. The theoretical and applied loads for each weekly winter flooding are presented in Table 1. Inspection of Table 1 reveals that the middle basin had accumulated ice after the first winter flooding on November 25, 1975 to the extent that only about 50 percent of the theoretical load could be applied the following week. The south basin, which has higher dikes than the middle basin, did not require a reduction in volumetric loading until the December 23, 1975 flooding.

By January 12, 1976, the south and middle basins had accumulated a volume of ice which almost completely filled the basins. The north basin which had a lesser applied load and higher dikes did not have ice accumulation problems to the extent that reduced volumes of wastewater had to be applied.

Figure 7. Multiple ice layers in the south basin after six weekly wastewater applications (December 31, 1975).

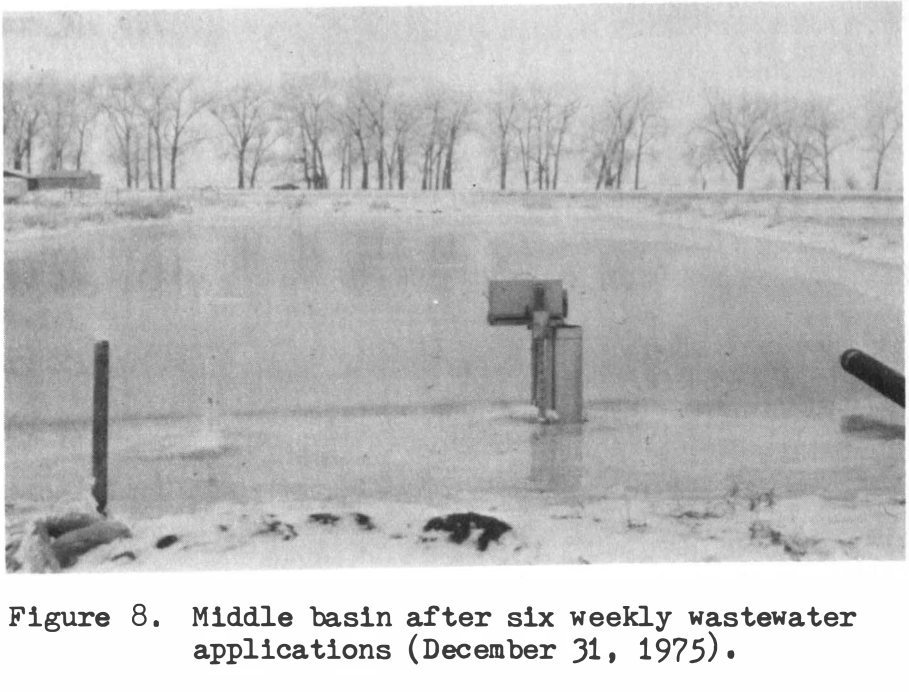

Figure 8. Middle basin after six weekly wastewater applications (December 31, 1975).

Table 1
Volumetric Loadings for Infiltration-Percolation Winter Operations-1975-76.

Date	Gallons of Wastewater Applied **South**	 **Middle**	 **North**
October 28, 1975	104,330	118,730	79,780
November 4, 1975	98,480	121,360	79,790
November 11, 1975	96,970	118,800	79,750
November 18, 1975	96,960	119,700	79,800
November 25, 1975	97,260	118,800	79,790
December 2, 1975	97,040	59,130	79,950
December 9, 1975	96,940	70,460	89,400
December 16, 1975	96,340	29,950	79,580
December 23, 1975	68,750	53,920	77,400
December 30, 1975	51,310	30,940	79,450
January 6, 1976	45,240	———	———
January 13, 1976	———	———	———
January 20, 1976	———	———	79,740
February 24, 1976 (Est.)	20,000	2,500	3,100
February 25, 1976	12,280	15,080	56,400
April 6, 1976	113,070	118,770	82,040
Theoretical Loadings	96,900 (24 inches)	118,700 (24 inches)	79,740 (18 inches)

The second weekly winter flooding was done on December 2, 1975. As the stabilization pond effluent was applied, the ice in the basins did not float. The report of the winter operation of the infiltration-percolation system at Lake George, New York (9-84) stated that the ice that was formed would float during the subsequent wastewater application. Consequently, it was expected that the layer of ice on the pilot units would float when wastewater was applied the following week. There are several factors that may have prevented the ice from floating.

The first factor that could have prevented the ice from floating was the presence of thick vegetation in the bottom of each basin. At Lake George, New York the basins were scraped which would have prevented weed growth. Analysis of both Figures 5 and 6 verifies the presence and the magnitude of the vegetation in the basins. The vegetation may have anchored the ice sufficiently to prevent it from floating.

Another possible cause of the nonfloating ice may be explained by the action of the ice produced by the first flooding after the blizzard. It is suspected that the buoyant force of the applied wastewater was not great enough to overcome downward forces created by the mass of ice. Possibly, only a small portion of the bottom surface area of the basin was subjected to the buoyant force of the applied effluent.

Infiltration Capacity

After the first weekly winter flooding of 1975, a three-to five-inch layer of ice covered each basin of the pilot unit. The next weekly flooding on December 2, 1975 created a hole in the ice directly under the inlet pipe allowing only a small portion of the applied stabilization pond effluent to go under the ice before spreading over the ice layer. Cracks randomly developed in the ice and allowed a small quantity of applied effluent to seep between the ice segments. There is a possibility that only a portion of the total infiltrative surface of the basin was exposed to the effluent after the first winter flooding because the first layer of ice may have extended into the upper layer of soil.

As reported in the literature review, lower liquid temperatures increase the viscosity of the wastewater. Also, the infiltration rates are inversely proportional to viscosity (14). Therefore, a decrease in temperature will cause a decrease in infiltration rates. The temperature of the stabilization pond effluent dropped to about 35°F during the winter months. As a result, the viscosity, due to a temperature drop from 70°F to 35°F, is increased by about 42 percent. Correspondingly, the infiltration rate would be reduced about 42 percent.

Any change in infiltration capacity can also be estimated by the time period for the applied load to completely percolate from the basin. During normal winter conditions, it was noted that there was a significant quantity of applied effluent still in the basin after

24 hours. But, during the normal fall operations, the basins were essentially free of applied effluent after 24 hours.

Based on the evidence as presented, a reduction of infiltration capacity was identified as another major winter operating constraint. This reduction may be brought about by a reduction in the infiltration area after ice formations, the freezing of the soil, or viscosity changes in the applied effluent.

Effluent Quality

Physical operation is not the only criteria used in determining the feasibility of an infiltration-percolation system for use in northern climates. The other major criteria is the quality of effluent that the system eventually discharges.

Table 2 shows the chemical qualities of the stabilization pond effluent and basin effluent of the pilot unit for the fall and winter operating conditions of 1975-76. The data represent the mean values for selected time periods to permit a comparison of changes in quality due to seasonal and operational variations.

The first selected time period is from September 23, 1975 through October 14, 1975. This time period represents early fall conditions. The next time period consists of only the October 21, 1975 flooding which represents the results following a week of continuous inundation of the basins. This special inundation study was undertaken to determine if the infiltration rates could be decreased and effluent quality improved. The third period of time is from October 28, 1975 through November 18, 1975. This period

Table 2
Chemical Quality of Influent and Effluent of Basins During Fall and Winter-1975-76.

Parameter/Time Period	No. of Samples	Influent	Basin Effluent*		
			N	M	S
Biochemical Oxygen Demand (mg/l)					
9/23/75-10/14/75	4	50.0	7.9	14.2	7.2
10/21/75	1	34.8	8.2	9.8	7.1
10/28/75-11/18/75	4	29.6	11.5	13.9	10.1
12/2/75-12/16/75	3	30.1	14.1	12.7	8.8
4/6/76	1	22.1	15.0	16.2	9.5
Suspended Solids (mg/l)					
9/23/75-10/14/75	4	43.2	5.3	10.5	5.3
10/21/75	1	32.4	9.2	12.4	7.0
10/28/75-11/18/75	4	58.5	18.6	28.8	18.0
12/2/75-12/16/75	3	19.1	8.9	6.2	4.3
4/6/76	1	34.0	15.4	16.7	7.2
Ammonia nitrogen (mg/l)					
9/23/75-10/14/75	4	7.70	1.05	1.94	0.92
10/21/75	1	16.68	4.14	6.78	4.26
10/28/75-11/18/75	3	15.19	3.20	5.23	3.23
12/2/75-12/16/75	3	22.53	8.92	6.22	4.85
4/6/76	1	16.08	4.30	5.00	2.24
Nitrate nitrogen (mg/l)					
9/23/75-10/14/75	4	4.15	5.24	4.88	5.98
10/21/75	1	9.98	1.00	1.50	3.10
10/28/75-11/18/75	3	1.09	12.72	11.74	16.69
12/2/75-12/16/75	3	0.038	8.47	13.23	12.60
4/6/76	1	0.242	2.70	1.39	1.86
Orthophosphate (mg/l)					
9/23/75-10/14/75	4	3.84	1.45	2.08	1.45
10/21/75	1	5.49	2.51	2.90	2.36
10/28/75-11/18/75	3	5.25	2.52	3.19	2.49
12/2/75-12/16/75	3	6.05	3.65	2.66	2.47
4/6/76	1	5.76	4.125	4.08	2.06
Total phosphorus (mg/l)					
9/23/75-10/14/75	4	4.64	1.56	2.29	1.57
10/21/75	1	5.85	2.84	3.05	2.55
10/28/75-11/18/75	3	6.28	3.56	5.11	3.28
12/2/75-12/16/75	3	6.40	3.80	2.95	2.63
4/6/76	1	5.94	5.76	5.25	3.92

*N, M, and S represent north, middle, and south basins, respectively.

represents the weekly floodings after the week of continuous inundation but before winter conditions. The fourth time period represents the winter operating conditions between December 2, 1975 and December 16, 1975. It should be noted that the severe November blizzard occurred between the third and fourth time periods. Finally, the fifth time period is the April 6, 1976 flooding which represents the first flooding in the spring. The conditions of the basins after exposure to sub-freezing temperatures and total ice coverage would be indicated by the quality of effluent from this flooding.

Analysis of the mean values of Table 2 indicates that effluent quality during the winter period was considerably inferior to that obtained during the early fall period. Compared to the third time period, the effluent quality during winter was only slightly inferior and this inferiority was judged almost entirely by the ammonia and nitrate nitrogen concentration of the basins effluents.

Alsaker (6) reported that as suspended solids concentrations of the influent increased, ammonia nitrogen decreased. The suspended solids consisted mainly of large quantities of algae. The algae or microbial mass apparently used ammonia nitrogen as a food source (6) and therefore, the ammonia nitrogen concentration was reduced. During winter operations, the relationship of suspended solids, microbial mass, and ammonia nitrogen concentration was also apparent, but reversed. Due to a reduction in microbial mass and algae in the winter, which is partially indicated by a reduced concentration in suspended solids, less ammonia nitrogen was probably consumed.

It can be noted from Table 2 that the ammonia concentration of the influent to the basins increased during the winter.

The objective of the week-long continuous inundation was to "saturate the soil profile in an attempt to lower infiltration rates, thereby improving treatment efficencies" (7). Analysis of the ammonia nitrogen data in Table 2 reveals that the effluent quality actually deteriorated slightly after the period of inundation. It appears from Table 2 that the infiltration-percolation basins never fully recovered from the inundation period. The ammonia nitrogen concentrations of the basin effluents in the late fall were never reduced to levels prior to the inundation. During the winter, ammonia concentrations in the basin effluents continued to increase. It is impossible, however, to conclude that the increase in ammonia nitrogen that occurred during the winter period as compared to the early fall period was due to winter conditions alone.

The first flooding after winter conditions were established did not show an improvement in effluent quality. Suspended solids and phosphorous concentrations were substantially higher in the effluent samples after the winter period. One possible explanation is that short-circuiting problems as suggested by Alsaker (6), may have been further advanced due to winter conditions. Worse short circuiting could have occurred due to the possible frost-heave action in the basins. As the water and the soil froze, the cracks in the soil would expand. This expansion would create larger cracks in the soil and, therefore, would tend to increase the tendency for wastewater to short circuit through the cracks. Consequently, the removal efficiencies would be reduced and the effluent quality would be poorer.

Analysis of the basin effluent quality data for the three weeks of winter indicates that another winter operating constraint may be the resultant poorer effluent quality during winter months. It is, however, impossible to conclude with available data that the poorer effluent quality was due to winter conditions alone. Further winter operation of the pilot unit would be necessary to evaluate if adverse changes in basin effluent quality was the result of winter conditions.

STORAGE REQUIREMENTS

Based on the operations during the winter of 1975-76, reliable and continuous winter operation of the pilot infiltration-percolation system was not possible with the present design. All winter operations were ceased in mid January 1976. If infiltration-percolation systems are utilized in northern climates, storage facilities should probably be included in the design for reliable operation and emergencies.

An evaluation of pertinent literature on land disposal methods of wastewater treatment reveals recommendations or estimations for determining the winter design period. One objective of this section is to evaluate each recommendation in relation to the operation of the pilot unit during the 1975-76 winter.

One recommended guideline for determination of the winter design period is the time period between the first and last frost for the winter (16-70). The average first frost for Brookings is September 21 while the average date of the last frost is May 17 (17). Consequently, based on the past winter operations, dates of the first and last frost do not provide a realistic winter design time period for possible storage. During the past year the pilot unit was operated to some extent through January and the first flooding after winter was accomplished in April. Furthermore, the blizzard that might require storage occurred in November.

Another suggested guideline for estimating the winter design period for storage is the time period based on frozen ground temperatures for the area (16-70). Ground temperature data will not be available for the Brookings area until after the winter of 1976-77.

Periods of snow cover were suggested as one guideline for the determination of the winter design period (16-70). A manual prepared under contract with the Environmental Protection Agency states that when dealing with land application systems, periods of snow cover will necessitate storage of effluent for later application except for infiltration-percolation systems (16-33).

Finally, the use of monthly or seasonal averages and variation in air temperatures data for the locality was suggested in an effort to determine the winter design period (16-103). The maximum design period should be based on historical winter weather data (16-70). The author's interpetation of the above suggested guidelines indicates the utilization of data similar to that shown in Figure 4 which shows the historical winter air temperatures for the Brookings area. The figure shows the average maximum, average minimum, and average mean air temperatures based on a historical time period of 1893 to 1975.

Winter operations of the pilot unit started with the blizzard during the middle part of November 1975. It is significant to note that the average mean daily air temperature for the Brookings area based on historical records drops to about 32°F during mid November (November 12). By contrast, the last routine flooding for the 1975-76 winter was in January. It is also significant to note from Figure 4 that the average mean daily air temperature rises to 32°F during late March (March 22). Even though not reflooded until April 6, 1976, the basins appeared to be suitable for flooding during the last part of March 1976. Thus, the total period between the fall and spring dates (November 12 and March 22) suggests a winter design period of about 130 days. This winter design period, however, does not necessarily define the required winter storage.

In designing storage facilities, it is important to maximize storage volume but not at the expense of purchasing excessive quantities of land for the construction of large and expensive storage facilities. Therefore, it is important to maximize the utilization of any existing and planned facilities.

Existing stabilization ponds or lagoons can be utilized to some extent for winter storage. Prior to winter operations, the ponds would be lowered sufficiently but not to the point of biological destruction of the system. Consequently, many small communities in South Dakota already have some volume in their existing stabilization ponds or lagoons to store the incoming wastewater from the community for some length of time.

Maximum utilization of planned facilities might resort to a design that has been altered for northern climates. The design of infiltration-percolation systems for winter operation should probably be oriented toward conservation of heat. It would be desirable for such a system to maximize the infiltration area while minimizing the exposed surface area. One such design might be a ridge and furrow system within the infiltration-percolation basin. The ridge and furrow system would be similar to the Westby, Wisconsin treatment system (11). The furrows would provide infiltration surfaces; the ridges would serve to support the ice cover that would form. The infiltration surface of the furrows would not be horizontal but rather at an angle. It should be noted that vegetation could not be harvested in this type of basin but wildlife habitat would be provided on the basin dikes.

Also, the planned infiltration-percolation system could be utilized for limited storage after the infiltration capacity is significantly reduced and ice starts accumulating. Figure 8 shows the applied stabilization pond effluent and the ice of the middle basin of the pilot unit. Reduced volumes of effluent were applied to the south and middle basins as the winter progressed (see Table 1) even though the basins were flooded to about the maximum physical limit on each weekly flooding. Therefore, the basins continued to provide storage while the ice accumulated in the basins.

The primary objective of this section was to investigate the required storage for reliable operation of infiltration-percolation treatment. The suggested guidelines for the winter design period were evaluated to determine if they might provide information to estimate the winter storage period. These suggested guidelines apparently do provide a reasonable estimation for a winter design period where storage may be utilized with basins designed especially for winter operations. All of the evaluated guidelines did not, however, appear to suggest reasonable winter storage estimates based on the operation of the pilot unit during the 1975-76 winter.

Even though the amount of required storage could not be determined, the operation of the pilot unit did, however, furnish some suggestions for operating during the winter and providing the necessary storage.

1. The infiltration capacity of the basins was never reduced to zero; some stabilization pond effluent did infiltrate during the winter, suggesting the potential of some advantage of continued operation as long as possible.
2. The basins of an infiltration-percolation system could be designed with ridge and furrows which would possibly increase the infiltration capacity of the system.
3. With adequate dike height, the basins of an infiltration-percolation system could provide some storage even though ice would accumulate.
4. Existing stabilization ponds or lagoons could be expected to provide varying quantities of storage.

All of the above suggestions are alternatives to the construction of additional storage facilities.

SUMMARY AND CONCLUSIONS

The objective of this portion of the overall study was to identify the major winter operating constraints of an infiltration-percolation system of wastewater treatment. The infiltration-percolation pilot unit at Brookings, South Dakota is designed to provide additional treatment to stabilization pond effluent and it was the operational experience with this unit upon which the following conclusions were made.

1. The blizzard in November 1975 proved to be the most dramatic winter operating constraint identified. Manual operation of an infiltration-percolation system during a severe blizzard should be considered unrealistic. Infiltration-percolation systems should be designed for the elimination of manual control during blizzards.
2. Ice accumulations represent a serious winter constraint to infiltration-percolation basins that must operate throughout severe winters. Extremely low temperatures or heavy snow accumulations at the time of flooding magnify the ice problem. The low temperatures of stabilization pond effluent also appear to be a major contributing factor to the ice problem. Vegetation in the basins may have anchored the ice sufficiently to prevent the ice from floating.
3. The infiltration capacity of the soil may have been lower during the winter as a result of a reduction in infiltration

area due to the initial ice cover, the freezing of the soil, or viscosity changes in the applied effluent.

4. There was a trend toward poorer effluent quality as winter approached, especially as related to ammonia nitrogen removals. It was impossible, however, to conclude that the deterioration in quality was due to winter conditions alone.
5. In a northern climate, reliable and continuous operation of an infiltration-percolation system probably requires some storage facilities. The quantity of necessary storage could not be determined from the available data.

Even though the length of operation of the infiltration-percolation pilot unit was not a success during the 1975-76 winter, the study successfully identified some of the major winter operation constraints. Further investigation during winter months to determine the feasibility of infiltration-percolation systems is important before such systems can be accepted for use in northern climates.

RECOMMENDATIONS

Based on the operation of the pilot unit during the 1975-76 winter, the following proposed recommendations should be evaluated for possible incorporation into future winter operation of the system.

1. Institute a strict mowing program prior to winter. This change would prevent the weeds from anchoring the ice that is formed and would possibly help produce a floating layer of ice.
2. At the first indication of severely cold weather, the basins should probably be flooded to a higher than normal level. This action is also designed to create a floating layer of ice.
3. Investigate the possibility of designing the infiltration-percolation basins especially for winter operation. Such designs should maximize the infiltration area while minimizing the exposed surface area of the water. The system should be designed to allow for a minimum of manual operation during blizzards.
4. Investigate the feasibility of using treatment plant effluent instead of stabilization pond effluent. Treatment plant effluent is warmer and possibly would increase the infiltration capacity.
5. Ground temperature data should be analyzed for determination of winter design periods.

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Appendix A
Stabilization Pond and Treatment Plant Effluent Wastewater Temperatures (^{o}F) for Brookings, South Dakota

	Stabilization Pond		Treatment Plant	
	Observed	Ave. Monthly**	Observed	Ave. Monthly**
November 4, 1975	48	38.2	63	57.8
11	44		54	
18	43		61	
25	33		54	
December 2, 1975	33	34.9	55	52.2
9	34		55	
16	34		47	
23	33		48	
30	35		49	
January 6, 1976	33	34.1	43	48.3
13	34		49	
20	33		51	
February 24, 1976	33	33.7	55	49.6
25	33*		55*	
April 6, 1976	53	46	56	53.5

* Estimated

** Computed Using January 1974-June 1976 Temperatures

Appendix B
Extreme, Average, and 1975-76 Observed Ambient Air Temperatures for Brookings, South Dakota

	Extreme*		Average Conditions**			Observed Temp(1975)		
Date	Max.	Min.	Max.	Mean	Min.	Max.	Mean	Min.
November 4	75	1	49.7	37.8	25.8	66	49	32
5	73	-2	48.9	37.2	25.5	71	52	32
11	64	-4	44.6	33.2	21.9	49	38	26
12	66	-11	43.0	32.3	21.5	41	33	24
18	72	-9	41.7	31.1	20.4	54	44	34
19	69	-7	40.7	30.2	19.7	56	45	33
25	65	-9	38.3	28.2	18.2	9	-1	-10
26	62	-13	36.6	26.9	17.1	9	2	-6
December 2	56	-18	33.3	23.9	14.4	20	12	3
3	61	-16	33.4	23.6	13.9	23	17	11
9	60	-22	28.1	18.6	9.0	26	22	18
10	55	-24	27.8	18.6	9.3	32	27	21
16	61	-26	27.7	17.7	7.7	21	7	-7
17	57	-22	25.6	15.9	6.2	3	-5	-12
23	54	-19	28.6	18.5	8.4	20	15	10
24	44	-21	27.0	16.9	6.9	21	16	11
30	51	-18	27.0	10.0	4.9	31	18	5
31	58	-29	25.1	14.2	3.4	37	23	8
January 6	49	-30	24.0	13.1	2.2	28	12	-5
7	50	-30	23.0	12.4	1.7	-5	-13	-21
20	61	-33	22.5	12.6	2.8	29	11	-7
21	54	-32	22.8	12.3	1.8	35	16	-3
February 24	54	-26	30.7	19.5	8.3	54	41	27
25	61	-20	31.3	19.9	8.5	57	43	28
26	60	-27	31.8	21.0	10.3	54	42	30

* Time Period 1893-1970

** Time Period 1893-1975